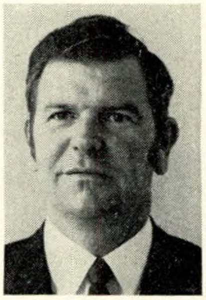
GAS AS AN ENGINE FUEL

P. W. A. Eke, C.Eng., M.I.C.E., M.I.Mech.E., M.I.GasE.,*
and J. H. Walker, B.A., C.Eng., F.I.Mech.E., F.I.GasE.†



Mr. Eke

Mr. Walker

This paper discusses the properties required of a fuel gas, particularly in an engine, and indicates the advantages of natural gas compared with gases hitherto available. Special emphasis is laid on liquid natural gas which the authors believe will be of great importance in the future.

The development of the gas engine from early times is reviewed and the reasons for its decline in popularity are considered.

The rise of the dual-fuel engine in the sewage treatment industry and the modern gas engine in the U.S.A. are described and their relative merits compared. Brief reference is made to natural gas as a fuel for gas turbines and steam boilers also.

The gas and dual-fuel engines installed or on order by the North Thames Gas Board, of which the authors have personal knowledge, are described in some detail.

Experiments in the use of liquid natural gas as a fuel in the transport industry are outlined and the paper concludes with a review of some possible applications of liquid natural gas, including use of the cold effect.

PROPERTIES REQUIRED OF A FUEL GAS

Much has been said and written about natural gas since its presence in the North Sea was confirmed, but it is a very important new source of indigenous energy which demands careful study by engine users.

To be worthy of interest, a fuel gas must be in plentiful supply, freely available and competitive in price compared with other forms of fuel. Doubts have been raised as to the life of the wells in the North Sea, but estimated reserves are equivalent to three or four times the present level of gas consumption in Great Britain for at least 25 years. Exploration and drilling still go on and already further supplies have been discovered, the extent of which is not fully determined. It would, indeed, be surprising if all the worthwhile gas in the North Sea has already been discovered; experience in the U.S.A. and the Middle East indicate that further discoveries always overtake the estimates. As to availability, a network of high pressure pipelines exists or is under construction linking up the various Area Board grids which at present distribute conventional gas.

At the time of writing the cost of Diesel oil to a large user in this country works out at about 7½d/therm, of which about 1½d/therm represents tax. Thus, in comparing the cost of gaseous fuels, a possible change in fiscal policy has to be borne in mind. To an industrial consumer there is no standard tariff for natural gas and the price will obviously depend on the load factor. In most cases a more favourable price can be negotiated with the local Gas Board on the basis of an interruptible supply; at times of heavy gas demand the consumer accepts that his gas supply may be cut off at short notice for a maximum agreed period.

TECHNICAL ADVANTAGES OF GAS AS A FUEL

Smaller industrial users requiring standby power equipment should also give natural gas careful consideration. Although, to them, the price per therm may be higher than that of Diesel oil, the difference may well be offset by the following:

1) the gas user does not have to provide storage and handling facilities nor access for tank wagons;
2) although an artificial odour, characteristic of conventional town gas, is added to natural gas for safety reasons, this smell will not taint food or fine chemicals, as Diesel oil does;
3) gas burns without smell or smoke: this means minimal carbon deposits in cylinders, turbochargers etc., and no exhaust nuisance is caused in built-up areas;
4) gas and dual-fuel engines are noticeably quieter than the equivalent Diesel.
5) gas is sulphur-free and the products of combustion are not corrosive; for this reason, and because there can be no lubricating oil dilution, the period between oil changes and engine overhauls can be extended.

Combustion Efficiency

It was shown many years ago⁽¹⁾ that the theoretical efficiency of an internal combustion engine is given by the expression:

$$1-\left(\frac{1}{R}\right)^{k-1}$$

where R is the compression ratio, and k is the isentropic (adiabatic) exponent, and Fig. 1 shows efficiency plotted against compression ratio for air ($k=1{\cdot}40$); a second curve is also shown, based on the brake thermal efficiency observed in actual engines⁽²⁾ and it will be seen that the curve tends to flatten out above a compression ratio of 12:1. The compression ignition engine naturally has a compression ratio of this order, but attempts to raise that of gas engines resulted in detonation.

Sir Harry Ricardo⁽³⁾ observed: "It is detonation, and detonation alone, that sets a limit, and a relatively early limit, to the power output and economy of a petrol engine; the incidence of detonation, in fact, determines both the weight of air which can be consumed, and the efficiency with which the heat thus liberated can be converted into power".

---

* Deputy Station Engineer, Romford Works, North Thames Gas Board.

† Mechanical Engineer, Dept. of Director of Engineering, North Thames Gas Board.

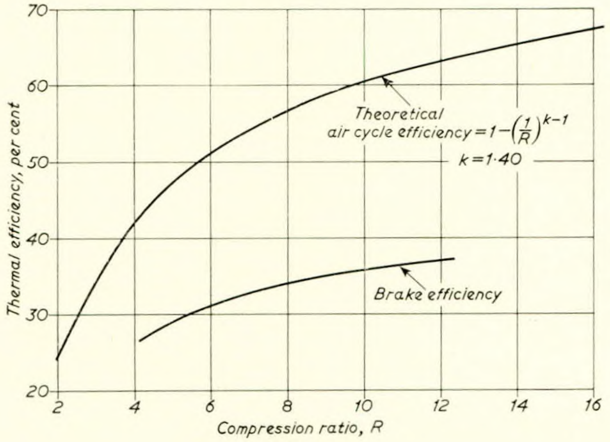


FIG. 1

This statement is equally true of gas engines and the following explanation by Ricardo of the phenomenon of detonation is generally accepted:

> "Where a combustible mixture of fuel and air is ignited by the passage of the spark, there builds up, slowly at first but with a rapid acceleration, a small nucleus of flame, at first somewhat in the form of a soap bubble: this spreads outwards with ever-increasing rapidity. As the flame front advances, it compresses ahead of it the remaining unburnt mixture, whose temperature is raised by both compression and radiation, until a point is reached when the remaining unburnt charge will ignite spontaneously, and almost instantaneously, thus setting up a detonation wave which will pass through the burning mixture at an enormously high velocity, such that its impact against the cylinder wall will give rise to a ringing knock, as though it had been struck with a light hammer".

Detonation causes rough running and lack of power and, if allowed to continue, may damage the engine. It is dependent on the following:

- i) the temperature of the unburnt charge which in turn depends on the temperature of the charge before compression, the temperature rise due to compression which varies with the compression ratio, and the degree of cooling in the combustion chamber;
- ii) the distance the flame front has to travel from the point of ignition until combustion is complete; the sparking plug is usually located centrally so as to reduce the length of flame travel, or in larger cylinders two sparking plugs are provided, one on either side of the combustion chamber;
- iii) engine speed and ignition timing;
- iv) speed of flame propagation; this is the most important factor influencing detonation; flame speed depends partly on the strength of the mixture and the degree of turbulence, but mainly on the nature of the gas.

In a petrol engine the chief means of overcoming detonation is by additives and modification to the fuel to improve its "anti-knock rating". Although recent experiments(4) suggest an additive which may be useful to improve gases with a poor anti-knock rating, in general the modification of gaseous engine fuels is not practicable.

However, the method established for measuring the octane rating of liquid fuels can be applied to gases. Standard laboratory engines are available in which the compression ratio can be altered under load; the engine is run on the test gas, mixed with the chemically correct mixture of air, under standard conditions of speed, temperature and loading; the compression ratio is gradually raised until detonation, as indicated by cylinder pressure diagrams, just begins. This point is called the critical compression ratio (C.C.R.) and Table I shows the values of the C.C.R. for certain common gases (2,5).

TABLE I

Fuel	Critical compression ratio
Methane	12·6
Ethane	12·4
Propane	12·2
Iso-Butane	8·0
N-Butane	5·5
Iso-Octane (100 Octane No.)	7·3
Ethylene	8·5
Hydrogen	8·2

It will be seen that the composition of a gas plays a very important part in its performance as an engine fuel, but that almost all the gases listed have an anti-knock rating better than 100 Octane petrol.

Generally gases which are rich in methane are not prone to detonation; on the other hand hydrogen has a flame speed four times that of methane and hydrogen rich gases are especially susceptible. The presence of inert gases such as carbon dioxide or nitrogen reduces the flame speed and therefore the tendency to detonate, but it reduces the calorific value of the fuel and therefore the power output of the engine.

AVAILABLE FUEL GASES

Gases of various kinds have been used as an engine fuel and Table II gives typical analyses of several of them, both manufactured and natural.

The manufacture of gas on a commercial scale began in 1812, using coal as a raw material and, although many variations in gas making practice were adopted to improve the product its composition was not altered materially. In 1955 various processes were introduced for making town gas by the catalytic reforming of oil refinery by-products and, in the few years since then, the use of coal in the gas industry has virtually ceased. It will be seen that these manufactured gases, whether derived from coal or oil products, are rich in hydrogen and unsuitable for use in a modern engine.

There was a time when large engines were run on producer gas made by drawing air through a furnace of coke or non-bituminous coal. The air was drawn in by the engine suction and the result was a cheap gas of low calorific value. Another cheap gas formerly used in engines was the waste gas from blast furnaces.

Natural gas was first used commercially in the United States in the 1920s but its use did not become general there until the technique of continuously welded high pressure pipelines was developed during the last war. Natural gas has since been discovered, frequently but not invariably associated with an oil field, in many parts of the world. About 10 years ago gas was discovered in great quantity in northern Holland; this triggered off the search for gas in the North Sea and, by good fortune, the most fruitful part of the Continental Shelf has been that allocated to this country under international agreement.

The calorific value of North Sea gas is roughly twice that of conventional town gas and the Gas Council decided to convert consumers' appliances to suit the different combustion characteristics; this procedure in effect doubles the capacity of the various Area Boards' distribution systems which, in many places, were in danger of becoming overloaded. This conversion process will take several years to complete and, in the meantime, some of the natural gas is being processed by catalytic reforming to conventional town gas. Natural gas, being almost pure methane, is an ideal engine fuel.

Similar to natural gas is sludge gas which is given off during the sludge digestion process of sewage treatment. This is a mixture of methane and inert gas and is much used as an engine fuel.

Liquid Gases

The supply of gas to mobile plant and to sites inaccessible to a pipeline has for some years been provided by liquid petro-

TABLE II

	Coal gas	Catalytic reformed gas	Blast furance gas	Producer gas	Sludge gas	Algerian natural gas	North Sea gas
Composition per cent by Volume:							
Hydrogen	52	49	2	12			
Methane	30	34			63	88	92
Ethane	3					9	3
Propane						2	2
Butane						1	
Carbon Monoxide ...	8	2	27	26			
Nitrogen	5		60	55	2		3
Carbon Dioxide ...	2	15	11	7	35		
Calorific Value:							
Btu/ft^3, higher	560	500	92	126	640	1140	1030
lower	500	450	91	120	570	1025	925

leum gases (L.P.G.) which are mixtures of butane and propane. Although these mixtures are not particularly suitable as an engine fuel and cannot compete in price with liquid fuels, they have found a successful application for mobile plant operating in factories, warehouses etc., where a clean exhaust is essential.

Whereas propane and butane can be liquefied at atmospheric temperatures by pressure alone, methane, the main constituent of natural gas, has a critical temperature of −116°F (−82°C), when a liquefaction pressure of 650 lbf/in^{2}g is required; if the gas is cooled to −258°F (−160°C) it remains liquid at atmospheric pressure and occupies 1/600 of its volume at ambient temperature.

Importing Natural Gas

Before natural gas was discovered in northern Europe a project for the importation of liquid natural gas (L.N.G.) was investigated by a team of British and American engineers.

In 1957, the Gas Council and Conch International Methane Limited jointly undertook a pilot scale operation of liquifying natural gas in the United States by cooling it to −258°F (−160°C) and transporting the cryogenic liquid to this country in a converted cargo ship with highly insulated tanks. The North Thames Gas Board already owned land on Canvey Island giving access to a deep water berth and it was here that the cargoes were landed into specially constructed insulated storage tanks. The liquid was drawn off as required, pumped up to gas main pressure in the liquid phase, and then vaporized by heat exchange with river water. The liquid gas is of course continuously boiling, and the boil-off gas from the storage tank or piplines was collected in a gasholder and then compressed up to main pressure.

After the completion of seven successful experimental voyages, a full scale scheme was given Government approval, in November 1961, and the Canvey Methane Terminal was constructed, receiving its first commercial cargo on 12th October 1964.

The natural gas comes from a gas field at Hassi R' Mel, in Southern Algeria, by pipelines to Arzew on the coast; there its temperature is lowered by the cascade process to −258°F (−160°C) when it becomes liquid at atmospheric pressure. It is brought to this country in two specially built tankers, *Methane Princess* and *Methane Progress*, each carrying 12 000 tons of liquid on a round ten day trip; because the specific gravity of L.N.G. is low, the size of the ships is equivalent to that of a 28 000 ton oil tanker and they are driven by 12 000 hp Pametrada turbines with a service speed of 17½ knots. The methane boil-off during the voyage is used in conjunction with heavy oil as fuel for the boilers and provides some 70 per cent of the total fuel requirements at sea.

Six new storage tanks, each of 4000 tons capacity, together with pumps and evaporator units, were provided and the gas is passed at a pressure of up to 1000 lbf/in^2 into the national "backbone" main which had been constructed from Canvey to Leeds. Four Alley horizontally opposed compressors, each of 100 000 ft^3/h, were installed to deliver the boil-off from the tanks into local mains at a pressure up to 150 lbf/in^2; two of these are driven by electric motors and two by normally aspirated Mirrlees National dual-fuel engines.

The installation was a great success and at that time provided about ten per cent of the gas requirements of the whole country. Designs were already in hand for stepping up the rate of importation when natural gas was discovered in the North Sea. Up to then the installation had been treated as a base load source of supply to Area Gas Boards who reformed or blended the gas to conventional town gas characteristics.

The North Sea discovery made the conversion of the whole industry to natural gas an economic proposition and it was decided to use the imported gas, which in liquid form could be cheaply stored, to smooth out peak loads in the winter and so even out the rate of supply from the North Sea wells over the year. Consequently, the storage capacity has been increased from 26 000 tons to 110 000 tons by the construction of four "in ground" frozen earth storage tanks, each holding 21 000 tons. Each tank is a hole in the ground, 130 ft diameter by 130 ft deep, covered with an aluminium roof and the cold from the liquid methane keeps the clay sub-soil frozen, and thereby stable and leak-proof. Naturally this increased storage capacity has necessitated further pumps and evaporators, and engine driven compressors to handle the additional boil-off.

HISTORICAL REVIEW OF GAS ENGINES

The first real gas engine is described in a patent specification of 1794, but it is believed that the first internal combustion engine that ever ran under its own power was made by the Rev. W. Cecil, of Cambridge, in 1818(1). Soon after this date a number of engines capable of doing useful work were constructed by various inventors, and coal gas which by then was widely available was invariably chosen as the fuel.

The first commercially successful gas engines were produced in France, by Lenoir in 1860 and by Hugon in 1865, and several hundred of these engines were sold. In 1867, Otto and Langen in Germany developed a free piston engine of which several thousands were constructed. Examples of all these engines may be seen in the Science Museum at South Kensington.

The really epoch-making advance was Otto's invention of the four-stroke cycle in 1876. The importance of this may be seen from Table III showing the following specific fuel consumptions:

TABLE III

Date	Inventor	Specific Fuel Consumption	
		ft^3/bhp h	Btu/bhp h
1860	Lenoir	96	48 000
1865	Hugon	85	43 000
1867	Otto and Langen	44	22 000
1876	Otto	24	12 000

These figures are based on a gas with a net calorific value of 500 Btu/ft^3; for comparison a modern gas engine will consume something less than 7000 Btu/bhp h.

All these early engines were of low power, one or two horsepower only, but Otto's invention opened the way to large engines and, before the end of the century, a single cylinder engine was in operation developing 600 bhp at 90 rev/min. It had a bore of 1300 mm (51·2 in) and a stroke of 1400 mm (55·2 in) and the b.m.e.p was 46 lbf/in^2.

The development of engines running on liquid fuels, both petrol and heavy oil, began about 1885, but progress was slow and in the industrial field the gas engine had a virtual monopoly until World War I. In fact it was estimated in 1908 that about a fifth of the whole supply of town gas was used in engines. At that time the cost of town gas to an industrial consumer was equivalent to 2½–3d/therm, which presumably was competitive with other available forms of energy. However, in 1881 Dowson had invented the suction gas producer which produced a gas of low calorific value, unsuitable for the domestic consumer, but much cheaper than town gas and suitable as an engine fuel. Virtually all large engines ran on either producer gas, or on the waste gas from blast furnaces, which is of similar composition.

Decline of the Gas Engine

After the end of World War I there was a two year boom and then gas engine production faded away. The principal reasons for this were:

a) the development of steam turbo-alternators operating in central power stations and using high steam pressures and temperatures; these central stations supplied a rapidly expanding country wide electricity grid, making electricity available almost everywhere, so that it became the natural choice for low power applications;

b) the rise in price of town gas compared with that of liquid fuels; the increase in demand for motor fuel kept the price of other petroleum fractions relatively steady in a period of generally rising prices;

c) the development of the compression ignition engine; not only was the cost per therm of Diesel oil cheaper than that of town gas, but the Diesel was thermally more efficient than the gas engine; although the running cost of a producer gas engine remained competitive, its extra capital cost and its inability to accommodate intermittent running and fluctuating loads ruled it out for most duties.

Therefore, virtually the only demand for gas engines came from iron works where blast furnace gas could be obtained at little cost, and from users overseas where neither an electricity grid nor a cheap oil supply was available. In these circumstances where a gas engine was called for, it was inevitably an adaptation of a Diesel engine and the scantlings were unnecessarily heavy for the lower pressures occurring in a gas engine at that time: thus the capital cost per horsepower was high.

Gas Engines and the Marine Engineer

As early as January 1827, a gas engine, designed and built by one Samuel Brown, was installed in a 36-ft boat and a demonstration voyage on the Thames from Blackfriars Bridge arranged. According to a contemporary record the boat travelled at the rate of between seven and eight miles an hour "with all the regularity of a steamer, and the paddles worked quite smoothly and seemed capable of continuing to go as long as gas was supplied"(1).

The engine was crude and weighed 600 lb, but, as the quotation suggests, the chief reason for the experiment being abandoned was probably difficulty in the supply of gas. How the gas was carried is not recorded, but presumably some form of gasbag was used: if this was so, no wonder that its range of operation was limited.

No doubt other experiments in marine propulsion by gas engine were carried out in the nineteenth century, but it was not until the first decade of this century, when the gas engine was at the zenith of its popularity, that serious schemes for gas engine driven ships were considered. At that time the hand stoked, coal fired Scotch boiler, without superheater, and the reciprocating steam engine were standard equipment and since the steam turbine, Diesel engine and oil fired boiler were all still in their infancy, the gas engine appeared to be a promising alternative.

One experiment concerned the gunboat *Rattler* of the Clyde Royal Naval Reserve(6). In 1907, the commanding officer, the Marquis of Graham, had the vessel, of 715 tons displacement, converted to use a 500 bhp Beardmore gas engine, with a suction gas producer and epicyclic reversing gearbox. "The engine gave satisfactory results and drove the ship at 8–9 knots. The time taken to start up from lighting the producer was half an hour, and the fuel consumed was only half that required by the original steam installation". The engine room staff was reduced from 17 to seven. In spite of this and other experiments, here and in Germany, the idea did not find general acceptance and further development work was abandoned.

Interest in the gas engine revived again in the 1930s when high unemployment and the shadow of war fell across Europe. Each country was trying to provide work for its miners and to make itself less reliant on imported fuel; suction gas producers appeared in various Continental countries, drawn on trailers behind motor lorries and installed in the holds of engine driven river craft. Anyone with experience of operating a gas producer will realize how unsuitable it would be in a seaway and virtually all marine conversions were confined to craft on inland waterways. Even then few of them survived the war and as far as is known, no further work in this direction has been done.

DUAL-FUEL ENGINES

When natural gas became available in some parts of the United States in the late 1920s, one company tried to develop a C.I. engine which would use this gas as a fuel; the idea was to take advantage of a cheap tariff for natural gas in the summer and revert to oil operation in the winter. With a modified, blast injection Diesel engine, it was found necessary to compress the gas to 1100 lbf/in^2 to obtain ignition; even then difficulty was experienced in obtaining regular running. Eventually a small quantity of oil was injected with the gas and much steadier running was obtained. Several of these engines were sold, but changing the engine from gas to oil operation took several hours and, at that time, blast injection was becoming unpopular with medium size Diesel engines.

In this country, the need for engines operating on alternative fuels arose in the sewage treatment industry. The sludge digestion process gives off a methane-rich gas, very suitable as an engine fuel, and the use of gas engines for the generation of electric power, or for compressing air required in the process, is obviously an economic proposition. Unfortunately it is not possible to match gas evolution, which does not take place at a constant rate, with power requirements.

At some sewage works therefore a range of similar engines was installed, some Diesel and some spark ignited; by changing cylinder heads it was possible to change from gas to oil fuel and *vice versa*, but this was not a routine operation.

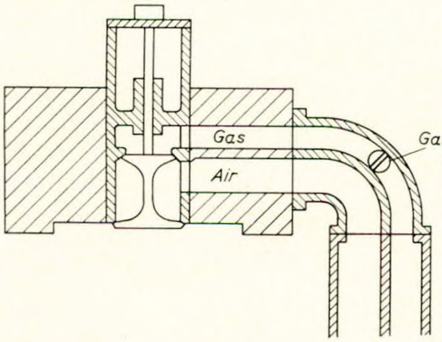
However the need for an engine which would operate on either liquid or gaseous fuel, without modification, became evident and the dual-fuel engine was the outcome of British developments and has since been adopted throughout the world. The dual-fuel engine is one in which a small charge of Diesel oil is injected on the compression stroke, the oil becoming ignited by the heat of compression and so firing the main gas charge; when required the gas supply can be shut off and the engine will continue to run as a pure Diesel.

The first such engine was developed by the National Gas and Oil Engine Co. Limited at the Coleshill Work of the Birmingham, Tame and Rea District Drainage Board(7). The engine had started life as a Diesel with a compression ratio of 13:1, developing 160 bhp, but had later been converted to a spark ignition gas engine with a compression ratio of 6:1 and an output of 120 bhp. The dual-fuel alteration consisted in essence of restoring the compression ratio to 13:1 and fitting oil injectors in place of the sparking plugs; under these conditions the engine developed 150 bhp. The pilot oil, representing about ten per cent of the thermal input required at full load, was maintained at a constant setting, to provide ignition, and the engine output was controlled by varying the amount of gas. The controls were so arranged that the engine could be changed over from dual-fuel to 100 per cent oil instantaneously, a feature much appreciated in the sewage works.

Harland and Wolff also pioneered dual-fuel engines at the Mogden Purification Works of the Middlesex County Council(8) and found it possible to reduce the pilot oil to 1¾ per cent of full load thermal requirements without misfiring, but on modern engines about five per cent is considered the optimum figure.

In the early days, difficulty was sometimes experienced in getting fuel pumps and injection nozzles which would provide the full quantity of oil for Diesel running, and the pilot quantity for dual-fuel without dribble; on some engines two sets of injection equipment were provided. However the problem has now been overcome.

Various methods have been adopted of admitting the gas and air into the cylinder; Fig. 2 shows the arrangement originally used by the National Company. Some makers introduce the gas into the induction pipe, claiming that good mixing of the gas and air is thereby ensured; others admit the gas direct into the combustion chamber, through a separate valve, and maintain that this practice avoids the danger of a leaking valve creating an explosive mixture in the induction pipe. In the earlier normally aspirated dual-fuel engines the quantity of air taken in on the induction stroke remained constant regardless of the engine load and, at part load, the gas/air mixture was too weak. With a pure gas engine this would mean misfiring and, with a dual-fuel engine, although ignition took place, exhaust gas analysis would show that combustion was only partial and specific fuel consumption, therefore, poor.



Courtesy I.Mech.E.

FIG. 2

With a turbocharged engine the air pressure depends on the blower speed and, therefore, on the engine loading; also the fuel gas has to be supplied under pressure, usually 25–40 lbf/in². Thus, the control of the gas/air ratio becomes more complex and some of the earlier turbocharged engines were not entirely successful(9). Fig. 3 shows the fuel consumption of a modern turbocharged engine with sophisticated control of the gas/air ratio, running as dual-fuel and Diesel. It will be seen that efficiency is higher on pure Diesel working, particularly at part load.

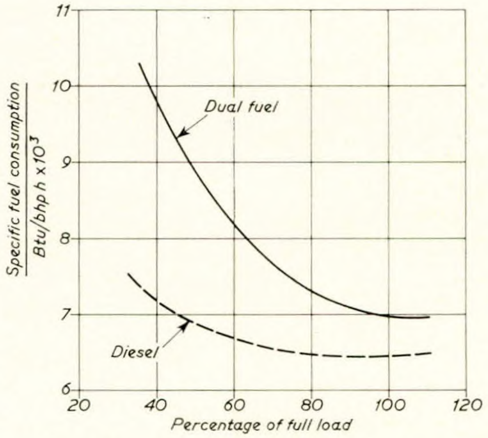


FIG. 3

Dual-fuel engines are started up as pure Diesels and changed over to gas when warmed up. On all modern engines, this change-over is carried out merely by the throw of a lever and, in the event of a failure of gas pressure, the engine automatically reverts to Diesel operation.

THE MODERN GAS ENGINE

Until the discovery of natural gas, there was practically no demand, in this country, for gas engines and it is not surprising that all the pure gas engines, at present available, are of American or Continental design.

Apart from the limitations imposed by detonation, a major problem is the control of the gas/air ratio; if the mixture is too rich, combustion will obviously be inefficient and, if too weak, misfiring will occur. With a Diesel engine, a large proportion of excess air is acceptable and this helps to keep the exhaust gases cool; with a gas engine the optimum excess air ratio (defined as the actual air/gas ratio divided by the stoichiometric air/gas ratio) must be controlled between 1·3 and 1·5(10). Thus in a gas engine, although the mechanical stresses because of the lower pressure are likely to be lower than in a Diesel, the thermal stresses are likely to be higher, and burnt exhaust valves and overheated pistons were not uncommon with normally aspirated engines. The introduction of turbocharging and charge air cooling however has provided scope for further development.

With normal aspiration, gas and air usually enter the cylinder simultaneously, but in the turbocharged engine, the air and gas are both under pressure and can be admitted separately; various forms of air scavenging can, therefore, be employed. The modern turbocharger can easily supply not only the air required for combustion, but also additional air for cylinder scavenging. Various methods of scavenging are employed, either by providing a valve overlap so that air passes in through the inlet valve and out through the exhaust for a short period before gas is admitted, or by having a third scavenge valve direct into the combustion chamber. It should be noted that a large part of the energy in the scavenge air is recovered in the exhaust turbine of the turbocharger.

The modern gas engine has a compression ratio of about 11:1, a maximum brake mean effective pressure of 160 lbf/in² and a maximum thermal efficiency of about 37 per cent.

Spark Ignition or Dual-fuel

In places where a fuel gas is very cheap, such as an oilfield or refinery, the higher cost of the pilot oil of a dual-fuel engine, although contributing not more than five per cent of the thermal energy, may be sufficient to tip the balance in favour of spark ignition. For pumping natural gas it is frequently cheaper to bleed off, for engine fuel, some of the gas being pumped than to provide facilities for handling Diesel oil; for this duty the integral gas engine-compressor unit was developed in the United States (see Fig. 4).

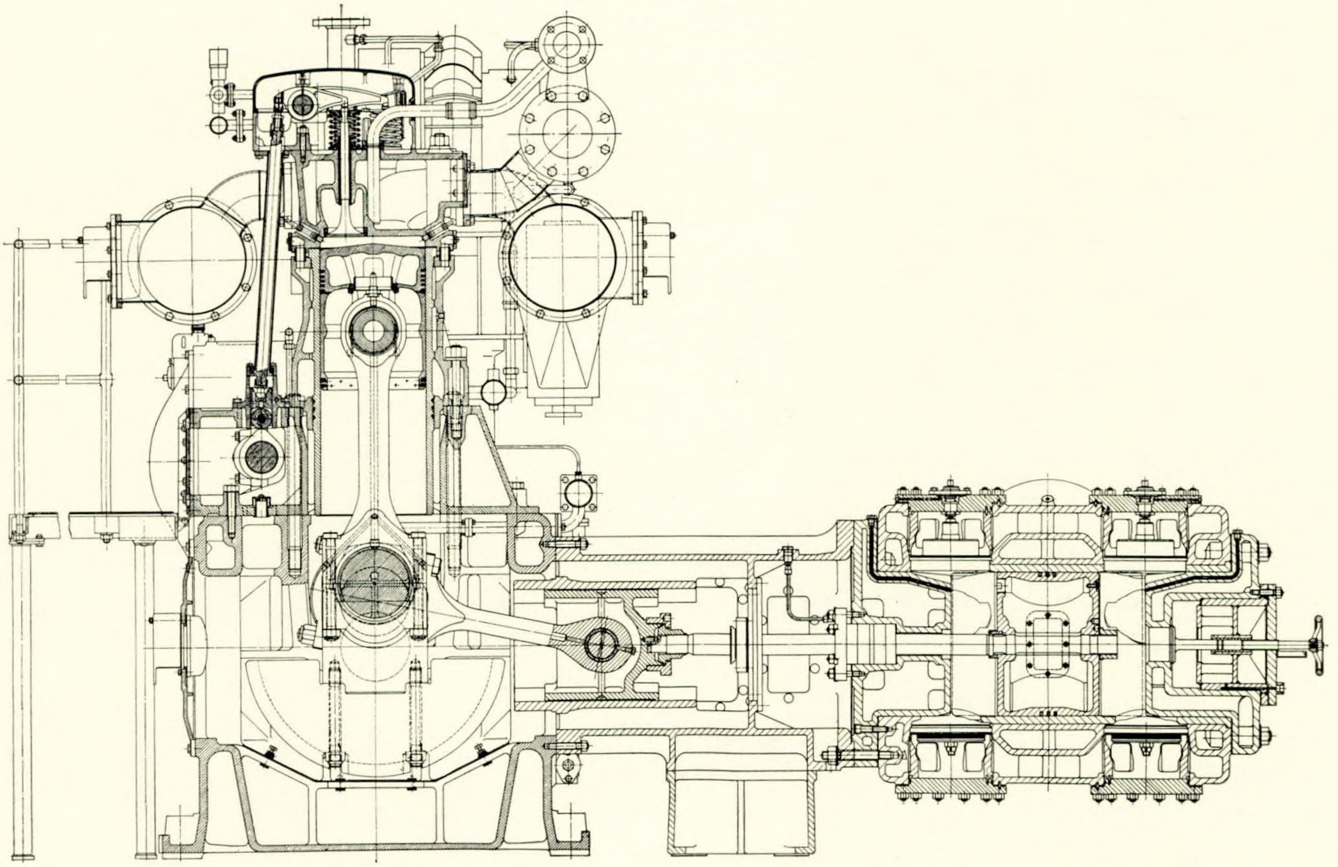


FIG. 4—*Thomassen type LGC gas engine compressor*

However, for many applications the dual-fuel engine will be the natural choice, some of the following factors tipping the balance:

1) the existence of oil storage facilities already on site;
2) the economics of an interruptible supply tariff;
3) less cyclic variation in speed, important when generating electricity; pilot oil ignition supplies many hundreds of times as much energy to initiate combustion as the best electrical ignition system; hence control of the fuel/air ratio is not so critical;
4) a weaker mixture can be burned economically with consequent better cooling of the exhaust valves;
5) because ignition is initiated at virtually an infinite number of points in the combustion chamber, detonation is less likely to occur;
6) because combustion is more rapid, ignition can take place later in the cycle and better mixing of the gas and air realized;
7) faster combustion more nearly approaches the constant volume combustion of the ideal Diesel cycle and, consequently, better thermal efficiency is to be expected;
8) experience shows that the maintenance of the spark ignition system is more expensive than that of a Diesel injection system(11); in a motor car the life of a sparking plug may be 15 000 miles at an average speed of 30 miles/h, representing 500 hours' work; in an industrial gas engine with a higher compression ratio, sparking plugs are found to last between 500 and 2500 hours and then can only be replaced; the servicing of Diesel injection equipment is needed less frequently and few new parts are required.

Gas Turbines

So far only reciprocating engines have been considered, but natural gas is an ideal fuel for gas turbines. The fuel consumption of a gas turbine is about twice that of the equivalent reciprocating engine, but a case for the gas turbine may be made out in the following circumstances:

i) where the fuel is very cheap, as in an oil field or sewage works;
ii) where standby duties only are required;
iii) where the low grade heat in the exhaust can be recovered usefully (total energy).

In medium sizes, the capital cost of a gas turbine is about the same as that of a Diesel, but a saving may be realized in lighter foundations and a less elaborate cooling system, and, with a clean fuel, maintenance is required less frequently. The single shaft gas turbine is very suitable for power generation and, for large scale gas boosting, the characteristics of a two shaft turbine match those of a direct coupled centrifugal compressor.

In large sizes, it is now usual to combine one or more aero-type gas turbines, used as a gas generator, with a free power turbine, thus utilizing a highly developed unit for the most critical part of the installation. Installations of this type are now designed for 25 000 hours' operation between major overhauls.

Where the gas supply is interruptible, the turbine can be made for alternative firing with Diesel oil, designed to cut in automatically when the gas pressure falls below a pre-set level.

Gas as a Boiler Fuel

It must not be forgotten that for large scale power generation, the internal combustion engine is in competition with the steam cycle. Boilers of the shell and the water tube type are available with alternative firing equipment for natural gas and liquid fuel, the change-over being made without interruption to steam raising. Most manufacturers make a combination burner, so designed that the flame shape and intensity is similar for

TABLE IV—NORTH THAMES GAS BOARD

Schedule of Gas and Dual-fuel Engines

Maker	Brotherhood	National	Mirrlees National	Thomassen	English Electric	Mirrlees National	Allen	Ruston
No. of engines installed	2	1	2	2	3	3	6	3
Year	1935	1937	1964	1967	1967	1969	1970	1969/1970
Location	Rayleigh	Canvey	Canvey	Canvey	Canvey	Beckton	Canvey	Fulham Beckton
Maker's Type No.		RVG4	R4AP	LGC35	CSVD	KP Major	GS37D	TA1500
Fuel	Gas	Gas	D/F	Gas	D/F	D/F	D/F	Gas or Oil
Pressure charged	no	no	no	yes	yes	yes	yes	—
No. of cylinders	4	4	8	6	16	7	9	—
Bore, in.	5	8	9	13·8	10	15	12·8	—
(mm)	(127)	(203)	(229)	(350)	(354)	(381)	(325)	—
Stroke, in.	5½	12	12	18·9	12	18	14·6	—
(mm)	(140)	(305)	(305)	(480)	(305)	(457)	(370)	—
Speed, rev/min	800	600	600	360	530	428	428	6000
Rated hp	36	124	416	1250	1455	2163	1210	1500
B.m.e.p., lbf/in^2	69	68	90	162	145	180	128	—
Mean piston speed, ft/min	735	1200	1200	1140	1060	1284	1250	—

either fuel and no difference in boiler performance can be observed.

GAS ENGINES IN THE GAS INDUSTRY

The gas industry was nearly 100 years old before electricity became a serious competitor and some time elapsed before the two industries learnt to respect each other's technological achievements and spheres of interest. It was natural that the gas engineer, for a time, resisted the advent of electric power and gas engines persisted in the gas works longer than in most other industries, driving either d.c. generators or line shafting. Now, of course, competition between the two fuels is confined to the respective sales departments.

Before the last war, at the extremities of many gas distribution systems, it was necessary to instal boosters for raising the gas pressure locally at times of peak demand; for this intermittent duty, gas engines were sometimes used. Peak loads in the gas industry coincide with those in the electricity industry and the tendency since the war, therefore, has been to avoid using electric motors and to instal Diesel engines. Gas engines were not again considered until the start of the methane terminal at Canvey.

Gas Engines in the North Thames Gas Board

Table IV is a schedule of all the gas and dual-fuel engines installed or on order by the Board, described in greater detail as follows.

The two Brotherhood gas engine compressor sets are a survival from before the war for occasional use; gas is pumped in oat receiver at 60 lbf/in^2 at times of low demand and released back into the main at times of super-peak load. The engines are unusual in that they are a crosshead type, designed originally, it is believed, as agricultural tractor engines to run on vaporizing oil; they operate normally on town gas, but tests show that they will run on natural gas with only minor adjustment of the gas carburettor.

The 1937 model National engine was moved to Canvey for a temporary duty during the early methane experiments and is still used occasionally; it uses butane as a fuel which has a very poor anti-knock rating (Table I), but it has a low compression ratio designed for hydrogen-rich town gas and its performance on butane has been satisfactory with minor modification only.

The two normally aspirated Mirrlees National dual-fuel engines drive two horizontally opposed Alley compressors each of which pumps 100 000 ft^3/h of boil-off gas from the liquid methane storage at Canvey to other stations in the Board at 150lbf/in^2. The boil-off is at the rate of about 0·2 per cent of the quantity stored per day, but, when a tank is being filled, it rises to perhaps three times this rate. These engines have a main oil pump for Diesel working and an auxiliary pump which supplies the pilot fuel for dual-fuel ignition. The original auxiliary pumps of cast aluminium construction were later replaced by a cast steel design. After initial troubles the engines have been very satisfactory; top overhauls are carried out at 3000 hours and major overhauls at 6000 hours frequency.

With the construction of additional liquid methane tanks, two Thomassen integral engine compressor units with spark ignition were installed to handle 300 000 ft^3/h of additional boil-off. These machines were built in Holland, but arrangements have now been made for their manufacture in this country. The units consist of a vertical in-line engine with horizontally opposed compressor cylinders on either side of the crankcase (see Fig. 5). The rate of flow of combustion air is regulated by the engine governor and the differential pressure across an air metering orifice acts on a diaphragm device controlling the rate of gas admission. In spite of the scavenge system (see Fig. 6) distortion of the exhaust valve seating through overheating was experienced, and water cooled valve seats have

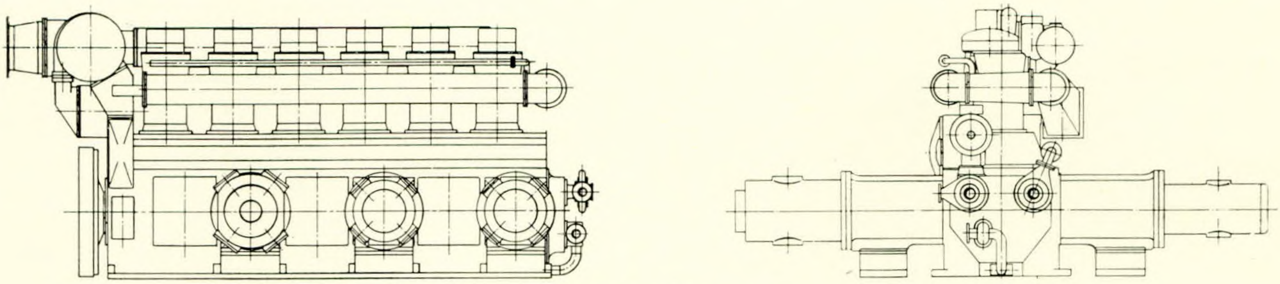


FIG. 5—*Thomassen type LGC 35 gas engine compressor*

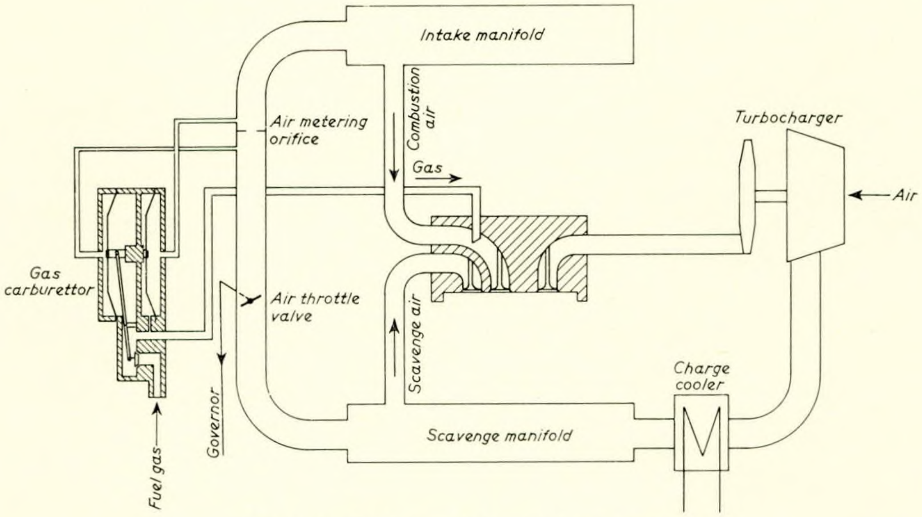


FIG. 6—*Thomassen induction system*

since been fitted. The life of the sparking plug extension tubes has been short, but fitting an alternative make of plug has improved the position. Starting has been difficult because of a leaking air valve which has now been modified. In addition a solid state electronic ignition system has been installed in place of the low tension magneto; this requires less maintenance and gives a higher energy spark at a slower speed. It appears that engine overhaul will be required at about 4000 hour intervals, this being determined by the life of the non-metallic piston rings on the compressor cylinders.

The English Electric engines drive vertical three-crank Burckhardt compressors each of 300 000 ft^3/h capacity. As will be seen from Table II, the calorific value of the liquid Algerian natural gas is higher than that of North Sea gas. It is therefore diluted with a "lean" gas (300 Btu/ft^3), made in an adjacent I.C.I. continuous catalytic reforming plant; these compressors pump the lean gas from 80 lbf/in^2 up to 1000 lbf/in^2 and inject it into the high pressure grid. Fig. 7 shows the system of gas admission and control; the gas admission valve is operated by a separate camshaft and a gas metering valve is controlled by the engine governor; there is a simple mechanical linkage between the gas metering valve and the air butterfly valve. When the engines were installed the flexible drive to the gas camshaft was found to be defective; the engines were so urgently required that they were put to work as Diesels and, at the time of writing, the dual-fuel system has not yet been commissioned.

The pressure charged Mirrlees National K Major dual-fuel engines have been ordered for a pumping duty at Beckton Gas Works. The conversion of consumers' appliances to natural gas is inevitably a slow process and conventional town gas, made by reforming natural gas, will be required in some districts for several years ahead. These engines will drive Donkin Crepelle compressors, each of 16·67 million ft^3/day capacity, for "line-packing" the Board's North Orbital main at pressures up to

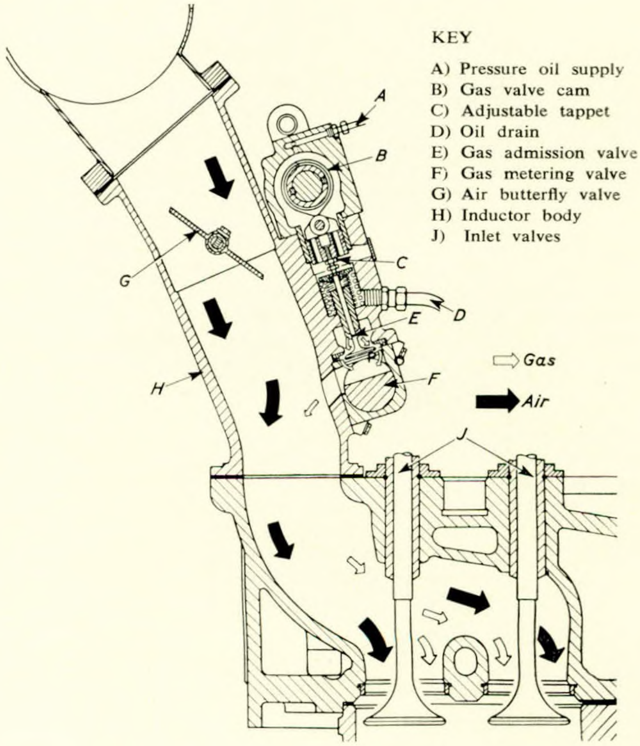
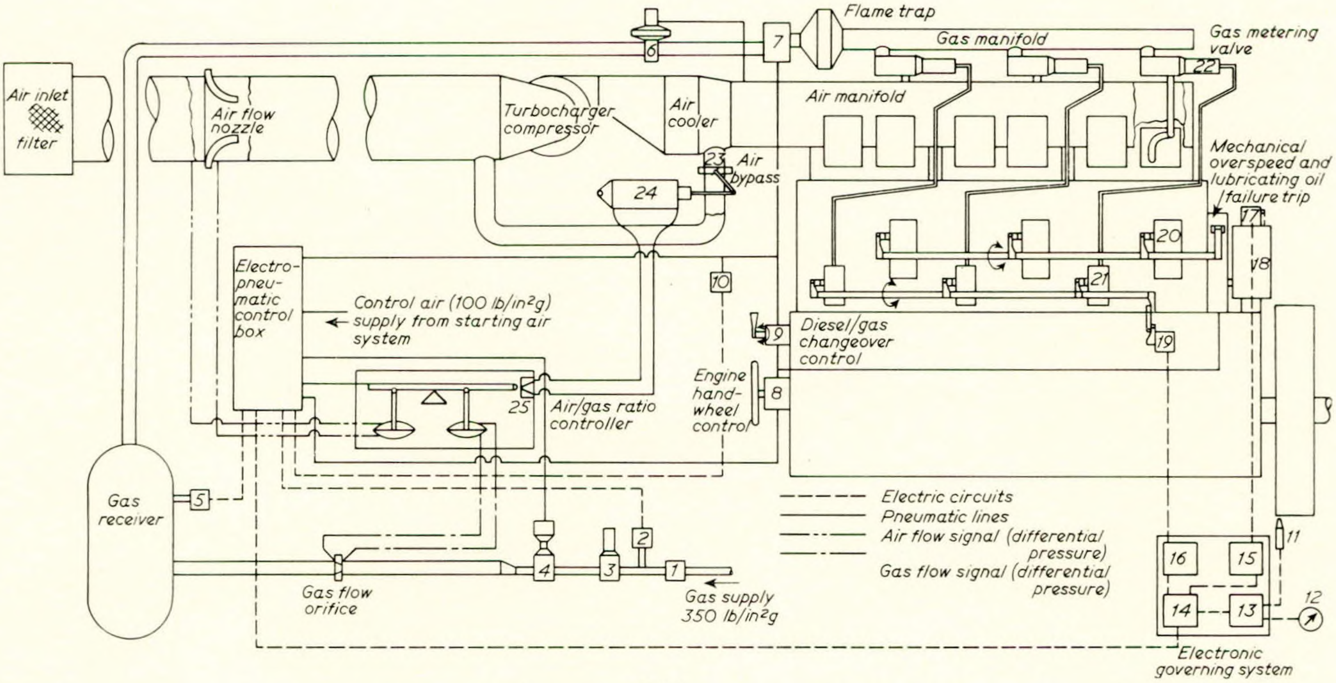


FIG. 7—*English Electric induction system*



KEY

1) Manual H.P. gas isolating valve
2) Pressure switch, detecting failure of gas supply
3) H.P. gas reducing valve, 40 lbf/in² outlet
4) Pneumatic H.P. gas shut-off valve
5) Pressure switch, detecting failure of reducing valve (3)
6) Gas manifold pressure governing valve, regulating gas pressure in relation to air manifold pressure
7) Pneumatic gas manifold shut-off valve
8) Pneumatic control valves on hand wheel control:
    a) providing air to set automatic overspeed and lubricating oil failure trip gear when starting
    b) admitting air to control valve (9) only when engine is running
9) Diesel to D/F (dual-fuel) change-over control, controlling air to open gas manifold shut-off valve (7)
10) Pressure switch, operating change-over relay in electronic governing system allowing governor to control gas metering valves
11) Electro-magnetic pick-up, generating signal proportional to engine speed
12) Governor speed setting control
13) Electronic unit converting speed signal from (11) to d.c. voltage comparable to signal from (12)
14) Diesel-D/F governing change-over relay
15) Diesel controller, when running on Diesel gives signal to electro-hydraulic actuator (17) controlling rack position of pumps: when running on D/F gives fixed signal, holding pump racks in pilot oil position
16) Gas controller, when engine is running on D/F gives signal to actuator (19) controlling gas metering system, when running on Diesel metering valves remain closed
17) Diesel actuator, converting electrical signal from (15) to mechanical power
18) Woodward governor, providing hydraulic power to actuators (17 and 19)
19) Gas actuator, controlling gas metering valve actuating pump racks
20) Main Diesel fuel pump
21) Gas metering valve actuating pump
22) Gas metering valve operated by hydraulic power from actuating pump (21)
23) Air bypass valve, reducing excess air when running on D/F
24) Pneumatic jack positioning air bypass valve
25) Air/gas ratio controller, comparing air and gas flow signals and maintaining a predetermined air/gas ratio when running on D/F

FIG. 8—*Mirrlees National dual-fuel control system*

350 lbf/in², thereby using the main for storage as well as transmission purposes. On this engine, gas admission and metering is carried out by a single valve on each cylinder; this valve is operated hydraulically, using a fuel injection pump as the source of hydraulic pressure, and the quantity of gas metered is proportional to the rack position as actuated by the engine governor. An electro-pneumatic control gear, shown in Fig. 8, maintains a constant and predetermined air/gas ratio.

The Allen pressure charged, dual-fuel engines will drive six Donkin Crepelle compressors at Canvey. The large in-ground liquid methane storage tanks give rise to a correspondingly large boil-off. Three of the compressors will each pump 300 000 ft³/h of gas to 150 lbf/in² for local distribution and three, working in series with them, will pump the gas up to 1000 lbf/in² into the Canvey-Leeds backbone main when the local system is already fully charged. From Fig. 9 it will be seen that separate valves are used for admission and metering the gas to each cylinder and the air/gas ratio is maintained by keeping the pressure drop between the air and gas manifolds constant. The change-over and shut-down system is actuated by the engine lubricating oil pressure.

One Ruston gas turbine has been installed at Fulham Works and two are being installed at Beckton, burning either natural gas or Diesel oil and driving centrifugal compressors, each 2 000 000 ft³/h against 9 lbf/in². Conventional town gas is made in reforming plants at a pressure higher than is normally required in the distribution grid system, whereas gas in the storage holders is at a lower pressure. Large scale injectors are provided whereby jets of high pressure gas draw the low pressure gas from the holder. The turbo-compressors are installed for use when the reforming plants are not at work and high pressure gas is not available. For this occasional duty their low thermal efficiency is offset by the following advantages:

a) low foundation cost;
b) absence of cooling water;
c) low maintenance cost and good availability;
d) quick start up from cold.

It will be seen that a wide variety of engines has been selected for the various duties. Because of the rapid rate of development following the discovery of North Sea Gas, it has been necessary to choose the engine with the shortest delivery. However the opportunity of evaluating the different machines available has been welcomed.

Other Area Gas Boards also operate gas and dual-fuel engines, and so do the oil companies at the terminal points where the North Sea Gas pipelines come ashore. Many of these are integral engine compressor units with two-stroke gas engines of

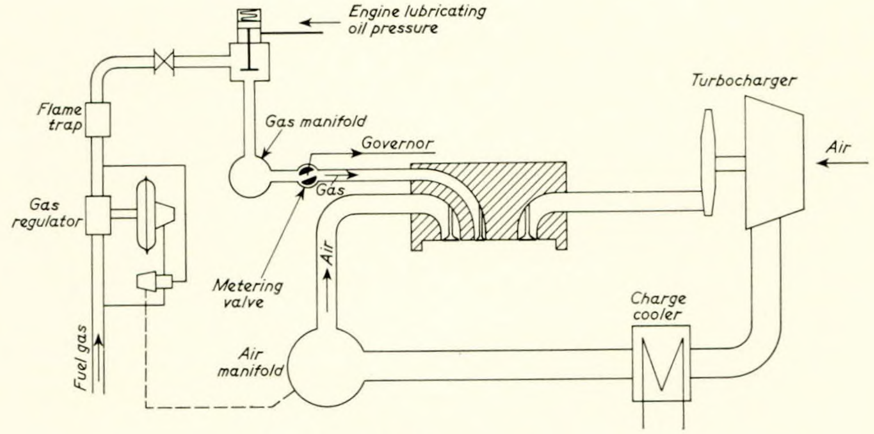


FIG. 9—*Allen fuel control system*

American design, though in some cases built under licence in this country or in France.

GAS IN THE TRANSPORT INDUSTRY

During World War I single-decker buses with a gasbag filled with town gas on the roof were a common sight, but their radius of action from the filling point was limited. Clearly, to store gas effectively on a vehicle, its volume must be reduced and, in World War II, cylinders of compressed gas, usually from the sewage works, were used successfully; gas compressed to 1500 lbf/in^2 occupies about one-hundredth of its volume at atmospheric pressure, but the storage cylinder must be robust, and therefore heavy.

In the U.S.A., several vehicles are operating experimentally on liquid natural gas contained in vacuum insulated tanks and occupying 1/600 of its original volume (12, 13). The principle interest of the experiments is in replacing petrol which, on an energy basis, is more costly in the western states, where there is also much concern with air pollution from motor vehicle exhausts. The experimental vehicles have an exhaust virtually free of carbon monoxide and the unburnt hydrocarbon content is less than half that of the petrol engine, without loss of performance.

The necessary vehicle modifications have included fitting a vacuum-insulated fuel tank, a gas vaporizer and a natural gas carburetter: the engine compression ratio is raised to 12:1 and a new camshaft installed to suit the slower burning rate of the gas. It would appear that L.N.G. is most suitable for a fleet of buses, taxis, tugboats, earth-moving vehicles etc., operating seven days a week from a central location where the vehicles can be refuelled: the insulated tank can be made suitable for a pressure of 15 lbf/in^2, sufficient to contain the boil-off during a night's standstill; in the morning the pressurized vapour can be used initially until the pressure in the tank is back to atmospheric.

LIQUID NATURAL GAS IN THE FUTURE

None of the experimental work so far published has made use of the "heat sink" or cooling properties of L.N.G., though workers are of course well aware of its possibilities(14).

If the L.N.G. were evaporated by heat exchange with the charge air, an improved power output and a reduced tendency to detonation would be expected. The gas turbine, which uses perhaps five times as much air as a reciprocating engine, is particularly sensitive to air intake temperature and cooling of the charge possesses great possibilities.

The aircraft industry is fully alive to the potentialities of L.N.G. and envisages the following advantages(15):

1) the lower calorific value for L.N.G. is 22 800 Btu/lb compared with 18 700 Btu/lb for aviation jet kerosene; this means that the specific fuel consumption, measured in pounds of fuel per shaft horsepower-hour, is improved by 15 per cent; however, the specific gravity of L.N.G. is lower (0·43 compared with 0·70) and a larger fuel tank (even discounting the insulation) will be required;
2) By using L.N.G. to cool the hot metal parts of the engine, a higher temperature drop across the turbine can be tolerated with consequently a significant increase in power; this procedure is standard practice with liquid hydrogen/liquid oxygen fueled rocket engines and accounts in part to the immense thrust which they give; not only does the L.N.G. as a cooling medium start at −258°F (−160°C), but it can be heated up to 1200°F (650°C) before it starts to break down, whereas kerosene cannot be heated above 500°F (260°C);
3) the L.N.G. could be used to cool some of the critical parts of supersonic transports;
4) in the event of an accident, L.N.G. presents many advantages; the spontaneous ignition temperature in air for methane is 1166°F (630°C) compared with 491°F (255°C) for aviation kerosene; the L.N.G. may cool hot metal to below the ignition temperature; since the fuel tanks contain a boiling liquid the free space contains vapour only, not an explosive mixture; any liquid spilled on the ground will evaporate and, being lighter than air, quickly disperse.

CONCLUSION

The aircraft industry is noted for its enterprise and has been experimenting with L.N.G. ever since it first became available. Have marine engineers and shipping interests given the same consideration to its potentialities, both as a fuel and as a source of cold for refrigerated ships?

The development of gas and dual-fuel engines has hitherto been held back by the absence of natural gas and, even today, it is not everywhere obtainable. However, the development of a high pressure distribution system is proceeding at a rapid pace. At present L.N.G. is only available in quantity at Canvey, but other storage depots are being built in the Midlands and Scotland, with others to follow in this country and overseas.

The engine building industry is alive to the new opportunities presented by natural gas; are engineers generally, and marine engineers in particular, prepared to take advantage of them?

ACKNOWLEDGEMENTS

The author's thanks are due to the Chairman and the Director of Engineering of the North Thames Gas Board for permission to publish this paper, to Mr. M. A. Williams and other colleagues for assistance in its preparation, and to various engine builders, in particular W. H. Allen Sons and Co. Ltd., English Electric Diesels Ltd., Mirrlees Blackstone Ltd., and N.V. Motorenfabriek Thomassen, for information concerning their products.

REFERENCES

1) Clerk, D. 1909. "The Gas, Petrol and Oil Engine." Longmans, Green and Co. London.
2) Newcomb, W. K. "Combustion Fundamentals of heavy duty gas engines." A.S.M.E., 24th Conference, Oil and Gas Power Division.
3) Ricardo, H. R. 1938. "The Progress of the Internal Combustion Engine During the Last Twenty Years." *Trans. I.Mar.E.*, Vol. 50, p. 185.
4) Alford, R. N. and Felt, A. E. 1969. "A Knock Suppressor for Large Gas Engines." A.S.M.E., Diesel and Gas Engine Power Division.
5) Holvenstot, C. E. 1961. "Performance of Spark-Ignition Four-Cycle Engines on Various Fuels." A.S.M.E., Oil and Gas Power Division.
6) Gibbons, J. F. 1938. "Gas Engines for Small Craft." *Trans. I.Mar.E.*, Vol. 50, p. 227.
7) Jones, J. 1944. "The Position and Development of the Gas Engine." *Proc. I.Mech.E.* Vol. 151, p. 32.
8) Keep, G. A. and Cummins, K. M. 1954. "Dual Fuel Engines." D.E.U.A. S231.
9) Roughton, J. H. 1969. "Dual Fuel Engines." D.E.U.A., Publication 327.
10) Land, M. L. 1967. "The Performance and operation of Spark Ignited Gas Engines." *Proc. I.Mech.E.*, Vol. 181 Part 1, p. 900.
11) Ulrey, L. 1964. "Engine ignition considerations." A.G.A.
12) Engler, M. R. 1967. "L.N.G. Utilisation" Chicago, First International Conference on L.N.G., Paper 43.
13) Moylan, J. E. 1967. "A Future Fuel for the Transportation Industry." Chicago, First International Conference on L.N.G., Paper 46.
14) Karim, G. A. 1969. "Some Aspects of the Utilization of L.N.G. for the Production of Power in I.C. Engines." "Cryogenics in Fuel and Power Technology" Symposium, Session 6, International Institute of Refrigeration.
15) Joslin, C. L. 1967. "L.N.G. Usage in Aircraft Engines." Chicago, First International Conference on L.N.G., Paper 44.
16) Stephenson, J. M. 1967. "L.N.G. as a Fuel for Helicopters." Chicago, First International Conference on L.N.G., Paper 48.

Discussion

Mr. E. J. Bannister (Associate Member), opening the discussion, said there had almost been the suggestion that the potentialities of L.N.G. in marine applications were not being fully exploited.

The authors rightly pointed out that the recent scale availability of natural gas in the U.K. provided scope to increase the use of gas engines for certain applications ashore. In the marine field, however, the fuel must essentially be stored in the liquid form. At present it seemed unlikely that L.N.G. would be carried by vessels purely for the purpose of providing energy for propulsion, unless the cost of storage and handling on board could be drastically reduced. This logically left one field where L.N.G. could, and already did, play a useful part as a gas at sea, namely when it was carried as a cargo, and it was in this field that he wished to direct his remarks.

The transportation of liquid natural gas was of great concern to many oil companies and a tremendous amount of development effort was under way, the bulk of which was devoted to carrying gas in the most economic and reliable way. As far as any economies were concerned, the design of the tanks for carrying L.N.G. was all important and the subject of continuous research. Where power plant was concerned, reliability was the keynote and in this respect it did not have to be emphasized how large the penalties were for non-delivery within a scheduled time.

Boil-off from L.N.G. cargoes was often erroneously regarded as a source of free fuel; this would be correct insofar as if it were not burnt it would be vented, discounting reliquefaction. However, if at the design stage the boil-off could be greatly reduced by more efficient insulation, the increased earnings from the extra L.N.G. delivered, would more than offset the cost of fuel oil required to substitute for the lack of that boil-off. From that it followed that a shipowner was unlikely voluntarily to use L.N.G. as a 'heat sink' in the manner suggested by the authors for the purpose of cooling engine charge air and the like.

It was interesting to note the authors' comments on the advantages of dual-fuel engines over plain gas engines, as marine engineers would favour the former both from the aspect of safety and the inability on board ship to match the rate of boil-off with the engine load (similar to the difficulties experienced at sewage works mentioned by the authors).

Methane Princess and *Methane Progress* were briefly described in the paper. These two ships had been very successful and as far as the boilers were concerned, the good combustion of gas resulted in exceptionally clean fireside surfaces. This was fortunate since the increased reliability required of L.N.G. ships was, to some extent, achieved by the nature of the cargo itself.

The possibilities of gas turbine propulsion for L.N.G. vessels appeared to be well worthwhile studying. The clean fuel was available, savings in weight and space were attractive, and the promise of considerably reduced maintenance could to a large extent offset the increased capital cost of such a plant. The savings realized with lighter foundations and simpler ancillary systems went without saying. Reliability of the gas turbine in the marine field was yet to be proven and this applied to uses such as cargo pumping, alternator drive as well as the main power plant.

The variety of plant described was impressive, with some interesting operational experience. In terms of overhaul life for marine engines, something better would be required than a top overhaul at 3000 hours and a major overhaul at 6000 hours. For the main plant he would expect to operate reliably for at least 8000–9000 hours without a single overhaul.

With regard to the use of L.N.G. for application such as refrigerated cargo ships, this would need to be related to the operating requirements on such ships and this form of cooling might not be economical for certain ranges of temperature required for refrigerated holds. While on the subject of utilizing the 'heat sink' or cooling properties of L.N.G. mentioned by the authors, surely at Canvey Island they had the largest store in this country, if not in the world, of energy in the form of 'cold'. He hoped a better use would soon be found for it besides freezing the unfortunate bathers at Southend with the discharge of the heat exchangers!

Mr. Bannister asked that the use of liquid natural gas as an engine fuel be applied to those areas where it was most suited. So often, a new innovation arose and it was found that it was put to use in areas totally unsuitable for its application. In this present context, he could not help feeling that great care should be exercised to prevent failures in some fields from adversely affecting the reputation of the new medium as a whole.

Mr. J. A. Smit (Associate Member) read a contribution written by Mr. A. Steiger from Switzerland in which he said that the authors had presented a well-rounded picture of the early and later development of the 4-stroke cycle gas and dual-fuel engine, whereas comparably little had been said about its 2-stroke cycle counterpart. He therefore proposed to fill in this gap with some remarks about the latter type of engine.

Up to the present, 2-stroke cycle dual-fuel engines had been limited entirely to the American continent, where reputable Diesel engine manufacturers had developed and marketed these engines with up to 1000 hp per cylinder. The Nordberg engine, in particular, which belonged with a bore of $21\frac{1}{2}$ in to the large-bore slow-speed crosshead type, had been widely accepted for power-plant duty in the U.S., whereas the Fairbank Morse opposed-piston medium speed version had been too briefly on the market to make its presence felt.

It was only very recently that in Europe this line of engine had been actively pursued, spurred on by the appearance of the L.N.G. carrier. This type of vessel has, up to the present, been exclusively equipped with steam turbine plants for the propulsion machinery, since the dual-fuel type boiler, as mentioned in the paper, made it possible to burn the inevitable boil-off from the liquefied-gas. To allow shipowners to utilize the considerably higher thermal efficiency of the Diesel engine for this type of ship, Sulzer Brothers have pursued the development of the heavy duty 2-stroke cycle engine to the point where it has become possible to provide cylinder outputs of 2000 hp adding five per cent pilot fuel only. Due to its low fuel consumption at full load and also at part load, this engine is, of course, also quite suitable for power plant duty. The fuel consumption curve which was measured during test runs with a 6 cylinder RD76 engine, which had a bore of 30 in, is shown in Fig. 10 and compares quite favourably with the curve presented for the dual-fuel engine in Fig. 3. A view of the cylinder heads of these particular engines was shown in Fig. 11, where the gas header and the individual gas admission valves on the cylinder covers might be seen.

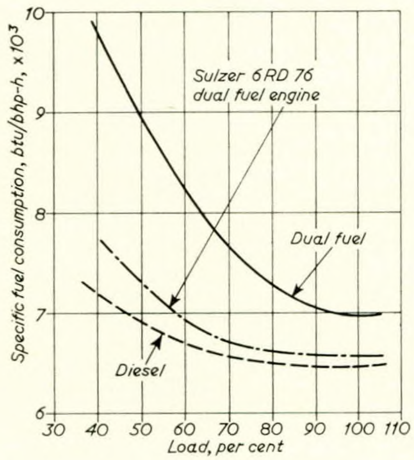


FIG. 10

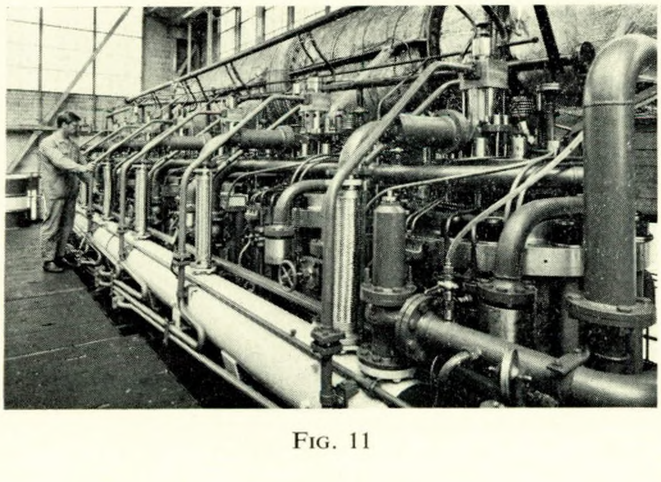


FIG. 11

This engine was publicly demonstrated on 15th July, 1969. The knock-free b.m.e.p. was 115 lb/in^2 when running in pure methane, a figure which, if compared with b.m.e.p. values shown in Table IV, looked quite favourable. A 4-stroke engine would have to produce 230 lb/in^2 to match this output. Piston speed was 1220 ft per minute at 120 rev/min. It is expected that the appearance of this new class of engine, capable of producing up to 24 000 hp per unit, will in due time considerably widen the scope of application for gas burning engines.

MR. E. J. EDWARDS said since December 1964, when gas was first discovered in the North Sea, its development had progressed rapidly to the point when there were some nine production platforms in use capable of producing at least 2000 million ft^3/day with considerably greater capabilities on demand. Four sub-marine lines from these production platforms reached the coast and independent but interconnected processing plants ashore gave a very high degree of reliability to this new source of gas supply. The rate of development in the North Sea was estimated as one of the fastest rates of development of a major gas field in the world ever before achieved. Over 1000 miles of large diameter pipeline had been laid ashore to various parts of the country and availability of natural gas was extending fast in all areas, particularly where close to existing pipelines. Over 1·5 million customers would have natural gas available by March 1970, and the network of new pipelines would extend to 2500 miles in due course covering a large part of the U.K.

The authors had described a number of usages of gas engines and dual-fuel engines and had shown the potentialities behind this form of prime mover. It was somewhat disappointing that there was not a wider choice of gas engine available from manufacturers in this country. One type alone that needed developing was, surely, the trouble-free air cooled engine of moderate size.

The authors' indication of the possible usages of gas engines, the gas turbines and the employment of gas as a boiler fuel, reminded one that total energy schemes had become a most interesting possibility to a large number of users from those recent developments in the availability of a cheap fuel. The beginnings of great interest in this application had been witnessed by the contract recently signed between the East Midlands Gas Board and John Player of Nottingham for the implementation of a total energy scheme at their new factory.

Another new fuel was liquefied natural gas. Although the widespread availability of L.N.G. in this country was a future prospect, it was interesting to note developments in the U.S.A., where the need for reduced pollution had led to some 30 cars and lorries running on L.N.G. in Southern California, and to an application of this fuel in a racing motor car named 'The Blue Flame' as a demonstration of L.N.G. capabilities and particularly its safety.

Although Mr. Edwards considered the use of L.N.G. in private cars somewhat futuristic for the United Kingdom there was no doubt about the reality in the United States of the ease of conversion of standard cars to this usage. In fact, he was reminded of a hot day in California when L.N.G. had advantages to cool the driver since the cool air from the L.N.G. evaporator, just below the dashboard, gave the driver an optional bonus from the application.

There were more than 16 installations for liquefaction of natural gas already completed or under construction in North America. These had arisen because of the great advantage in allowing the main gas transmission systems to run at a steady loading and for meeting peak demands on local gas networks. Something of the same condition existed here where the Gas

Council transmission system delivered to local supply areas, so one would expect some growth in L.N.G. installations.

MR. W. TIPLER, M.A. (Member) commented on the authors' assurance that natural gas was in plentiful supply. He stated that:

i) enormous reserves of natural gas did exist, but most of them were remote from centres of industry and and population. This fact was of economic significance since the transport of natural gas was more costly than that of liquid fuels. Even the North Sea fields were not particularly accessible in view of the turbulent nature of that sea;
ii) reserves of natural gas were usually quoted in "millions of cubic feet". To bring these large numbers into perspective, one should remember that, on a thermal basis one million cubic feet of natural gas was equivalent to only about 25 tons of fuel oil;
iii) gas satisfied less than 10 per cent of the energy demands of this country. While the "local" reserves of natural gas were large compared with this offtake, they could be diminished rapidly by major expansions of gas consumption, for example, to the C.E.G.B.

The conclusion of the paper implied criticism of marine engineers for lack of interest in L.N.G. but possibly the paper lacked encouragement for such interest. In order to make an assessment of the practical possibilities of L.N.G. for marine applications, information on several points was required:

a) how rapidly and how extensively would L.N.G. bunkering points become available? a world wide coverage comparable to that of conventional bunkering facilities would be needed if L.N.G. was to become a significant fuel at sea;
b) the specific gravity of L.N.G. was 0·43 compared to 0·85–1·0 for marine fuels. This in itself was a grave handicap, even after allowing for differences in calorific value. In order to fully assess the problems of L.N.G. bunkering, data were needed on the thickness of insulation needed for L.N.G. tanks, and also information on the weight, cost and maintenance of such insulation;
c) to what extent were the Gas Boards prepared to cooperate in the development of new applications of L.N.G.? The marine industry had long enjoyed close co-operation with the oil industry in work to develop new applications of petroleum products, and to improve existing uses. To what extent would the Gas Boards engage in such collaboration?

COMMANDER J. H. ROUGHTON, R.N. referred to the end of the section on dual-fuel engines in the paper where the authors referred to a paper he presented before the D.E.U.A. earlier this year. He had mentioned the gas compressors at the Maple Lodge works of the West Hertfordshire Main Drainage Authority which discharged at nine to ten lb/in^2, turbocharger pressure being about four lb/in^2 at the manifold (as far as could be remembered).

They had had many problems with the first of their super-charged engines, which replaced two of the old naturally aspirated engines. These troubles stemmed from failure to obtain correct combustion of the gas/air mixture. Imperfections of operation associated with this still persisted, it was understood. In the original design, ignition fuel was supplied by separate fuel pumps which discharged to "pilot" injectors located at the side of the cylinder heads on the line of the crankshaft. Although the small injector apparently worked satisfactorily on the test rig under site conditions with sewage gas, lack of spray penetration soon became evident. Dirty exhaust and high exhaust gas temperature at part load together with heavy load swing all pointed to poor combustion. In fact two faults, each one fatal in itself lay at the root of this trouble. Over lean gas/air mixture resulting in power loss was aggravated by incomplete and non-uniform ignition of the mixture which produced detonation by excess of "after gas". Eventually the ignition system was scrapped and the main pumps and injectors used for ignition oil. The central location of the main injectors was correct to give the necessary depth and spread to the oil spray, so with clean injectors it was possible to achieve 110 per cent full load on gas. It soon became evident that full rated load could only be relied upon if the injectors were cleaned at intervals not exceeding 200 hours, possibly less. This was understood to be the position today. Any erosion of the fuel pump plungers would have a similar effect. This brought one straight back to the first fault mentioned; i.e. over-lean mixture. No means of limiting the supply of combustion air to the engines to that required for gas operation was fitted on these engines. Since operation on liquid fuel was entirely satisfactory, the authors of this paper made it quite clear why this could not possibly be satisfactory when the engines were running as gas engines, since the turbo-charger was supplying the same amount of air in both cases. It would seem, therefore, that at Maple Lodge with fuel injection equipment in tip-top condition an ignition supply of just under 7 per cent would be satisfactory. It was obviously not possible to maintain this state with the result that power loss, load swing and all the attendant dangers of bad combustion were bound to continue until arrangements were made to match the air supply to the cylinders to a gas/air ratio nearer to the theoretical ideal. It was understood that as a result of this, gas from the digestors had to be blown off to atmosphere.

Commander Roughton said he was intrigued to read that burnt exhaust valves and overheated pistons had been met with in naturally aspirated engines operating on gaseous fuels. He wondered if this was with the use of natural gas or again with the more "knock-prone" of the other gases. Sewage gas not only had a lower C.V. but, he suggested, the high percentage of CO_2 tended to keep piston crown temperature down. They had had no incidence of burnt valves on the old engines at Maple Lodge when he had been there, but they knew that the piston crown temperature was on the high side when running on liquid fuel, and at one period it led to ring-sticking, blow-by and several piston/liner seizures from light to heavy in degree. These engines were originally de-rated to about 550 bhp on liquid fuel by the makers, independently driven Roots type blowers being fitted to attain the rated output of 820 bhp. However, when operating on gas an output of 666 bhp was permissible, showing the cooler running conditions on gas. Since gas compressors were not fitted, the M.D. blowers could not, of course, be used in gas operation. This proved a very satisfactory compromise for these engines, which had run for almost 20 years and were still going strong, without significant loss of economy or efficiency.

Gas on these engines was admitted but the upper lid on the inlet valve had a parallel portion at the top and passed through the seating with a fine clearance. Unlike the modern engine, the ratio of ignition oil could be varied at will while running and so take up gas shortage or need for maintenance at the price of extra fuel consumption. This was often very handy! Finally, Commander Roughton would like to support the authors' contention as a user that both the gas Diesel and the dual-fuel engines were completely viable propositions. In marine service where circumstances favoured the use of a gaseous fuel, there would no doubt be some special problems, but personally, as a seagoing engineer, he could not see any reason why these should not be quickly overcome and equally reliable and economical service obtained as on shore.

MR. P. T. BRANDHAM agreed with the authors that detonation was the major limiting factor determining power output, but pointed out that the critical compression ratio values for various fuels shown in Table I were those from only one of the various A.P.I. test procedures available for the assessment of knock rating. If figures from one of the other methods were used, then a different impression as to the relative merit of the various fuels was obtained. For example, one could compare critical compression ratio values determined by the A.P.I. 600–212° procedure (those in Table I), with values for the same fuels obtained from the A.P.I. 600–350° test method. He suggested that the latter values were more representative of the relative merits of the fuels when used in medium speed dual-fuel engines.

The importance of air/gas ratio control could be illustrated to show the effects of air/gas ratio on gas consumption of a turbocharged dual-fuel engine. For the engine a reduction in fuel consumption of some 20 per cent at 25 per cent rated load could be obtained by automatically maintaining the air/gas ratio at a fixed value irrespective of load.

Mr. R. A. Jones agreed that North Sea gas was a very important new source of energy for Britain, but the key to its use as proposed in the paper, namely "As an engine fuel" was price. Supplies seemed to be assured for some considerable time to come and the Leman Field producing at this time some 600 million ft^3 per day was reputed to be the largest offshore gas field in the world with an estimated development capability of 2000 million ft^3 per day. In addition there was Hewit, West Sole, Viking, Indefatigable and Rough fields with, it was hoped, more discoveries in both the North and Irish seas to come. The authors had indicated that the price per therm for the small industrial user might be higher than the cost of 7½d per therm for a distilate fuel. Could the authors be more precise and say how much higher? It was the low cost (as low as 2d per therm) of natural gas in the U.S.A. that had led to its rapid widespread use in that country as an engine fuel for on-site power generation for hospitals, office blocks and industry. As shown in Table I the critical compression ratio of the gas limited the compression ratio of the gas engine to a value below the C.C.R. The modern Caterpillar spark ignition gas engines with which he was familiar had high and low compression pistons depending on the type of gas used. High compression was normally 10:1 while low compression was normally 7:1. These engines were made in both naturally aspirated or turbocharged after-cooled form. The choice of one of these four configurations was determined by the following:

1) type of fuel used;
2) the ambient conditions;
3) temperature of water to the turbocharger aftercooler;
4) horsepower required.

It should be noted that turbochargers were always used in conjunction with aftercoolers so as to keep the mixture temperature within the cylinders well clear of detonation. It was noted that only the slow speed relatively expensive and complicated ignition Diesel/gas configuration had been considered. Had the authors considered L.N.G. as a standby fuel for spark ignition gas engines? In the U.S.A. it was common practice to use liquid propane as a standby fuel supply and this could be accomplished cheaply and simply on a modern medium speed spark ignition gas engine. He did not agree that a modern spark ignition gas engine had a major problem in the control of gas/air ratio or that turbocharging was introduced to reduce thermal stresses to an acceptable level. A gas engine ran hotter than a Diesel but the engine was designed for this condition. Exhaust temperatures varied about 25 per cent between no load and full load and the exhaust temperature of a Caterpillar engine was 1100°F (after the turbocharger), the corresponding Diesel temperature being 850°F at rated full load output at 1200 rev/min. A Diesel engine did not have a constant air fuel ratio. If too much fuel was injected black smoke was the only result. A gas engine ran at a set air/fuel ratio. Running with either too low or too high air/fuel ratio resulted in increased fuel consumption and reduced power but had no significant effect upon engine or exhaust temperatures.

Mr. J. P. Harmsworth said although, as a natural gas engineer he had had little or no experience of marine engineering, he had however spent a considerable amount of time during the last four years on the technological and economic problems of "total energy" and "on-site" power systems for industrial users.

It would thus seem important to consider the likely economics of fuel availability and utilization in the early years if serious consideration were to be given to the use of natural gas as a marine fuel.

In answer to one of Mr. Tipler's questions, there was no doubt that plenty of natural gas existed as roughly one-third of the proven petroleum reserves of the world today were in the form of natural gas. The problem lay in the high cost of liquefaction and transportation of natural gas to the required number of bunkering ports.

The only form of natural gas that could be considered as a marine fuel at present was Liquefied Natural Gas—and even L.N.G. occupied nearly twice the space of heavy fuel oil for the same thermal quantities. The cost of storage and transport must always be expected to be higher than for heavy fuel oils, and the total cost of production, liquefaction, transport and storage was heavily dependent upon the scale of operation. As a result one might expect that the first uses of L.N.G. as a marine fuel were likely to be restricted to the ports involved in the large scale movements of L.N.G. for the gas industries of the world. Even when operating between these ports L.N.G. would have to have a higher value to the user than heavy fuel oil—on a thermal basis. Refrigerated food ships would seem to be a possibility.

For most ships the likely higher thermal cost of L.N.G. would have to be justified by improved economics of shaft horespower production. Here there was a parallel with the shore based "total energy" and "on-site" power systems.

The need to obtain improved economics led to the authors' conclusion that dual-fuel engines were the best solution due to their high thermal efficiency.

On the other hand the following two cases might provide some food for thought, and the authors' comments would be appreciated. Firstly, the vast majority of natural gas fuelled reciprocating engines were in the U.S.A. and most of these used spark ignition systems—despite the fact that the price differential between natural gas and heavy fuel oil was often more than two to one.

Probably the main reason for this was that a large number of small medium to high speed engines were used per installation to get high reliability and low cost per installed horsepower. Did this mean that the case for multiple medium/high speed engine installations should be reconsidered for marine use when L.N.G. was available?

Secondly, he had recently come across a case outside the U.K. where a group of industrial plants had been generating their own power with low speed Diesel engines and gas turbines for the past eight years on quite a large scale.

In this case the regenerative gas turbines produced considerably cheaper power than the dual-fuel reciprocating engines despite their lower thermal efficiency. No use was made of the available "waste" heat. The main reason for the good economics of the gas turbine was the much lower maintenance costs. Would the lower capital costs and costs of maintenance and fuel preparation for L.N.G. fuelled marine gas turbines compensate for the lower fuel cost of heavy oil fuelled reciprocating engines?

There did not seem to be any large obvious market for L.N.G. as a marine fuel, but those concerned with long range developments should not forget the possibility, as the number of ports having L.N.G. storage for the gas industry could be expected to increase steadily from now on.

Mr. M. Z. Navaz (Associate Member) said the paper referred to petroleum and methane gases only. In the years to come there might be a host of other gases that could be used for power generation.

The burning of L.P.G. and L.N.G. fuels in marine engines presented different problems to those encountered on shore installations mainly due to the compactness of the ship's engine room. Ashore vast volumes of free air could be allowed to circulate around the gas engines, auxiliary services might be located far away in segregated compartments and other services might be tapped off by pipes and cables. In a ship's engine room all the services had to be located in close proximity within the engine room, with the crew living nearby. Therefore, protection against leakage called for far stricter control particularly when the fuel was not detectable by the naked eye nor by smell.

For marine application, some important points were:

1) Construction of the engine room should be considered with special reference to:
    a) engine room flats;
    b) girders, deep frames, webs and other fabrication;
    c) engine and auxiliary seating;
    d) engine room floors and double bottom construction;
    e) the question of gas tight sub-division within the engine room spaces, e.g. the electrical main and sub-distribution centres might require to be in a compartment of their own;
    f) communication between the compartments would require careful study.
2) Safety devices against leakage of gas.
3) Ventilation of the compartment would have to be critically studied.
4) Compartments would have to be constantly monitored for gas leak.
5) The electrical system from power generation to supply distribution, utilization, etc., would have to be examined very carefully (including lighting and ventilation).
6) Bilge wash and drainage system and arrangement of floor plates.
7) The piping system with special reference to the run of hot pipes.
8) The location and segregation of sources, making use of a naked flame, e.g. boiler, inert gas generation, etc.
9) Fire-fighting system.
10) Protection of human life against dangerous fumes.

One could see from this that simple installations designed and well proved ashore could not automatically be incorporated for marine use.

At present the boil-off of L.N.G. cargoes was burnt in the boiler for propulsion purposes. When one examined the safety requirements required by the various authorities one found that this method of power generation required far greater caution and care than conventional fuels.

Many engineers took the view that burning of boil-off vapour from a refrigerated liquefied gas presented a false economy and that containment by means of refrigeration was the true long term economic proposition. Observations showed that maximum boil-off occurred with adverse weather conditions when power requirements were a minimum resulting in leakage to the atmosphere. Conversely the boil-off was a minimum when weather conditions were good, resulting in supplementing fuel consumption by the use of convection fuels.

Greater utilization of the cold sink in liquefied gases at the discharging port would call for maximum transhipment on a loaded voyage without loss, and that the value of x per cent boil-off burnt in the boiler and y per cent lost due to boil-off with z per cent fuel oil burnt in the boiler might be far less economical in comparison with the chemical by-products value together with its low heat sink refrigerants usefulness at the discharging port.

Experimental work was going on in the utilization of the cold sink of liquefied gas for refrigeration purposes and then to use the boil-off for propulsion purposes. Work had been carried out in shrimp trawlers and they appeared to be an economic proposition in relation to conventional ones.

L.N.G. particularly appeared to be a very attractive fuel for super and sub-sonic aircraft. Already Kennedy Airport in New York was being re-tooled for L.N.G. bunker service. It was estimated that this airport alone would consume two L.N.G. tank loads per day (about 40 000 tons of fuel per day).

Man's awareness to pollution problems associated with the atmosphere in which he was living and the desire to conserve it was going to lead to the utilization of fuels whose products of combustion were to be less dangerous than oil fuels used today. Methane was featuring very favourably in comparison to conventional fuels and the fact that a quarter of the world's hydrocarbon resin existed in a gaseous form there was no doubt the next few years were going to accelerate the growth in the use of gaseous fuels for power generation in reciprocating and rotary engines.

MR. N. J. MATTHEW (Associate Member) said as a marine engineer he was concerned about the potential of natural gas for sea-going use and was not convinced that the discussion had made it in the least attractive for large scale application at sea in the immediate future or for several years to come.

Mr. Tipler had posed some very interesting and straightforward questions, one of which was security of supply. Reserve figures had been quoted but this was no guarantee of availability of supply. Mr. Matthew had very vivid memories of 1965 when the West Midlands Gas Board, faced with its inability to meet demand, shut off supplies to the major industries of the area at a time when flat-out working was essential. This was in part caused by the hard selling campaign in the domestic appliance field exceeding the Gas Industry's highest expectations. If similar success attended present sales campaigns in various fields what guarantee would the marine industry have that such a situation would not be repeated? Reserves were impressive but with disasters to drilling rigs prevalent, accidents affecting the supply lines from the North Sea fields were not out with the realms of possibility.

Mention had been made of bunkering facilities. Sea-going members present were well aware of the excellent and comprehensive network of bunkering facilities maintained by the oil industry and of the way in which chief engineers encouraged by "head office" planned their bunkering schedules to take advantage of the fluctuations in prices in various parts of the world. To become truly competitive the Gas Industry would require to set up an equivalent network—the cost of that exercise would be frightening.

Some of the practical difficulties had not been thought through. Section 4, under the heading "Liquid Natural Gas in the Future", claimed L.N.G. as safer than oil fuel in case of spillage. Was it not a fact that the French L.N.G. tanker *Jules Verne*, had a cargo spillage, resulting in severe cracking of the hull structure on her maiden voyage? He had been involved in re-writing legislation on gas holders in Hong Kong, and discovered a lack of information on approved methods of storage. He would point out that storage facilities aboard ship would have to meet with the approval of the Classification Societies and the Board of Trade (or equivalent). Again on the safety aspect the question of leakage from engine systems fittings and pipings arose, particulary as the fuel in its cheapest and most attractive form was colourless and odourless. One had only to think of explosions arising from leaks of methyl chloride which had led to the banning of the use of that refrigerant to realize there was also an area for concern here.

Recent trends in the marine industry, both with turbine installations and large Diesel engines had been towards a return to inherent simplicity. From the paper it appeared the use of L.N.G. complicated matters particularly where some use of oil fuel was retained.

It was perhaps worth restating the obvious—for any technical innovation to win general approval and wholesale adoption it must show a decided cost advantage plus technical advantage. Technical excellence itself was scarcely ever sufficient as witness the first gas turbine vessels and nuclear ships. To talk of L.N.G. engines in terms of "in the laboratory and on the test bed we can produce them to be nearly as efficient and powerful as moderately rated Diesel engines" was not going to make much impression. What was needed was a demonstration of a positive saving in costs.

He felt that L.N.G. might well have a place at sea in the future provided that the gas turbine was developed for marine use. He had heard of four large container vessels being built using gas turbine engines and this appeared to offer the best chance of utilizing L.N.G. but not until many of the problems mentioned had been overcome.

Looking back, he felt that he might have made the impression of being too severe but he was afraid that at present L.N.G. as a fuel at sea had little to offer except on L.N.G. tankers and that this should be made clear to the gas industry. The answer to "Gas as an Engine Fuel" should be "not at sea for the present".

Correspondence

MR. J. J. STENNETT in a written contribution said, from Fig. 8 it would appear that in the event of lubricating oil pressure failure or overspeed, the pilot oil was cut off whilst the gas supply remained open to the engine. This could result in considerable quantities of gas accumulating in the exhaust system with consequent risk. Could the authors confirm that this was the case or did the system in fact provide for automatic closure of the gas valve under such conditions?

Fig. 9 illustrated the Allen fuel control system and suggested that no air control was employed. A simple form of air control had, in fact, been employed on Allen dual-fuel engines for many years in both naturally aspirated and pressure charged engines. He suggested that in this figure a butterfly valve should be inserted between turbocharger and charge cooler, this valve being hydraulically operated from the engine control system such that it was fully open when operating as a Diesel engine and partially closed when running as a dual-fuel engine.

MR. G. E. TUBMAN (Associate Member) wrote that with reference to sludge gas, although the production of methane took place in the Activated Sludge Process the gas was not a product of activated sludge. It was a product of the digestion process that took place in the primary digestors which were fed with raw settled sludge and maintained at a temperature of 90°F to promote lively digestion.

The main object of digestion was to reduce the volume of sludge and render it to a non-septic liquor for further treatment. The methane given off during digestion was a "free" by-product. It was generally known that one cubic foot of methane was produced in the digestion process, per capita of population catered for.

Mr. Tubman knew of four National B.A.R. naturally aspirated dual-fuel engines which had been running on sludge gas for twenty years and to-date they were giving very good service.

The air/fuel ratio of these engines could be regulated manually over the load range by butterfly valve. The normal pilot injection was 10 per cent but this could be manually increased or decreased to suit operating conditions. In his opinion successful operation of dual-fuel depended upon:

1) crisp and clean fuel atomization;
2) correct adjustment of air/fuel ratio;
3) accurate timing of pilot injection (which might be one or two degrees in advance of straight oil);
4) adequate cylinder relief valves fitted to each cylinder;
5) fuel gas free of water and dirt.

With regard to item (2) the respective stoichiometric ratios of carbon/oxygen and methane/oxygen were 2·67 lb/lb and 41 lb/lb.

On the naturally aspirated engine using slude gas with 65 per cent methane and a calorific value of approximately 640 Btu/ft^3 the changeover from oil to gas could be made without adjustment of air requirements when at or near full load.

This was because the total requirements to burn 65 per cent methane to maintain the thermal output of the engines were compatible with the air requirements to burn fuel oil at say 85 per cent carbon. In the actual case a slight increase in power (about 50 kW) was experienced when on gas.

This was not true for part loading, however, the engine revolutions were the same hence the swept volume was the same, but fuel quantity had decreased, the mixture became weak as the air/gas ratio increased. At this stage the air intake required automatic or manual adjustments.

Did the authors think that North Sea gas with 92 per cent methane would give similar conditions on the naturally aspirated engine?

Mr. Tubman also knew of two Mirrlees National B.S.C.P. engines, turbocharged. These engines were running on sludge gas with a pilot injection of 7 per cent and the supercharged air pressure up to 6 lb/in^2 above atmospheric pressure.

Both engines were very sensitive even when running at or near full load, and he considered it fortunate if 350 h continuous running on gas was obtained.

The running gear on these engines was excellent, the sensitivity on dual-fuel running centred on the combustion system and the inadequacy of air/fuel ratio control. With turbocharged engines, the turbocharger was matched to the engine oil running conditions at full load, in order to optimize turbine and compressor output. Further, the output of the turbine depended upon the engine load only, as stated in the paper. With reduced load, the turbine and compressor load characteristics were not compatible, and it seemed to him that air/fuel ratio should automatically be controlled for successful running.

What were the authors' views?

He was interested in the authors' remarks on pilot injection. Engineers would appreciate that a fuel pump delivering only 7 per cent of its total volume accurately over long periods of time placed very stringent conditions on the pump. Any slight deterioration of pump, barrel, plunger, injector or linkage would show up in engine performance.

At the present time errosion of fuel pump plungers had not been overcome, even after fitting specially designed erosion plugs to guide and smooth spillway turbulence. He considered that pilot injection would be best accomplished in a separate and specially designed fuel pump.

Would the authors give their opinion on pilot injection?

Authors' Reply

The authors, replying to the discussion, said Mr. Bannister had related the vague speculations of the authors, who were not marine engineers, to the realities of marine engineering.

In the early experiments in carrying L.N.G. cargoes by sea back in 1957, the oil industry, with one or two exceptions, was apparently indifferent to their outcome; today intense interest was being shown and very probably in a few years' time the transportation of L.N.G. by sea and land would form an important part of the international fuel trade. Mr.

Bannister might be right in asserting that L.N.G. could only be a useful marine propulsion fuel when it was carried as a cargo. However, when L.N.G. became a common form of fuel, as it certainly would, it might find a wider use at sea, particularly when its cold potential could be utilized.

Mr. Bannister mentioned the comparatively short periods between overhauls of the engines at Canvey. It was emphasized that the frequency was dictated by the gas compressor which had no cylinder lubrication and had piston rings made of Teflon-carbon composition. He also criticized the fact that the "heat sink" in the L.N.G. at Canvey was not used. Unfortunately Canvey Island was a remote place on the Thames estuary, not readily accessible by road or rail, and the establishment of cold storage facilities would not be economic. One possible method of making use of this cold potential was by generating power with a turbine using propane as a working fluid. The propane would be boiled by heat exchange with the Thames water, expanded in a turbine and condensed by heat exchange with the L.N.G.; the temperature difference between the river at about 50°F and the L.N.G. at −258°F was quite sufficient to generate a useful amount of power, and it was only the capital cost of the scheme, largely concerned with the development of a turbine to operate over this abnormal temperature range, that had prevented its adoption. This idea of power recovery might have marine possibilities.

The contribution from Mr. Steiger, presented by Mr. Smit, was especially welcome. The authors only learned of the development in Switzerland of the Sulzer dual-fuel engine after their paper went to print. That such an obviously successful marine engine should be developed so far from the sea and from a source of natural gas was a remarkable achievement. England had been a leader in the development of medium speed engines, both Diesel and dual-fuel, and had tended to neglect the slow speed crosshead two-stroke engine; the authors did not know of any such engines used for power plant duties in this country. The efficiency of the Sulzer engine, especially at part load, was remarkably good, and its adoption by marine engineers was awaited with interest.

Mr. Edwards offered some most interesting information concerning the availability of natural gas both in this country and the U.S.A. It would come as a surprise to many that there were at least 16 liquefaction plants in the U.S.A. and Canada. This was believed to be only a beginning and there would be many more all over the world in the near future. He had put in a plea for the development of the small gas engine, preferably air-cooled. In the U.S.A. there was available from several makers a range of spark-ignited medium to high speed gas engines between 80 and 1200 hp; in general they were not very efficient but the low cost of natural gas in America made them an attractive proposition. In this country only in places where gas was very cheap, or in total energy applications where the waste heat could be utilized, were they likely to be economic.

The authors agreed with Mr. Tipler that the discovery of gas in the North Sea, instead of on dry land, added to its cost but even so it was a serious competitor with other forms of fuel in many fields. It was a useful comparison that thermally one million cubic feet of gas was equivalent to 25 tons of fuel oil; the maximum rate at which gas could be sent out from the L.N.G. storage at Canvey was 250 million cubic feet per day, equivalent to 6250 tons of fuel oil, and at Bacton North Sea gas terminal the installation was sized to send out 4000 million cubic feet per day or 100 000 tons of fuel oil equivalent; this would be a substantial proportion of this country's energy requirements. He had asked how rapidly and extensively L.N.G. bunkering points would become available; there were already some dozen L.N.G. marine terminals working or under construction throughout the world. The authors submitted that oil bunkering facilities did not develop any more rapidly when oil burning ships were first introduced.

It was admitted that the low specific gravity of L.N.G., although an advantage in aviation, presented a handicap at sea. Data on the insulation of L.N.G. tanks on land and sea were available and thickness and cost were dependent on the amount of boil-off that could be tolerated.

On the question of collaboration between engine builders and the gas industry an example already existed with development work carried out by a leading engine builder in a works of the North Western Gas Board. The initiative taken by Sulzer in collecting L.N.G. from a point 700 miles away for the development of their dual-fuel engine was another example showing what could be done.

The contributions of Commander Roughton and Mr. Tubman were considered together, since both referred to the sludge gas dual-fuel engines at the Maple Lodge Works of the West Hertfordshire Main Drainage Authority. This installation was important in that it was the first in this country to be designed from the start on the dual-fuel principle, and the pressure charged dual-fuel engines later installed were pioneers of that type. The operating experiences quoted were a useful addition to the paper and confirmed that the main problem when burning gas in either a spark-ignited or a dual-fuel engine was control of the gas/air ratio at varying loads. Modern dual-fuel engines operated satisfactorily with a single fuel pump specially designed to operate at about 5 per cent of the normal rating.

The authors agreed with Mr. Brandham that the 350° test method gave a more realistic measure of the relative merits of the various gaseous fuels, though it did not in fact alter the order in which they were placed by the 212° test, quoted by the authors.

Replying to Mr. Jones, they said the U.S.A. natural gas was very much cheaper and maintenance men were even more expensive than in the U.K. and their engines tended to concentrate on reliability and low maintenance cost rather than efficiency. Few American engine builders quoted in their literature guaranteed specific fuel consumptions, but the authors would be surprised if the full load figure of the Caterpillar engines was much better than 8000 Btu/bph h. The authors never intended to imply that turbocharging was introduced in order to reduce thermal stresses to an acceptable level. A gas engine ran hotter than a Diesel, and turbocharging increased the power, and therefore the heat developed in the cylinder; however, turbocharging allowed charge cooling and positive scavenging, which were the chief means of keeping temperature down to an acceptable level.

Mr. Harmsworth discussed the economics and utilization of L.N.G. and concluded that there was no obvious market for L.N.G. as a marine fuel, but that those concerned with long range developments should not forget the possibility. The authors agreed generally with this view.

He asked why the spark-ignited gas engine was so popular in the U.S.A. in spite of the price differential between natural gas and heavy fuel oil. The authors believed that most of these gas engines were in the 600–1200 rev/min speed range for which heavy fuel oil was unsuitable, and that in these cases the gas was in competition with Diesel oil. Furthermore, many of these gas engines were used in a 'total energy' application. The comparatively cheap price of gas, coupled with the prevailing climate which created a steady demand for heat in the winter and air conditioning in the summer, made comparatively small units an economic proposition. Dearer gas and a more unpredictable climate in this country required in most cases an electrical demand of at least 2 MW to make total energy viable.

Mr. Harmsworth quoted the case of an installation, not in this country, where regenerative gas turbines produced cheaper power than dual-fuel reciprocating engines because of their lower maintenance cost. This and other advantages of the gas turbine, less space requirements and no cooling water, might well offset its higher capital cost and fuel consumption in marine propulsion applications too.

Mr. Navaz stated that there could be a host of other gases that could be used for power generation. This was true and in oil refineries it was common practice to burn a wide variety of waste gases in gas engines which were constructed with a lower compression ratio than standard in order to avoid detonation problems. However, natural gas, because of its world-wide availability and excellent anti-knock properties, was the only one likely to be used at sea in the foreseeable future. It was agreed that gas fuelled ships required a high standard of maintenance and careful design, including the provision of flameproof electrical equipment in certain areas, and this applied whether the fuel was burned in a boiler or an internal combustion engine. However, many vessels throughout the world carried hazardous cargoes, liable to form explosive mixtures, and the design problems involved were well understood.

When discussing the boil-off from L.N.G. storage, it should be realized that a fall in barometric pressure would lower the boiling point of the liquid; since a constant pressure was maintained in the tank, the rate of boil-off would increase; similarly a rise in atmospheric pressure would decrease this rate. The boil-off rate was also increased by surging of the L.N.G. in the tank in rough weather. Rough seas and low barometers usually went together, and these factors, and not atmospheric temperature, accounted for the high rate of boil-off in bad weather.

The authors hoped that enough had been said about security of supply to set Mr. Matthew's mind at rest. He was referred to the authors' reply to Mr. Tipler concerning L.N.G. bunkering facilities.

It was agreed that there was no case for a wholesale changeover of sea-going vessels to gaseous fuel. However, experiments were being conducted by certain far-sighted engine builders and marine engineers in the use of gas as a fuel at sea. Who knew what the outcome of these small beginnings might be?

The authors apologized to Mr. Stennett for over-simplifying the Allen fuel control system, as shown in Fig. 9. The butterfly valve between the turbocharger and the charge air cooler was an important feature of the system in that it reduced the air supply to the engine when changing from Diesel to dual-fuel running. It was not however the means used to maintain a constant air/gas ratio at varying engine loads.

Concerning the Mirrlees control system, in the event of an emergency trip there was no danger of unburnt gas passing into the exhaust system. There was a mechanical linkage, not shown in Fig. 8, between the two rack control shafts, which forced the gas racks to zero fuel if the Diesel racks were returned to zero by the trip gear.

In conclusion, the authors thanked the contributors and the Institute for the opportunity of raising the topic of gas. The former president, Mr. Frederick Bolton, in his inaugural address, observed that there might be benefits from "closer liaison between the marine engineering industry and shore engineering"; the authors had certainly benefited from this occasion and hoped that the benefits were mutual.

Marine Engineering and Shipbuilding Abstracts

No. 4 April 1970

Spanish Built Freedom Ship

Astilleros De Cadiz has recently delivered the 15 500 dwt Freedom-Hispania vessel *Gundulic* to her owners Atlanska Plovidba of Yugoslavia.

Gundulic is built with all accommodation and machinery arranged aft of the four cargo holds, two of which (Nos 1 and 3) are short and the other two long, divided by vertically corrugated bulkheads. Upper wing tanks are provided throughout the length of the cargo holds, those in way of holds Nos 2 and 4, the long holds, may be used for additional grain cargo or water ballast, while the remaining tanks are for ballast water only. The hold capacity (grain) is 730 000 ft^3 and the additional grain capacity afforded by the tanks is 60 000 ft^3. Each of the short holds is served by a single hatch on both the main and 'tween deck while the larger holds have two hatches on each deck. All the main deck hatch covers are of Sevilla-MacGregor Single-Pull type measuring 30 ft × 32 ft 6 in while the 'tween deck covers, all having dimensions of 30 ft 2 in × 32 ft 5 in are Sevilla-MacGregor End Folding type. Three pairs of masts, each pair fitted with four 10 ton derricks, are provided for cargo handling, the masts being located between holds Nos 1 and 2; between holds Nos 2 and 3, and midway along No. 4 hold thus each hatch can be served by two derricks. Twelve Manises cargo winches each having a drum pull of five tons, are installed on winch platforms at the base of each pair of masts. Other equipment of Manises manufacture include the windlass, which has a pull of 26 tons, and the electro hydraulic steering gear.

The Freedom Ship design is such that the essential characteristics of a bulk carrier are combined with those of a closed shelter deck vessel, this combination allowing the vessel to carry bulk cargoes such as coal, bauxite, sugar etc., any kind of general cargo; any type of vehicle; and containers.

The propulsion machinery consists of a Manises-Sulzer 6RD68 having a maximum continuous rating of 8000 bhp at 150 rev/min. The engine operates on heavy fuel in service condition and on light fuel for manoeuvring. Electrical power requirements are met by two Diesel alternator sets each comprising a 480 hp Diesel engine driving a 320 kW alternator supplying current at 380 V 50 c/s.

Other engine room equipment includes an oil fired/exhaust gas composite boiler producing 2645 lb/hr of steam at 100 lb/in^2.

Principal particulars are:

Length, o.a.	471 ft 5 in
Length, b.p.	442 ft 6 in
Breadth, moulded	67 ft 9 in
Depth, moulded	41 ft 9 in
Draught, maximum	30 ft 4 in
Deadweight	15 500 tons
Speed	15·5 knots

Shipbuilding International, November 1969, Vol. 12, p. 36.

Superconducting Motor in Operation

International Research and Development has recently shown a 3250 hp, 200 rev/min superconducting motor in operation. Built by IRD under a contract from the National Research Development Corporation, the motor will be used to drive a coolant water pump.

The superconducting motor is based on the principle that electrical resistance is virtually eliminated when certain metals and alloys are cooled to near absolute zero. The IRD motor is the first commercial application of this well-known electrical phenomenon.

Its significance for the marine industry is that a highly efficient and very compact motor results from the application of the superconducting principle and studies are being made by IRD and NRDC to see how this could be applied to marine propulsion.

The motor recently shown in operation at IRD's laboratories consists basically of a field coil enclosed in a cryostat. The coil is made of niobium-titanium/copper composite which is cooled down to the temperature of liquid helium, that is about 4°K or −269°C (−425°F). At this temperature the coil is superconducting and can carry a very large electrical current without any resistance or power loss.

The superconductor was supplied by Imperial Metal Industries Ltd. in 18 lengths, totalling 33 km and weighing 5·3 tonnes. The closed circuit refrigerator, which supplied liquid helium to cool down the cryostat, was constructed by the British Oxygen Co.'s Cryoproducts Division. Its ability to remove 25 W at 4·4°K is more than adequate for this particular motor.

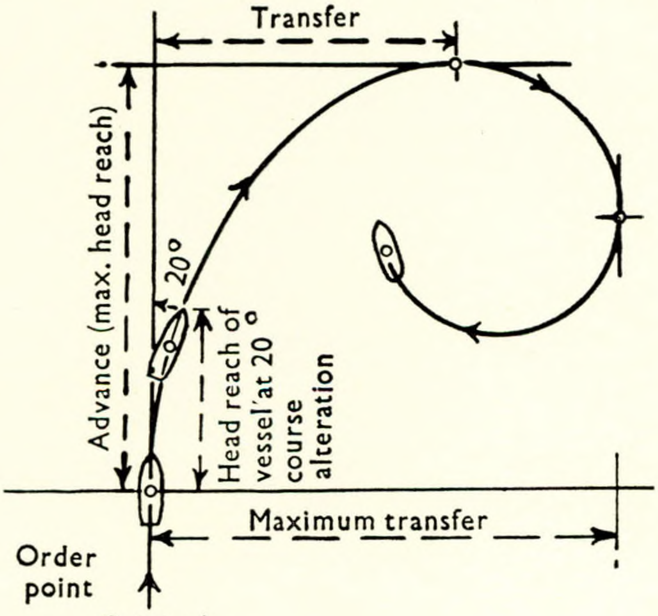
A 1 MW generator using the superconducting principle will be designed and manufactured by IRD and this is the type of machine, in conjunction with a superconducting motor, which will form the basis of studies into marine propulsion systems.

It is of interest to note that a conventional motor of 8000 hp would weigh about 370 tons compared to 40 tons for a superconducting unit of the same output and the efficiencies of the two types would be 94 per cent and 97 per cent respectively.—*Shipbuilding and Shipping Record, 28th November, 1969, Vol. 114, p. 11.*

Trends in Vessel Type and Size

A 200 000 ton ship going at full speed may take between five and seven miles to bring her to a position stopped in the water, but seamen concerned with the operation would put it quite differently and say that a master knowing that he must have his ship stopped in a given position, say to pick up a pilot, would expect to commence reducing his speed five to seven miles before he reached that position. He would not regard that as in any way unreasonable.

Similarly, a 200 000 dwt tanker running with engines full astern would take 2½ miles to crash-stop. Again, this is true, but no practical seaman would envisage running for 2½ miles with the engines running full astern, because if he wished to take avoiding action—either to reduce the ship's headway along its course, or to avoid some other ship or obstacle—he would use rudder, and very large tankers have rudder efficiency rather superior to the smaller ships they have replaced. The results of this can be demonstrated by some tests recently carried out in the author's company indicating that a 500 000 dwt tanker requires one minute to alter course 20 degrees, during which time she will proceed two ship's lengths. A 200 000 tonner will alter course 20 degrees in one minute twelve seconds and proceed 1½ ship's lengths.



Terms used to illustrate turning circles

All those concerned have given very serious consideration to comparison of the manoeuvring ability of 200 000 dwt ships to the manoeuvring ability of the smaller ships they have replaced, and it is probably most sensible to represent manoeuvrability under three separate considerations:

a) ability to stop;
b) ability to turn;
c) ability to steer.

Table I shows the stopping distance which ships require with full astern power from full speed and from 4 knots.

The easiest way to illustrate turning circles of tankers is by diagram and the diagram shows the terms used. Table II gives values obtained from trials.

Very considerable care has been taken in giving these ships good steering characteristics, and practical tests have confirmed that very large ships can generally maintain course without difficulty at speeds of less than two knots. Alterations of course cannot be quickly implemented at such slow speeds, nor can an established swing be readily countered, but short periods of increased propeller revolutions associated with maximum helm can ensure that the required degree of directional stability can be maintained.

In the author's own company when consideration was first given to acquiring a fairly large number of 200 000 dwt ships, the risk to which these would be subject because of their size was carefully considered. The characteristics given, which indicate broadly how they can manoeuvre, formed an important part of the data to be considered, and a conclusion was reached based on an evaluation of difficulties which had followed previous increases in ships' size and the ability of navigators to make the appropriate adjustments to the larger ships. Essentially, the conclusion reached was that, taking all risks in port and in the open sea, including that of oil pollution, there was no reason to conclude that increase in ships' sizes should increase the risk per ton of oil moved. Perhaps the simplest way to illustrate this would be to postulate that 200 000 tons of oil have to be moved up the English Channel, and this must involve some risk, but the oil can be moved in one 200 000 ton tanker or in four 50 000 dwt ships. Now, while the navigational risk to a 200 000 ton ship must be greater than the navigational risk to the smaller 50 000 dwt ship it can be argued that, because the risk is taken once, the overall risk per ton of oil moved does not increase.

An important consideration is that as tankers become larger it is possible economically to provide them with very sophisticated navigational equipment, and it is generally well known that very large tankers are now among the best equipped ships in the world so far as navigational instrumentation is concerned.

It has been argued in this paper that in respect of ocean navigation, the increased size in ships has not given rise to any unacceptable increase in navigational risk, and so far as navigation of the high seas is concerned there appears to be no reason why this should change in the future, even if tanker hull size were to increase by a further very large step.

There are, however, areas where draught limitations may have to be seriously considered, and if one considers the voyage from the Middle East to Japan and the Middle East to North-West Europe there are two important areas requiring critical examination. These are the Malacca Straits and the Straits of Dover. Of the two areas the Malacca Straits presents a more difficult navigational problem, but traffic conditions are less severe than those prevailing in the Straits of Dover. In both areas the parts of the Straits which control the draught are subject to sand waves which may give rise to changes in effective depth, and in neither area is there yet adequate hydrographic survey control to ensure knowledge of the exact depth of water available.

Leaving aside the Dover Strait and the Malacca Strait, there seems to be no reason from a navigational or port limitation point of view why tanker draughts should not increase to 90 or even 100 ft, which could equate to 750 000 or perhaps even 1 000 000 dwt.

TABLE I—STOPPING DISTANCES REQUIRED BY VARIOUS CLASSES OF TANKER

Class	*Length*	*Stopping distance, engines going full speed astern*	
		From full speed	*From 4 knots*
18 000 dwt	556 ft	1·0 mile	0·15 mile
50 000 ,,	750 ,,	1·5 ,,	0·16 ,,
110 000 ,,	870 ,,	1·6 ,,	0·22 ,,
210 000 ,,	1076 ,,	2·5 ,,	0·32 ,,

TABLE II—RESULTS FROM TANKER TURNING CIRCLE TRIALS

Class	*Advance*		*Transfer*	
dwt	cables	(ship's lengths)	cables	(ship's lengths)
18 000	2·6	2·8	2·3	2·5
50 000	4·1	3·2	2·6	2·1
110 000	4·9	3·4	2·4	1·7
210 000	6·6	3·7	3·8	2·2

Class	*Maximum transfer*		*Time and head reach to achieve a 20 degree alteration of course*		
dwt	cables	(ship's lengths)	min	secs	(ship's lengths)
18 000	4·0	4·3		40	1·0
50 000	4·8	2·9	1	10	2·0
110 000	4·7	3·2	1	0	1·8
210 000	7·2	4·1	1	12	1·5

Dickson, A. F., paper presented at a symposium on tanker and bulk carrier terminals arranged by the Institution of Civil Engineers, 13 November 1969; Shipping World and Shipbuilder, December 1969, Vol. 162, pp. 1687–1689.

New Ship Steels

The increase in use of new steels has been explosive. The reasons for and the nature of this sudden increase indicate the inherent characteristics of designing with the new steels.

Prior to this revolution in marine steels, most American merchant ships were built of American Bureau of Shipping conventional structural ABS grades—Types A, B and C. These are "mild" carbon steels with minimum yield strengths of about 32 000 lb/in^2 and tensile strengths ranging from 58 000 to 71 000 lb/in^2.

But the new steels have two overwhelming advantages when compared with the conventional grades in terms of today's competitive industry situation. They have significantly higher tensile and yield strengths and so can be used in thinner sections, and they provide much better resistance to brittle fracture.

Mr. D. C. MacMillan of George G. Sharp Co., has pointed to weight savings at equal cost as the principal advantage. For *Van Buren* and sister ships, MacMillan reported that the hull weight of the vessels was reduced by 880 long tons of steel, an 18 per cent reduction from the weight of a comparable vessel built with conventional steels—a weight saving of 1 800 000 lb.

The American Bureau of Shipping has pointed out the following additional advantages:

1) lighter gauge plates are easier to handle in fabrication processes;
2) require fewer man hours of welding;
3) electrode consumption.

The most widely used of the newer steels fall roughly into three groups: high-strength low-alloy (H.S.L.A.), heat-treated carbon, and heat-treated alloy steels. The individual characteristics of each of these groups determine where they can best be used.

One of the most important recent developments in high-strength low-alloy steels is Armco's V.N.T., which combines the higher strength levels of H.S.L.A. with the toughness of quenched and tempered steels.

V.N.T. is a normalized silicon-killed, vanadium-nitrogen treated steel, made to fine grain practice. In the normalized condition it provides 60 000 lb/in^2 minimum yield strength through $3\frac{1}{2}$ in thickness.

Charpy V-notch ratings are 20 ft-lb longitudinal and 15 ft/lb transverse at –60°F (–51°C). V.N.T. is easily weldable following low-hydrogen techniques.

The high-strength low-alloy steels have higher strength levels than conventional grades, and yet cost just slightly more. They are usually made as killed steels to fine-grain practice and may be heat-treated for improved toughness and resistance to crack propagation.

In general they are easy to weld, with low-hydrogen procedures and pre-heating to remove all traces of moisture as necessary precautions. Formability is good.

ASTM A 242 has the same tensile and yield strength as A 441, but A 242 has markedly better atmospheric corrosion resistance than carbon steel, and is known as "weathering steel". More important for marine application is the extremely good bond formed with paint by this material. Because of paint damage to moving parts, A 242 is frequently specified for hatch covers and containers.

ASTM A 572 is the most economical H.S.L.A. steel. Compared with ABS Grade C, Grade 50 offers 56 per cent more yield strength but only a 4 per cent increase in cost.

A combination of columbium and/or vanadium gives this material higher strength. Its tensile strengths range from 42 000 to 70 000 lb/in^2 according to thickness, and yield strength ranges from 60 000 to 85 000 lb/in^2. Formability and weldability are excellent, and in general closely resemble A 441.

Initial marine applications for High Strength C have been in offshore drilling rigs. But A 572 promises to become a major new material for vessel construction.—*Frisby, D. L., Marine Engineering/Log, October 1969, Vol. 74, pp. 86–88.*

Largest Vessel in World-Wide (Shipping) Fleet

The 215 400 ton *World Chief*, completed this year at the Sakaide Shipyard at Kobe, of the Kawasaki Dockyard Co., is a good example of the class of tanker being built in Japan for export. This vessel has been built for Liberian Express Transport Inc.

World Chief is the present largest ship in the fleet, although three 227 000 ton vessels have recently been contracted in Sweden. She has a deadweight of 177 500 long tons at a draught of 54 ft 3 in, a loaded service speed of 17 knots and of 17·8 knots when in ballast condition.

Principal particulars of *World Chief* are:

Length o.a. ...	1 081·69
Length b.p. ...	1 026·90
Breadth, moulded ...	158·14
Depth, moulded ...	82·35
Draught, loaded ...	63·35
Gross register ...	100 300 tons
Deadweight at 54 ft 3 in draught ...	177 500 tons
Deadweight at 63 ft 3 in draught ...	215 400 tons

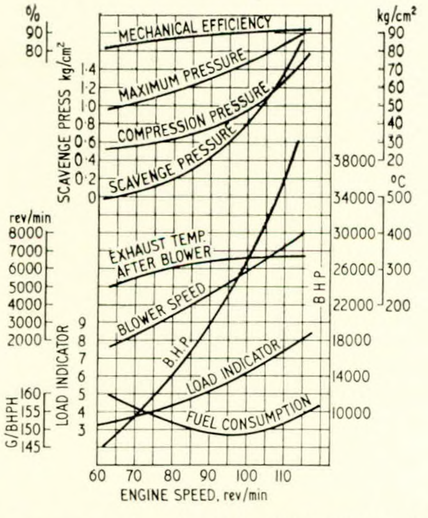
Four cargo oil pumps are installed to discharge the equivalent of 16 000 tons of water per hour. The cargo vent system and the two 800 mm-diameter cargo mains are designed to take the full cargo of 215 400 tons in 12 hours. The tank arrangement and the piping system are so arranged that cargo loading can be undertaken simultaneously with the discharging of the ballast holds. To counter one of the main problems in the operation of modern tankers, that of tank cleaning, this ship is equipped with a close-cycle slop tank system and Gunclean machines are permanently installed so that during voyages the tanks required for ballast use can be cleaned in four hours. A Golar Vent system is also fitted to this vessel to ensure quick gas-freeing.

The main propulsion unit is a Kawasaki U-design turbine consisting of an H.P. and L.P. turbine delivering to a six-bladed nickel-aluminium propeller, through double-reduction, double-helical, articulated gearing and a line shaft. The unit is designed to operate on superheated steam of 60 kg/cm² (850 lb/in²g) and 520°C (970°F), and for exhausting under 720 mm Hg. vacuum to the main condenser. The maximum continuous output of 33 000 shp at 95 rev/min makes this the highest-powered unit yet installed by Kawasaki in an export ship. The guaranteed fuel consumption is 212 g/shph (0·467 lb/shph).

Steam is supplied by two Kawasaki/BDU-type watertube boilers capable of supplying superheated steam at 62 kg/cm² and 525°C (977°F) at the maximum evaporation capacity of 78 tons/h each. The efficiency at the normal evaporation of 47 tons/h each is said to be 88·5 per cent.—*The Motor Ship Japaneses Shipbuilding Survey), 1969, Vol. 50, p. 56.*

Most Powerful Japanese-built Sulzer Engine

The most powerful Sulzer engine yet built—a Mitsubishi-built 9RND105 unit with a maximum continuous rating of over 34 000 bhp—entered service recently when the 19 914 dwt container ship *Hakozaki Maru*—the first of a class of three—commenced operation for Nippon Yusen Kaisha. Designed to give a service speed of 23·10 knots the vessel actually registered a trial speed of 26·70 knots—the fastest yet recorded by a Japanese merchant vessel on official trials.



Performance curves for the Mitsubishi-Sulzer 9RND105 engine installed in Hakozaki Maru

During testbed trials the engine installed in this vessel developed 37 654 bhp while undergoing a 10 per cent overload test of half-an-hour's duration; the full load developed was 34 137 bhp at 107·8 rev/min. Corresponding values of i.h.p. were 41 107 and 37 308, representing mechanical efficiencies of 91·8 per cent and 91·5 per cent respectively.

The full load fuel consumption recorded during the test was 155·9 g/bhp, using a fuel with a lower calorific value of 9710 kcal/kg; the fuel consumption at 75 per cent full load, however, was as low as 148·5 g/bhp; at this load value the thermal efficiency of the engine was 41·9 per cent and the mechanical efficiency 90·3 per cent. The exhaust gas temperature (after the turbine) was 267°C at 25 per cent load and increased gradually to 330°C at 75 per cent load, beyond which the temperature curve levelled out considerably.—*The Motor Ship, December 1969, Vol. 50, pp. 404–405.*

Merchant Ship Applications of Medium Speed Geared Diesel Engines and Associated Auxiliary Machinery

The scope of Y·ARD's work in investigating the applications of medium speed Diesel engines to ocean-going merchant ships under contract from the Ministry of Technology is briefly outlined.

The concepts of packaged propulsion machinery installations and auxiliary machinery modules are described and the advantages of both packaging and the use of modules studied.

The designs of propulsion machinery packages, incorporating auxiliary machinery modules, for three specific ship types are then discussed in some detail. The logic leading up to the selection of a twin medium speed geared Diesel installation with controllable pitch propeller and gear-driven alternator(s) as the basic configuration for each of the three ships is described, and each of the auxiliary systems for the propulsion and generating machinery is examined and a standard system for each proposed.

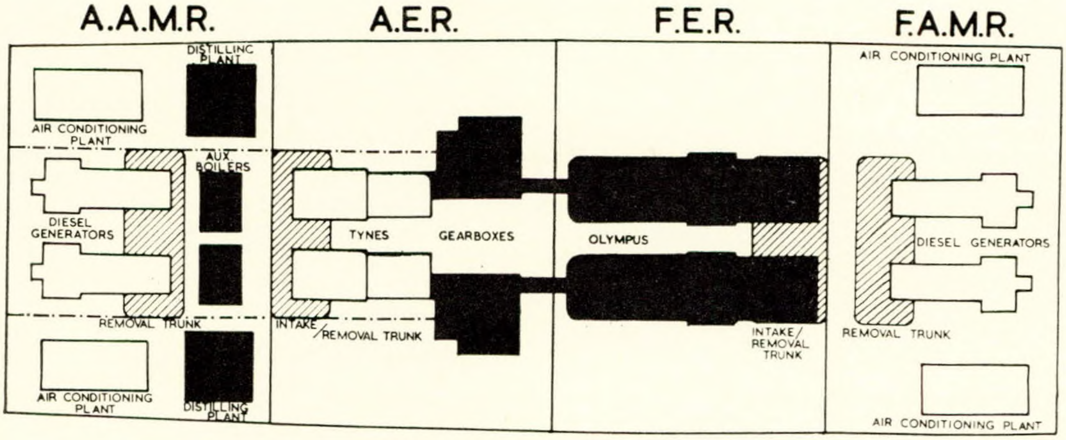
The design of a series of auxiliary machinery modules suitable for medium speed Diesel engines is described. The engines used in preparing these designs are the Ruston and Hornsby AO and the Mirrlees K Major, but the general principles used apply equally well to any of the available medium speed Diesel engines in the 400 to 1000 bhp/cylinder power range. Examples of the resultant module designs and the general arrangement of the machinery installations for each ship are illustrated.

The concepts of packaging and moduling to fit in with current trends in ship construction are considered and outlined are the next steps necessary in the evolution of standardized machinery installations to keep pace with these trends.—*Transactions, The Institute of Marine Engineers, January 1970, Vol. 82, pp. 1–33.*

Gas Turbine Installation for Guided Missile Destroyer

The Type 42 guided missile destroyer, the first of which is being built by Vickers Ltd. Shipbuilding Group at Barrow, is 125 m overall in length and has a maximum beam of 14·35 m. It has two shafts each of which is powered by one Rolls-Royce Olympus TM3B gas turbine for full power conditions and one Rolls-Royce Tyne FPT gas turbine for cruising power conditions.

Each set of main engines has been designed to operate as a COGOG set of propulsion machinery. This means that only one gas turbine provides power to the propeller at any one time. The main or cruising turbine, whichever is in use, drives a controllable pitch propeller through a set of main gearing and shafting. The propulsion gearing is supplied by David Brown Gear Industries Ltd. and the controllable pitch propeller by Stone Manganese Marine Ltd.



Machinery arrangement in Type 42 guided missile destroyer

Selection and control of the engines and propeller pitch are achieved from the bridge or the machinery control room. The gas turbines are automatically connected to, or disconnected from, the main gearing via Synchro-Self-Shifting (SSS) clutches which are provided between each turbine and the main gearing. The design of the air intakes and exhaust uptakes has been important; consideration having been given to the elimination of spray in the air intakes and the establishment of an acceptable noise level from the propulsion machinery as a whole.

The layout of machinery has been designed to withstand action damage. This can be seen in the positioning of the Olympus and Tyne gas turbines in separate compartments and by the apportioning of the Diesel generators and air conditioning plants between the two auxiliary machinery rooms. The auxiliary boilers and distilling plants, the providers and main users of steam, have been sited in the same compartment to simplify the design and installation of the steam system.

A large proportion of the equipment is designed to be overhauled by replacement, i.e. items are removed to shore workshops and are immediately replaced by identical equipments which have already been overhauled. To achieve this it has been necessary to allow for the removal of most equipments by recognized withdrawal routes.—*Lockyer, A. A., Marine Engineer and Naval Architect, November 1969, Vol. 92, pp. 445–456.*

Japanese Production of Marine Propulsion Engines

Most of the high power marine Diesel engines made in Japan are manufactured under licences from various foreign firms.

In the field of the large size Diesel engine Japanese licensees have played a very important part in the development and production of such units and it now appears that the initiative for future development has passed into their hands. This situation has been brought about by the superior reputation gained by the efficient operation of Japanese-built engines. This owes much to the extensive research and development work carried out in Japan. The international competitive ability of the Japanese marine Diesels will rest on the development of series production of super large-bore engines, the development of medium-size geared engines for multiplant operation, and the development of automation in the engine room.

In the field of the medium-size Diesel engine, the multi-unit system incorporating a number of medium-speed engines driving through flexible couplings and reduction gearing, has been increasingly adopted in Japan. The SEMT-Pielstick PC2 engine, manufactured in Japan by I.H.I., Nippon Kokan K.K. and Fuji Diesel Co. Ltd., is a high-output unit with a 500 hp per cylinder rating.

With the aid of research and development aimed at improving fuel consumption and raising propulsion efficiency, the steam turbine has been regaining its former position *vis à vis* the big Diesel engine. This has been achieved by *inter alia* adopting the reheat cycle and using motor-driven vacuum pumps in place of ejectors. It has also been found that propulsion efficiency can be increased by five to six per cent by decreasing propeller shaft speeds from 105 rev/min to 80 rev/min through suitable reduction gearing. This, in turn, decreases the output demand on the steam turbine by five to six per cent for the same ship at the same speed.

Japanese engine builders have developed several notable steam plants. Mitsubishi have produced the MR type reheat cycle turbine installation which has locked-train type reduction gear; Kawasaki have developed the UR type reheat cycle turbine plant in which the astern turbine is arranged in the l.p. turbine; Uraga Heavy Industries is making AP turbines under Stal Laval license and is using planetary type reduction gearing; I.H.I. has developed the R804 reheat cycle turbine plant which includes an ESRD type mono-wall main boiler and a two-drum water-tube auxiliary boiler.—*Amari, Shoichi, Shipping World and Shipbuilder, January 1970, Vol. 163, pp. 86–147.*

Versatile Hatch Cover Installation

Two small cargo ships from the Jos. L. Meyer shipyard, are among a number of vessels for which hatch covers are designed by the Von Tell Trading Co.

The two sisterships are owned by AB Transmarine, of Hälsinborg, Sweden; they are each of 5985/6750 dwt on a gross register of 4400 tons and have a total capacity (bale) of 291 000 ft^3, including 25 000 ft^3 of refrigerated cargo space.

Built to Det norske Veritas requirements and with the suffix "Open Ship", the two vessels are designed for about 85 per cent vertical cargo handling coverage. This has been achieved by the provision in each vessel of no fewer than 16 Von Tell covers, specially designed to provide fast and reliable operation with the minimum outlay. The covers close an area totalling some 1385m^2 and weigh approximately 225 tons.

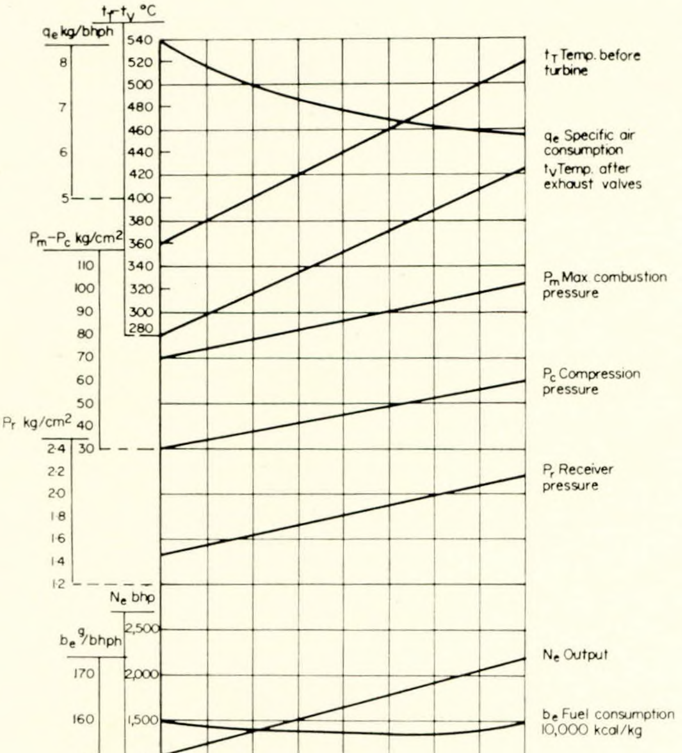
The weather deck covers are of the multipanel type with actuation by large hydraulic cylinders using a patented levering operation. Two hydraulic circuits are provided: circuit No. 1 serves Nos. 1 and 2 holds while the second circuit serves holds 3, 4 and 5. High-pressure hydraulics are employed and although each circuit is normally operated independently of the other to permit simultaneous opening of two weather deck hatches, provision is also made for cross-connecting the associated pumps in case of failure of one of the units.

To reduce wear and tear during operation, the covers are fitted with a hydraulic lifting system to ensure smooth operation and to avod damage to the rubber gasket seal.

The middle three weather deck hatches are fitted with a new type of cover—each 15·5m long—opening in four sections from each end of the hatch. Each stowage package consists of four sections operated by two cylinders, located outside the clear hatch opening. One end of the hydraulic ram is attached to the first section and the other end to a lever moving about the centre of the end hinge. By moving the piston rod out of the hydraulic cylinder the pressure thus created opens the first two sections of the cover while during this sequence the unattached end of the lever rests on the deck.—*Shipbuilding and Shipping Record, November 14 1969, Vol. 114, p. 42.*

Werkspoor TM 410 Engine in Vee-Form

Following the introduction of their medium-speed in-line engine, the TM 410, Werkspoor, a member of the Dutch VMF Stork/Werkspoor group, have now developed this engine in Vee-form.



Test results for 4 TM 410 engines at 500 rev/min, air temperature at 30°C, water temperature 25°C, fuel 1500 sec Redwood No. 1 at 100°F

Details of the Vee-form engine are:

Bore	410 mm	16·2 in
Stroke	470 mm	18·6 in
Cylinder centre distance	700 mm	27·6 in
(present running conditions)		
Output	550 bhp/cyl	
Speed	525 rev/min	
B.m.e.p.	15·25 kg/cm^2	216 lb/in^2
Mean piston speed	8·2 m/sec	1620 ft/min
Maximum cylinder pressure	102 kg/cm^2	1450 lb/in^2

It is expected that through improved turbocharging and fuel injection techniques these ratings will be increased significantly as development progresses. An eight-cylinder in-line engine has already achieved an output of 720 bhp/cyl at a speed of 550 rev/min with a b.m.e.p. of 18·8 kg/cm^2 on test, and it is hoped that service outputs of 650, 700 and possibly 750 bhp/cyl may be attained for the Vee-type engine.

Testing of the Vee-type engine commenced in March 1969 and preliminary tests were run at an output of 550 bhp/cyl at 500 rev/min. Results of these tests are given in the diagram.—*Shipping World and Shipbuilder, December 1969, Vol. 162, pp. 1710–1711.*

First Offshore Mooring Facility in U.K.

Construction has begun on the first offshore mooring facility in the United Kingdom. The system permits supertankers to discharge crude oil at ports where the giant ships cannot navigate or where berthing conditions are not favourable.

Called the single point mooring system, the facility is being built by Crude Oil Terminals (Humber) Ltd., on behalf of Continental Oil (U.K.) Ltd. It will be located at the mouth of the Humber estuary about five miles from Tetney Haven on the mainland. When completed late next year, the floating buoy, connecting pipe lines, and storage facilities will provide an oil link from the Humber estuary, through Tetney Haven and terminating at Conoco's Humber Refinery at nearby South Killingholme.

The project calls for a 36 in five mile sea line from the offshore installation to Tetney Haven where a storage tank farm is being constructed.

The mooring system will be capable of handling tankers up to 200 000 dwt fully laden. Initially, however, it will be restricted to vessels of about 110 000 dwt due to the depth of water in the approaches to the buoy.

Anchored in position in four directions, the single point mooring is connected to a sea pipe line leading to shore. Flexible submarine hoses connect from the underside of the buoy to the sea pipe line. Floating hoses that can rotate in a full circle connect from the top of the buoy to the tanker's cargo discharge lines.

The buoy wil be equipped with navigational lights, fog horn and automatic safety equipment. It remains operational in almost all weather and ships can remain safely moored to the buoy even during storms of great intensity.—*World Dredging and Marine Construction, September 1969, Vol. 5, p. 28.*

O.B.O. Carriers

One of the papers presented at the recent ASCA Conference in Gothenberg, Sweden, was by T. M. Karlson, of Naess Shipping Company Inc. Entitled "O.B.O. Carriers—Some thoughts on their Design and Operation" it deals with the development and economics of these ships and the rapid expansion of this class of tonnage during the last three years, to a fleet amounting to about 4·3 m dwt. Although the ore oil carrier had been in existence for a considerable time, it was not the forerunner of the O.B.O. carrier, which stemmed from the pattern of trade and restrictions often imposed by loading equipment. It is fundamentally a bulk carrier able to carry oil. This design permits oil cargoes to be added to the trading pattern, but only at an increased initial cost of 12 to 15 per cent which is raised by a further 2 per cent when related to cost per dwt due to the smaller deadweight capacity of the O.B.O. carrier compared with an ordinary bulk carrier of the same overall dimensions. The extra cost has to be justified by fully taking advantage of the flexibility of the design in the owner's transportation network, particularly the ability to change over from dry to liquid cargoes. The feature, it is remarked in the paper, has resulted in narrowing the difference between tanker and dry bulk charter rates, a difference which will narrow still further as more O.B.O. tonnage comes into operation.

Various points of design are examined in the paper, such as single versus double skin construction. The latter makes for easier cleaning of cargo holds, reduced free surface effect, and, with correct positioning of the inner skin, more holds able to be simultaneously loaded or discharged while maintaining adequite stability. Nevertheless, it has to be remembered that for equal cubic capacity the double skin calls for increased depth of hull, thereby involving increased steel weight, a corresponding loss of deadweight and additional first cost.

Transverse bulkheads are considered next in the paper, with respect to horizontal corrugated/vertical corrugated or cofferdam construction. The first is rejected despite some weight saving because of constructional and cleaning problems while the third is favoured because of ease of cleaning and certain operational advantages despite some loss in cubic capacity.

The paper considers heating coils, which are essential in such vessels for maximum flexibility in carrying a wide range of oil cargoes, and are preferred by the author to large bore pipes. It is his opinion that one square foot of coil surface per 500 to 600 ft^3 of cargo space will be sufficient for heating most cargoes. The arrangement of cargo piping is discussed and mention made of the lower cost of adopting ducts built into the double bottom compared with piping. However, a preference is expressed for piping as against using part of the hull structure for this purpose.—*Shipbuilding International, December 1969, Vol. 12, p. 36.*

Satisfactory Inspection of Split Tailshaft Bearing

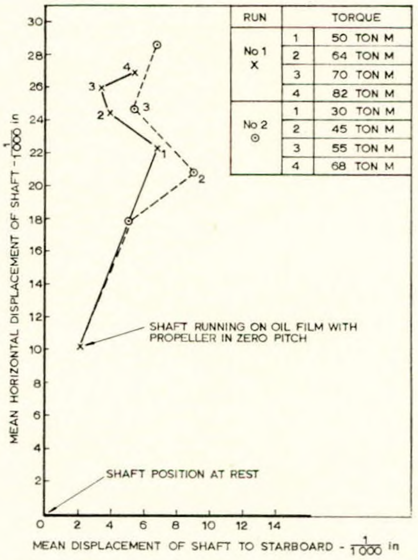
Considering the expensive delay caused to a ship each time its tail shaft is surveyed it is somewhat surprising that the concept of a one-piece bearing—which requires the removal of the propeller and the withdrawal of the tailshaft to permit inspection—should still be retained 130 years after the introduction of the screw propeller. And yet it was not until 1968 that any basic change to this arrangement took place, when a stern bearing of a completely new design was incorporated in the stern frame of a British container ship.

This was the split stern bearing designed by the Turnbull Marine Design Co. Ltd., and the ship in which it was installed is the 12 000 dwt *Manchester Challenge* owned by Manchester Liners Ltd.

During its 12-month period in service it is claimed that the tailshaft bearing has given no trouble whatsoever. No leakage problem was encountered at the butts of the bearing nor were there any signs of vibration or fretting occurring between the two halves of the bearing or at the pressure faces of the securing jacks. Thus it would appear that the holding down arrangements for the bearing cap have proved to be entirely satisfactory.

Less than three hours was required to withdraw the inboard shaft seal and open up the top half of the bearing for examination. This, of course, is an important feature of this type of bearing. Furthermore, by careful design and the application of some good, practical commonsense it has been so arranged that this work can be done by only one man, although the working space is ample to permit access for two or even three men.

Upon removal of the top half of the bearing the shaft journal was cleaned and examined and found to be in good condition, although a number of scratches were evident. These could well have been caused by foreign matter remaining in the lubricating system from the initial assembly period in the shipyard. This problem of cleanliness in the construction period is one quite common to the industry; unfortunately it is difficult to eradicate, and has been the cause of more than one expensive failure of equipment.



Graph showing movement of tailshaft within Camella-type stern bearing of Manchester Challenge *during trial runs—This phenomena believed due to centre of thrust of propeller being off-set from shaft centre*

Examination of the top half of this bush showed signs of the shaft running on it; this discovery was not entirely unexpected since shaft position readings, which indicated that this was the case, were taken on the ship's sea trials by the Research and Technical Investigation Department of Lloyd's Register. When these readings were taken it was suspected that the shaft might be misaligned, but a subsequent check on this by Lloyd's, using a strain gauge technique, confirmed that the alignment was, in fact, in accordance with the original design specifications. Readings taken later on sea trials of a sister ship fitted with a similar bearing gave much the same results; these have been reproduced in the accompanying graph.—*The Motor Ship, December 1969, Vol. 50, pp. 393–394.*

Ingredients for U.S. Nuclear Merchant Fleet

N.S. Savannah has been in service since early 1962 to demonstrate a peaceful use of the atom. The demonstration of nuclear merchant ship economics was not the intent of this project. The design emphasis was placed on safety and reliability.

N.S. Otto Hahn, built in Germany, recently started sea operations. The purpose of *Otto Hahn* is to extend the technology of nuclear ship propulsion beyond that which has been obtained from *Savannah*.

N.S. Savannah has demonstrated that the crew, ship and public are adequately protected. The reliability is good. The performance of the reactor plant, realizing it represents a first-of-a-kind in many areas of design and operation, has been excellent. The original core is still operating in the reactor with no fuel failures of any kind.

N.S. Savannah has travelled over 350 000 nautical miles. The itinerary has included all major ports in northern and southern Europe, United States and Far East (except Japan). The ship has been, and is continually received on favourable terms in domestic and foreign ports.

The pressurized water reactor which powers *Savannah* is of the spread-out design. The pressurized water reactor which powers *Otto Hahn* is of the integral or Consolidated Nuclear Steam Generator (CNSG) type.

Based on a study made by Babcock and Wilcox and presented to the Joint Committee on Atomic Energy in August, 1966, annual fuel cost savings equal to 40 per cent of conventional fuel costs can be obtained from a first generation of 270 *MWt* CNSG reactor cores. This 40 per cent savings is equal to about $500 000 per year per ship, based on a shaft horsepower of 100 000, 70 per cent ship utilization factor, first-core nuclear fuel cost of 2·0 mills per shp/h, an oil-fired plant fuel rate of 0·45 pounds per shp/h and a bunker C fuel oil cost of $2·10 per barrel.

The firm believes the prime requirement for a nuclear-ship programme is leadership. This leadership needs to be established at the national level to formulate and implement a programme and to establish effective communications with the variety of participating organizations ranging from the designers to government agencies to the maritime unions.

The first task to be accomplished is the establishment of a recognized requirement for U.S. nuclear merchant ships. This requirement will probably be justified either on the basis of national security or national prestige. It is doubtful that the justification can be established on current economic incentive, except in a few extreme applications involving large high-speed ships over long trade routes.

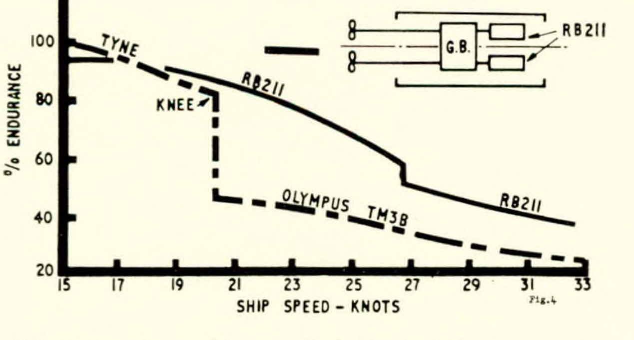
The second essential step toward a U.S. nuclear merchant fleet is a national programme. Many programmes have been suggested in the past, each with its own merits. Any future programme should be based on a commitment to at least five to ten high-speed ships incorporating duplicate propulsion systems of the 100 000 shp class.—*MacMillan, J. H., Maritime Reporter/Engineering News, September 15th 1969, Vol. 31, p. 32.*

Selection of Machinery for Naval Frigates and Destroyers

The introduction a number of years ago of the gas turbine was purely as a boost engine, necessitating the use of complex plants with mixed philosophies, gas turbines—Diesels, gas turbines-steam. This trend has evolved to the next logical steps, aero gas turbines and then all-gas turbines as fitted in the case of H.M.S. *Exmouth*, now at sea, and in the Type 42 machinery installation which is presently building.

In all these mixed plant concepts, when the cruising engine is necessarily different from the main boost engine in order to save fuel at low powers, there is a vital question in the machinery selection logic which every naval designer must face. This question is, "what power is required from the cruising gas turbine", and in most cases the answer will be "as high as possible".

The diagram shows a typical endurance curve with the now well known "knee" for combined plant installations. The "knee" occurs at the operating changeover point for the engines and is due to the difference between the main and cruising engine specific fuel consumptions at that point. The diagram shows a changeover point at a ship speed of about 20·5 knots and this could clash with the staff trend for high cruising speeds. To improve the situation would require either an increase in the power of the cruising gas turbines or a very significant improvement in the specific fuel consumption of the main gas turbines at the changeover point. The diagram also compares endurance between a machinery scheme employing Tyne and Olympus gas turbines which are available now and a future machinery scheme, which may be with us in five to ten years' time, employing Rolls-Royce RB 211 gas turbines.



Selection of machinery—Estimated endurance showing "knees" at engine transition points—RB 211 proposal provides for driving both shafts from one or both turbines

In each case the fuel carried by the ship is the same but the striking features of the new scheme are the large reduction in the "knee" and also the fact that it occurs at a ship speed of around 27 knots, which should be more than adequate to meet any future staff requirement for very high cruising speed. The future machinery scheme will give the ship's captain much greater flexibility in being able to operate at will across a wide plateau of ship speeds and moreover with marked improvement in endurance at full speed.—*Good, E. B., Marine Engineer and Naval Architect, November 1969, Vol. 92, pp. 450–452.*

Diesel Engines

The Paxman Ventura engine has been supplied as a power unit for patrol boats and is in service with the Royal Australian Navy and the navies of Canada, Kenya, Libya and Trinidad. It is in use for shipboard power generation both in naval and commercial ships.

The Ventura is a conventional four-stroke turbo-charged and intercooled Vee-form engine with a fabricated crankcase, fork-and-blade big end arrangement and four-valve cylinder heads. A single camshaft in the centre of the Vee operates inlet and exhaust valves and block-type fuel pumps are mounted on the crankcase.

The design is a compromise between low weight and overall cost. Although weight is important in its effect on the total cost of a ship or a locomotive, other factors such as reliability, fuel consumption and maintenance costs affect the overall performance.

The Ventura has been in service since 1960 and as a result of operating experience and development, it has been possible to re-design for a substantial power increase for the same overall size.

A cross section of the new engine shows the individual fuel pumps operated by a camshaft on the outside of each bank and the improved cylinder head cooling the inter-valve.

The most radical change is in the crankshaft which has unusually large diameter journals to accommodate the increase in firing pressure necessary to maintain a high thermal efficiency at high power. Theoretical work predicts that even at the increased loadings the main bearings will have an oil film thickness greater than that of the current design. The condition of the bearings on development engines suggests that this prediction may be correct.—*Hughes, R. V., Marine Engineer and Naval Architect, November 1969, Vol. 92, pp. 462–464.*

Roll-on Roll-off Containership

The roll-on/roll-off containership *Tor Mercia* Messrs. Gebr. van der Werf of Deest-Nijmegen have built for Triport Shipping is arranged for the carriage of trailers as well as containers.

The twin-screw shelterdeck ship has been constructed to Lloyd's Register of Shipping ✠ 100 A1 and complies with the

Board of Trade requirements for unrestricted service outside the tropics as well as the Convention for the Safety of Life at Sea. She is arranged for unmanned engine room without time restrictions and for unrestricted services.

The ship has been constructed with longitudinal framing in the bottom and decks and with transverse framing in the sides and at the ends. A double bottom extends over the full length of the hull. It is subdivided into tank compartments for water ballast, fuel oil, lubricating oil, cooling water, fresh water and a number of other purposes. A McMullen Flume stabilizing system is installed.

The main deck of the vessel is arranged for carrying trailers and containers, while the shelterdeck is also suitable for carrying empty containers. Arrangements are available for the mechanized handling of cargo by trucks. A deckhouse is built on the hull and is provided with a shipside bulkhead to screen the after deck. Principal particulars are:

Length, o.a.	108·50 m
Length, b.p.	100 — m
Breadth, moulded ...	19·20 m
Breadth at loaded waterline	18·794 m
Depth to shelterdeck ...	13 — m
Depth to maindeck ...	6·20 m
Draught on summer freeboard	4·95 m
Corresponding freeboard	min. 1·25 m
Deadweight capacity ...	2500 tons
No. of containers ...	155 (20 ft)
No. of trailers carried ...	48 (10 m)
Trial speed at 6300 bhp	approximately 17 knots

Flush hatchcovers in the main deck over the engine room provide the possibility of overhauling the cylinders of the main engines, the servicing of the auxiliary and the steering engine and the machinery store.

The loading ramp is operated by HP hydraulic rams. An electrically driven pump unit with integral tank is provided for this system, which includes the hydraulic locking device. A hand pump is provided for emergency operation of this device. The derricks and cargo winches serve the same purpose in respect of the ramp.

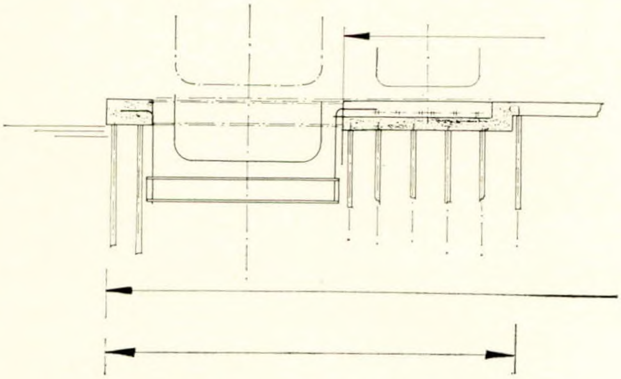
The steering gear is of the Svendborg type and has a rudder-angle indicator in the wheelhouse. Propulsion of *Tor Mercia* is by two 4-stroke non-reversing 8-cylinder in-line Lindholmen SEMT-Pielstick Diesel engines, type 8 PC2L, having a continuous output of 3500 bhp at 500 rev/min. The engines are equipped with Brown Boveri turbo-chargers type VTR 320 and with air coolers of the type 500 MD 4. The engines drive two 4-bladed KaMeWa c.p. propellers type 792/4, made of stainless steel and having a diameter of approximately 2500 mm. This is achieved through two Lohmann & Stolterfoht reduction gears of the type GUA 710 with one flexible coupling between each engine and the reduction gear. This installation gave the vessel a trial speed of approximately 17·1 knots.—*Holland Shipbuilding, November 1969, Vol. 18, pp. 44–46; 48.*

Hydraulic Ship Lift

The shiprepairing industry is characterised by irregularity in the flow of work. During slack periods, yard facilities such as drydocks are insufficiently occupied, whereas during busy periods ships may have to be kept waiting.

A great deal of ingenuity is therefore required to keep the customer satisfied without producing any detrimental effects on the economy of the enterprise. After investigating the pros and cons of the various methods in use, HYKU Shiplift Ltd., International, of Amsterdam has found that the ship lift together with an accompanying transport system, provides an excellent solution to these problems of the shiprepairer.

The HYKU ship lift is a vertically operating lift functioning by means of a series of hydraulic-ram winches which are provided with a synchronizing system and protection. The hydraulic winches are placed on either side of the steel platform which moves exactly vertically along guide rails. All the hydraulic pipelines for the control of the winches are brought together in a central operating panel, installed on an easily surveyable point. This panel also serves for the remote control of the valves, and incorporates the necessary signalling and protection devices.



Cross-section of the HYKU ship lift

The cylinder winches are simultaneously operated from this control panel and are arranged for programming the operations. The special synchronization system ensures that all the cylinder winches operate at the same speed, independent of the load, and highly accurately. If all the winches operate in unison, the platform moves in the manner of one rigid surface. The synchronization of the cylinder winches has made the ship lift economically and technically acceptable. In principle the lift can be operated by one man at the control panel. In comparison with other systems this means a considerable saving in labour.

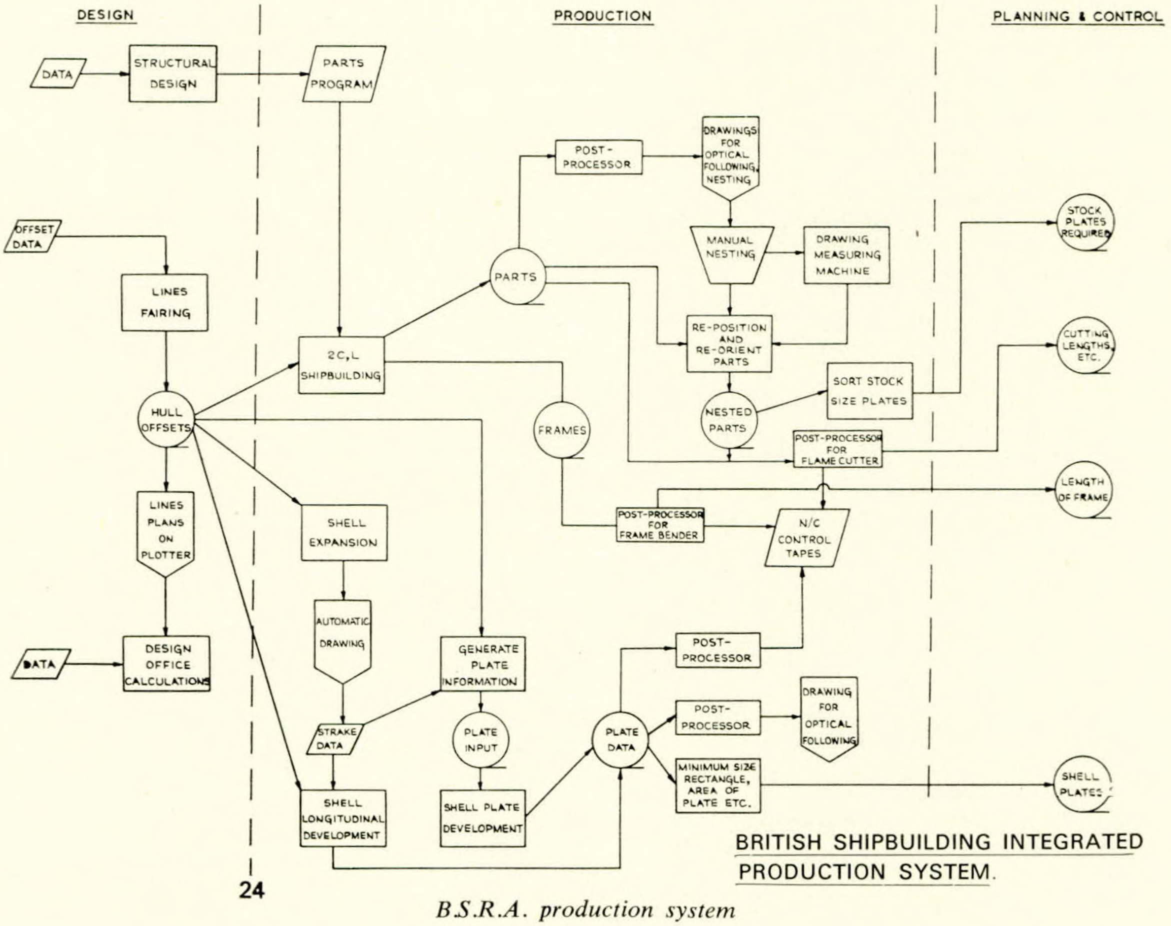
The ships to be docked are placed on a hydraulically driven roller carriage supported by the movable floor provided by the ship lift. A rolling bridge enables the ships to be moved by rail to the various repair or maintenance shops, where work can be carried out summer and winter. In this way it is possible to handle several ships per day and new arrivals can be transported without disturbing the ships already present. In this way a larger number of vessels can be accepted for repairs at the same time, while in case of time-consuming repairs slipway or dock costs per ship can so be reduced to a minimum.

If necessary the rapid handling of all sorts of ships can also take place on the roller carriage. This carriage is provided with keel and bilge blocks to provide sufficient stability during transport. This makes it possible to build ships in an enclosed shop space, while the lift is occupied for a few hours at the most to put the vessel into the water.

When ships have been lifted from the water, the platform offers the possibility of reaching them on all sides for smaller jobs such as small repairs on hull and propellers, surveys and expertises, of short duration and this work can be done unhampered by dockwalls. The great accessibility makes further savings possible.—*Holland Shipbuilding, October 1969, Vol. 18, pp. 126–128.*

B.S.R.A. Production System

During the last decade considerable progress has been made in the mechanization and automation of shipyard processes and it is realized that the full potential of computer programming can only be attained by the employment of an integrated system ranging from initial design to final production.



B.S.R.A. production system

British Ship Research Association has announced the development of the British Shipbuilding Integrated Production System "Britiships". The system which makes full use of the British 2C,L part-programming computer language developed by the National Engineering Laboratory, covers: preliminary and detailed design, joining of lines, control tapes for cutting and bending machines, material ordering data, and the creation of management control data related to scheduling and costs. It is expected that the scheme will be in operation early in 1970.

By reason of adopting a comprehensive computer language the same basic data can be used throughout and the system consists of self-contained linked units which can be used independently so that it is modular, thus providing for extensions to include new processes or to allow for up-dating or replacement of elements. The normal lines plan supplies the initial input data which is faired by a lines fairing programme and the offsets printed out or stored. A numerically controlled drafting machine draws the faired lines plan to provide a visual check and the data can be used to determine the shape of structural components and the outline of shell plates. The former are described by a parts-programming language based on the national 2C,L engineering system and a computer programme, the language processor, converts geometrical description of cutting sequence into a tape for operating a numerically controlled machine or producing drawings for use with an optical flame cutter. Part-programmed plates are nested to ensure the maximum economy in cutting size thus yielding a minimum of scrap. The use of another computer programme, post processor, enables output from the language processor to suit any existing numerically controlled flame cutting machine. Additional processors can, by using the stored information, supply materials ordering particulars and scheduling and also production control data for management.—*Shipbuilding International, December 1969, Vol. 12, p. 24.*

Non-Destructive Testing of Iron Castings

During the last twenty years, there have been very substantial advances in engineering design, particularly in terms of speed of manufacture and reduction in the size and weight of finished products. These advances have been made possible by the development of new materials and by the improvement or more effective use of existing materials. The ironfounding industry has reacted to the more exacting requirements of the engineer primarily by the installation of new plant, equipment, processes, and control techniques designed to ensure that purchasers will receive castings which have a good appearance and small dimensional tolerances, which are free from defects in critical locations, and which have the correct structure and mechanical properties. Improvements in the technical operation of the moulding, melting, and casting processes have been such that only a relatively small increase in the amount of non-destructive testing applied during final inspection of the casting prior to its despatch to the customer has been necessary.

By definition, a test is a method which enables the quality of a product to be evaluated, and a non-destructive test is one which does so without impairment of the serviceability of the article examined. Non-destructive testing has therefore a much wider application than just in those tests carried out in the inspection department immediately prior to despatch of the castings. Every time a casting is handled and its appearance is examined during the manufacturing process, a non-destructive test is applied in which the operator is checking that the casting has a good appearance and is free from obvious surface defects. Similarly, gauging the size of castings during fettling and the examination for cracks on, say, unannealed malleable-iron castings are recognizable as non-destructive tests that form an integral part of the casting production process.

Conventional non-destructive testing in the inspection department, as well as involving a final look at the outward appearance of castings, has become associated with tests designed to reveal information about quality aspects which cannot be visually assessed. Thus, there are tests available to evaluate whether or not internal defects are present and whether the structure and properties of the castings meet the required specification. Although the most easily recognized function of inspection is to sort good from bad, the final inspection of castings prior to despatch to the customer guards the foundry's reputation for quality and protects the customer's interests, since, in this context, inspection provides the link between the producer of the castings and the machine shops of the user.

A review is made of non-destructive tests which may be applied to iron castings, but consideration will be given only to those tests which reveal some aspect of casting quality that is not visually obvious. The fact that few of the tests described have been developed into automatic procedures within the foundry industry is a reflection of the success which the industry has achieved in the attainment of quality by investment in process control. This is a situation which may well change during the next decade, since there is evidence to suggest that users of castings will bring increasing pressure upon foundries to reduce still further the number of unacceptable castings occasionally entering their machine shops. Under such conditions, the non-destructive testing by foundries of a much higher proportion of the castings produced may become necessary, and the development of automatic non-destruction testing methods may be stimulated.—*Fuller, A. G., Engineers' Digest, December 1969, Vol. 30. pp. 71–73.*

Ships of Tomorrow

Today the naval architect and marine engineer has an almost bewildering choice of power plants and propulsion devices to meet his needs. Available prime movers include slow, medium, and high-speed Diesel engines, gas turbines, and steam turbines of reciprocating engines supplied by either conventional or nuclear boilers; similarly, the long-established marine screw propeller is far from being the only propulsion device in marine use. Faced with this diversity, and by a barrage of technical and other literature extolling the virtues of each system, the designer of even a relatively conventional ship is often in a difficult situation; for the designer of an unorthodox advanced marine craft the choice is sometimes more awkward in some respects, though perhaps more restricted in others.

Most ships of the future will undoubtedly continue to be propelled in ways which closely resemble those most frequently used today; the steam turbine and the Diesel engine will long dominate the seas, albeit with growing competition from the gas turbine, while the conventional open marine screw, which is both practical and highly efficient, will continue to be used on the great majority of ships. However, other power units and propulsion devices will find more applications; thus, the nuclear reactor, either to raise steam or perhaps later as a more direct source of mechanical power, will doubtless find more merchant ship uses, though these will be crucially dependent on its overall operating economics. Similarly, several types of unconventional propulsion device will find increasing use; some, like ducted, controllable pitch, and contra-rotating propellers, have been in regular if limited use for many years; others, like fully cavitating propellers and water jet systems, have undergone considerable engineering development in prototype installations; a third group, which includes airblown ram jets and magneto-hydrodynamic devices, are still in the early stages of laboratory investigation and are, in some cases, little more than "ideas in principle."

In assessing the prospects for the widespread use of any unconventional marine propulsion system it is essential to recognize that its choice and design must not be considered as a series of separate and isolated units, each selected to have maximum component efficiency, but as an integrated whole in which the characteristics of main machinery, propulsion device, shafting or other connexions, and needs for auxiliary power must be closely related. Indeed, such choice must take into account much more than the cost and performance characteristics of the system, even though these naturally include fuel consumption and bunker requirements; propulsion systems must increasingly be chosen and designed on a "life cycle" basis in which the costs and difficulty of maintenance over a long period of service are regarded as important items. Thus, once again, economic criteria will be dominant. Indeed, in deciding whether to depart from a well-established but conventional system, the shipowner will be very conscious of the relative importance of possible improvements in propulsion compared with those which may be obtained in quite different ways, such as by reducing crew costs and turn-round times, or by increasing the useful payload.—*38th Andrew Laing Lecture presented by Silverleaf, A. at a meeting of the North East Coast Institution of Engineers and Shipbuilders, 8th December 1969.*

Privately Owned Ship Model Basin

The largest privately-owned ship model basin in the United States of America has recently been placed into operation by Hydronautics Incorporated. This facility will be employed for testing and evaluating characteristics such as resistance, powering and performance in waves of surface ship designs, submarines, hydrofoil craft, offshore oil and mining equipment and other marine vehicles. Furthermore, the facility can be used to study other related problems such as propeller performance, flow and wake characteristics of marine vehicles.

Hydronautics facilities include a towing tank, free surface and closed jet water tunnels, wave tanks utilizing both wind-generated and/or mechanically induced waves, materials testing systems, etc. Instrumentation, provided as part of an overall facility, or independently, includes planar motion mechanism system having six degrees of freedom, transmission dynamometers for thrust or torque measurements, transducers of various types and configurations, and complete electronic instrumentation including data acquisition and readout systems.

The towing tank has a length of 310 ft, a width of 25 ft, is 13 ft deep and has been designed so that it can be extended by an additional 700 ft in the near future, thus giving it a total length of 1000 ft.

The tank is equipped with a hydraulically-driven plunger-type wave maker which can produce regular waves of up to 50 ft in length and 2 ft in height. This wavemaker can also be programmed to produce irregular waves.

A beach is located at one end of the tank to minimize reflection of the waves produced by the wave-maker. This beach consists of a multiplicity of gratings set in the tank at an angle of about 12 degrees and its design was based upon studies performed at St. Anthony Falls. In addition to this end damping afforded by the beach, the cantilevered sections of the tank provide side damping throughout its length.—*Shipbuilding International, December 1969, Vol. 12, pp. 10–12.*

Ship Design Procedure

The small number of published articles on the subject of practical ship design suggests that naval architects are reluctant to discuss this most important part of the overall ship production sequence. It is felt that constant discussion of all aspects of ship design would enable progress to be made in what, at the moment, is an empirical art. A ship design procedure is therefore presented in the hope that it will provide a basis for discussion. Each stage in the procedure is discussed in detail in separate sections and both standard forms and data are given.—*Lamb, T., Marine Technology, October 1969, Vol. 6, pp. 362–405.*

Design Considerations for Boiler Forced-draught Systems

The boiler forced-draught system is basic to satisfastory plant operation and merits more attention than it often receives. This paper discusses the determination of combustion air requirements, system draft losses, and the factors which must be considered in allowing margins over calculated requirements. The role of burner selection in determining draught requirements and fan sizing is considered with the intent of determining the economic trade-off between high "turnup" ratios with resultant high draft loss versus higher minimum firing rates utilizing steam dumping at low load conditions.—*Giblon, R. P. Shauer, K. M. and Rolih, J. H., Marine Technology, October 1969, Vol. 6, pp. 406–417.*

Japanese Shipbuilding Practices

The amazing success story of the Japanese shipbuilding industry during the last 14 or 15 years has made shipbuilders throughout the world wonder how this came about. This paper discusses many aspects of Japanese shipbuilding, including its historical development, organization, research, employment practices, salaries, engineering, planning, scheduling, production techniques, facilities and equipment, and welding procedures. The paper points to the reasons that have made Japan the leading shipbuilding nation in the world today.—*McQuaide, J. and Christensen, K. K., Marine Technology, October 1969, Vol. 6, pp. 418–439.*

Deep Sea Oil System

Economical development of offshore oil wells at depths from 400 to 1200 ft will be possible with a new production system. The system consists of a number of components in which men will be able to work in "shirt-sleeve" environment to depths of 1200 ft or more while remaining at the same atmospheric pressure as the surface. A wellhead cellar is lowered and fastened automatically onto the well head. Next a smaller ship carrying a steel utility capsule is moved into position over the well and lower the capsule carrying men and equipment, which mates securely with the cellar, forming a watertight seal and a hatch between the units is opened to form a work area.—*Canadian Research and Development, September/October 1969, Vol. 2, pp. 51–52.*

Study of Erosion by Solid Particles

The influences of the impacting velocity and the nature of the particles on the erosion of different materials have been studied using a vacuum whirling arm rig. The most important characteristics of natural sand were found to be the size distribution and percentage of quartz present. For artificial abrasives used in industrial processes, erosion can be related to the hardness and sharpness of the particles. It is suggested that the extent of fragmentation of the particles as well as the properties of the target material are important in determining the erosion behaviour.—*Goodwin, J. E., Sage, W. and Tilly, G. P., Paper submitted to The Institution of Mechanical Engineers for written discussion; Paper P15/70.*

Mechanical Properties of Cast Iron Alloyed with Molybdenum and Tungsten

Favourable mechanical properties can be obtained in cast iron containing flake graphite by adding molybdenum and tungsten to pure charge materials. Compared with ordinary cast iron, high tensile strength, toughness and elongation values are secured with relatively low hardness. The usual carbon and silicon contents are retained, so as not to impair the good casting properties and other characteristics of cast iron with flake graphite.—*Mayer, H., Sulzer Technical Review, 1969, Vol. 51, No. 3, pp. 127–132.*

Progress in Corrosion Research

Current density/potential measurement provides a valuable supplement to the normal long-time testing in corrosion research; in many cases it allows the duration of testing to be reduced considerably. A facility developed by the firm with which the authors are connected, enables tests to be performed fully automatically, without supervision. The results achieved are shown in a diagram of current density versus potential, its amperages being referred to the unit surface, and its potentials to the standard hydrogen electrode.—*Fot, E. and Weber, J., Sulzer Technical Review, 1969, Vol. 51, No. 3, pp. 112–116.*

Some Aspects of the Correlations Between the Wire Type Penetrameter Sensitivity and the Hole Type Penetrameter Sensitivity

A study of the correlations between the wire penetrameter sensitivities and the various hole type parameter sensitivities in radiographic testing is described. The relations between the wire diameters and the thicknesses of the 2T type penetrameter in the various detectable low contrasts were obtained experimentally reducing the contrast of the image by the double exposure method.—*Kanno, A., Papers of the Ship Research Institute, Tokyo, July 1969, Paper No. 31.*

Study of Bending Fatigue Strength of Gears

In this report the authors consider and analyze the mechanism of bending fatigue breakage of gear teeth such as occur in various kinds of gears made of many kinds of heat treated materials. They summarize their findings as follows: Not only the failures on the tension side of the fillet, but also those on the compression side should be carefully observed. The mechanism of bending fatigue breakage of unhardened gears differs considerably from that in the case of surface hardened gears, where the residual stress induced by heat treatment is a factor.—*Aido, T., Oda, S. and Inoue, S., Transactions of the Japan Society of Mechanical Engineers, No. 264; Bulletin of the Japan Society of Mechanical Engineers, 1969, Vol. 12, No. 50, p. 395.*

An Automated Approach to Ship Structure Analysis

Described is the application of the finite element method to ship structures, and particularly to large tankers. Emphasis is placed on the development of a computer programme package, starting from basic information about the ship and loading conditions and proceeding to the structural analysis of the entire vessel, followed by local analyses to obtain a detailed stress distribution. The authors present the finite element method in a nutshell, and follow with a discussion of the elements employed in the model. The structural programme DAISY, is briefly described. An account of the generation of data, both geometrical and structural, that lead to the complete definition of the ship is provided, as well as sample results from the analysis.—*Kamel, H. A., Birchler, W., Liu, D., McKinley, J. W. and Reid, W. R., Paper presented at the Annual Meeting of The Society of Naval Architects and Marine Engineers, 12th–14th November 1969, paper No. 7.*

Theory of Tooth-surface of Bevel Gear by Method of Enveloping Spheres

In order to find the characteristics of the tooth-surfaces of bevel gears, the tooth-curves on the sphere with a certain radius, of which the centre is the intersection of the axes of meshing gears, are generally used. Also, the method of enveloping circles on the sphere is applied for the same purpose. However, they are not enough to solve many problems about the tooth-surfaces. A new method, called "the method of enveloping spheres" was derived to solve the problems.—*Matsuyama, T. and Suga, K., Transactions of the Japan Society of Mechanical Engineers, No. 263; Bulletin of the Japan Society of Mechanical Engineers, 1969, Vol. 12, No. 50, p. 395.*

Model Navigator Based on Laser

This article gives a description of a measuring device to determine the position of a ship model in a basin. The position is determined by two light-beams, projected from a laser, the beams being automatically orientated to the model. The direction of the light-beams is controlled by servo-motor driven mirrors, a circular row of triple mirrors installed in the model reflecting the light-beams to photocells. The output voltages of the cells control the servo-systems. The position of the model is obtained in the form of two angles; these angles are transformed into the co-ordinates of a Cartesian system.—*Loesberg, P. P., International Shipbuilding Progress, October 1969, Vol. 16, pp. 301–307.*

Preliminary Fleet Design by Geometric Programming

Geometric programming is a mathematical method for restricted optimization of a certain kind of polynomial functions. The purpose of this paper is to apply this method to a problem of preliminary fleet operations analysis. Three versions of this problem are fully discussed with a view to present a working knowledge for the general application of this method to other problems of ship design and operation.—*Folkers, J. S., International Shipbuilding Progress, October 1969, Vol. 16, pp. 308–326.*

Patent Specifications

Sea-going Vessel

With the large and very large sea-going vessels recently built, for example tankers of over 100 000 tons and cargo vessels of over 50 000 tons, the draught cannot be increased to correspond with the increased breadth of beam. When these ships are viewed in the longitudinal direction, therefore they have a relatively shallow cross-section. If they retain the conventional form of stern with a central post, the stern contains long, narrow spaces which cannot be used economically. If the stern portion were shortened, the flow round the ship's screw would become unsatisfactory and the efficiency of the whole propulsion plant would decrease.

These disadvantages may be reduced or avoided by adopting a hull shape in accordance with the invention while still providing satisfactory housing for the propulsion plant. The hull shape may also make possible a shorter stern than is possible with the known hull shapes, and more effective use of the space within the hull.

With a hull shape with two bulges, the underside of the hull at the stern may slope upwards between the two bulges in a substantially flat manner, i.e. apart from the necessary rounded portions. This gives a simple shape which is effective from the point of view of flow dynamics.

As shown in Figs 1 and 2, the stern (1) of the vessel has bulges (2) containing bedplates (8) for engines (3). The engines are arranged with their crankshafts substantially parallel to the longitudinal axis of the vessel. Relatively short propeller shafts (4) lead astern from the engines (3) and carry screws (5). Two rudders (6) are slightly offset relative to the shafts (4) towards the longitudinal axis of the vessel. These rudders are in the streams downstream of the screws (5), but are offset so that the propeller shafts (4) can be demounted by pulling them out. As Figs 1 and 3 show, the underside of the hull between the two protuberances (2) slopes upwards (line (7) in Fig. 1) in a substantially flat manner.

The cross-sections of the hull are seen best in Fig. 3. The breadth of beam in the present case is more than 2·4 times the draught, a value which may be regarded as an approxi-

Fig. 1

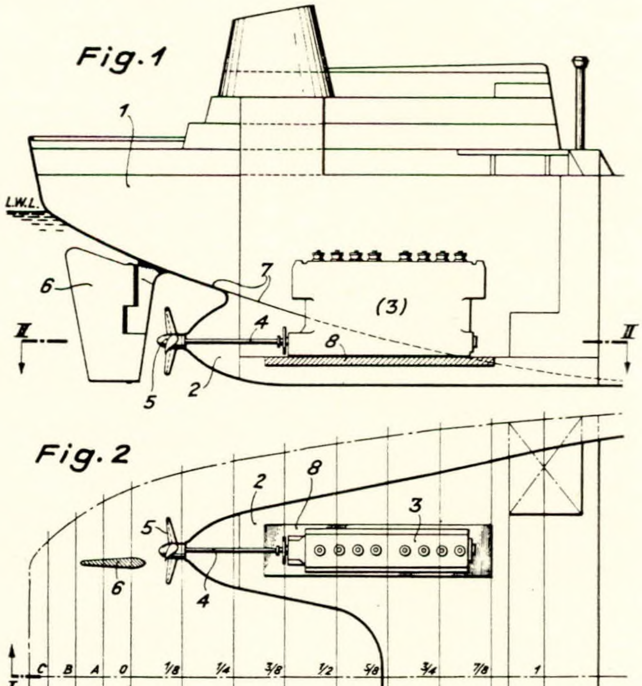


Fig. 2

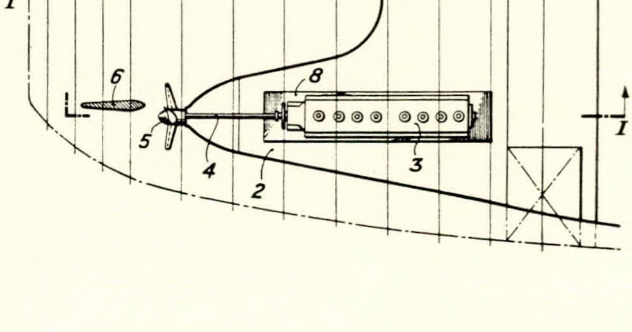
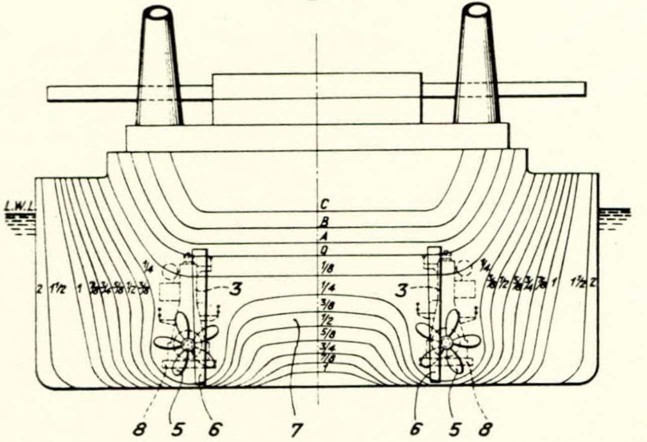


Fig. 3



mate limit as regards suitability of the design embodying the invention.

Fig. 3 also shows in a conventional manner cross-sections of the hull. The designation in the present example corresponds to the customary designation according to which the hull is divided into ten equal parts between the water-line at the bow and the rudder-pivot.

The design embodying the invention permits the stern of the hull to be made very short and particularly good use to be made of the vessel for holds, while the flow resistance is favourable and, in particular, the flow round the propellers is good.—*British Patent No. 1 166 976 issued to Sulzer Brothers Limited. Complete specification published 15th October 1969.*

Ship for Transportation of Containers

This invention relates to a ship preferably but not exclusively for the transportation of containers.

Referring to Figs 1–4, the ship comprises two laterally spaced parallel pontoons (1), each having a propeller and propulsion machinery (2). The pontoons are also provided with fuel, trimming and ballast tanks (not shown). At the stem the pontoons (1) are provided with vertical columns (3) supporting a cross beam (4) provided at its ends with recesses (5) opening downwards, the columns (3) being movably engaged in the recesses (5). The recesses are so shaped that the cross beam (4) is movable in relation to the pontoons (1). The cross beam houses a navigation cabin or pilot house and cabins for the staff and is engaged by an arm (6) secured to deck (7) situated behind the cross beam and adapted for loading container (8) (Fig 4). The deck (7) is thus carried at the fore ends in movable manner by means of the cross beam (4). The aft end of the deck (7) is carried by two further columns (9) which with their lower ends engage upwardly opening recesses (10) in the respective pontoons (1) such that the deck is movable in relation to the pontoons.

As indicated in Figs 1 and 2, the deck (7) may also at the fore end be provided with two columns (11) engaging movably in the pontoons (1).

Each column (3, 9) is at its end free and shaped with a spherical portion engaging in a corresponding dish-shaped portion at the inner end of the corresponding recesses (5, 10) so as to ensure the desired movability.

Several separate decks (7) may be provided, these decks being arranged on supports (12) (Fig. 4) in different harbours (13) where the decks are loaded and unloaded by hoisting mechanisms (14). The ship with the two pontoons (1) and the cross beam (4) is moved in under a first deck (7) either being empty or loaded with containers (8). The two pontoons (1) are pumped dry until the deck has been lifted from its supports (12) and the ship then sails to the next harbour where a second deck is ready for being transported empty or loaded.

In the second harbour the same course of events is carried out as in the first harbour and the ship sails with the second deck as soon as the first deck has been deposited on suitable supports and the second deck has been lifted by the ship as indicated.—*British Patent No. 1 177 023 issued to Aktiebolaget Internavia. Complete specification published 7th January 1970.*

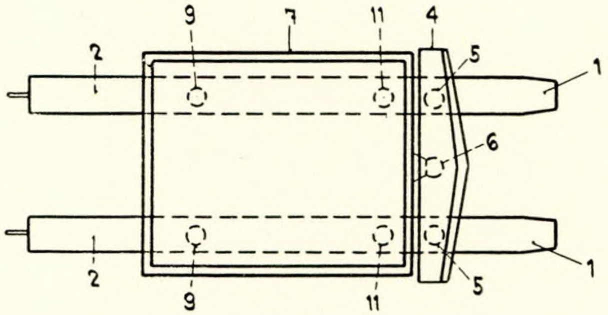


FIG. 1

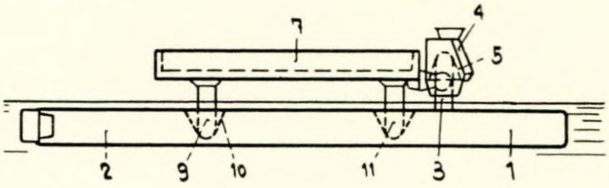


FIG. 2

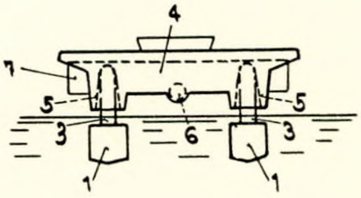


FIG. 3

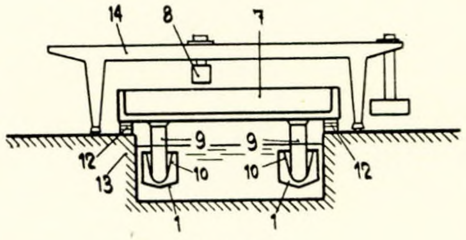


FIG. 4

These abridgements are reproduced by permission of the Controller of H.M. Stationery Office. Full specifications are obtainable from the Patent Office (Sale Branch), 25 Southampton Buildings, Chancery Lane, London, W.C.2, price 4s. 6d. each.