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OFFSHORE FIREFIGHTING: The Development of a High Capacity Shipborne System

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Offshore Firefighting: The Development of a High Capacity Shipborne System

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SYNOPSIS

The need for offshore firefighting and control systems is examined, and the requirement for a shipborne high capacity water supply for operation off the offshore structure is established. The required characteristics for such a system are then listed and various vessel types evaluated as to their suitability for the mobile offshore firefighting duty. The main components of such a fire control system—water monitor, pump, and prime mover—are examined and the required characteristics of each item evaluated. A description of the specific gas turbine driven system under study follows, including the options available. Examples of this gas turbine driven system already installed are outlined and some operational experience evaluated, concluding with a survey of those aspects requiring further research.

INTRODUCTION

With the increased exploitation of offshore oil and gas reserves, coupled with the recent occurrence of a number of offshore fires, considerable attention has been focussed on the provision of adequate firefighting systems for the protection of personnel and equipment.

The types of protection provided for an offshore structure may be broadly divided into the:

i) detection and alarm equipment located on the structure, which will provide a monitoring function; identify a dangerous or potentially dangerous situation; set off a visual or audible alarm; and in certain circumstances automatically start the fire extinguishing system installed on the platform;
ii) on-platform fire extinguishing system;
iii) back-up fire extinguishing or control system provided off the structure itself, to be brought into operation when the on-platform system is insufficient, or inoperative, or when the platform has been abandoned.

The paper is concerned with this third category, the off-platform or shipborne system, and specifically with the application of a single shaft radial gas turbine to the development of a system which is compact enough to be located on an offshore vessel of reasonable size, yet of sufficiently large capacity to provide the large quantities of water required.

THE NEED FOR A LARGE CAPACITY WATER JET SYSTEM

Experience with offshore fires and wellhead blowouts has shown a primary requirement for a large supply of water in the form of jets capable of being directed onto any part of the platform structure. This water is required for one of a number of purposes:

1) if a blowout has occurred but not ignited, a continuous dampening spray is required to minimize the chances of ignition of the escaping gas and oil;
2) when a fire has occurred, and the jets can be accurately directed at the heart of the fire, there is a possibility that it may be extinguished by a combination of cooling (using the latent heat of evaporation) and steam blanketing to cut off the supply of oxygen to the fire;
3) where the fire is extensive, i.e. a blowout fire which cannot be extinguished by water alone, a continuous water spray supply is needed in order to:
   i) gain access for emergency work;
   ii) cool the structure to prevent deformation and collapse;

while alternative extinguishing methods are prepared such as capping the well, explosives, directional drilling, etc.

REQUIRED CAPACITY OF SHIPBORNE FIRECONTROL SYSTEM

Because of the large variation in:

- the type of structure to be protected (e.g. steel or concrete, with helicopter deck or without, etc.);
- the range of vessel types on which it is necessary to locate the system (large semi-submersible or small standby vessel);
- the weather conditions in which it will be called upon to operate,

it has not been easy to lay down specific and quantitively defined rules as to the water pumping capacity, pump discharge pressure and required jet trajectory for the system. One major Classification Authority prepared a set of Guidelines(1) for this type of vessel which provided two broad groups:

- Firefighter I—with a total capacity not less than 2400m^3/h and a horizontal range of 120m;
- Firefighter II—with a total capacity not less than 7200m^3/h and a horizontal range not less than 150m;

and these Notes also defined the required jet height at a given distance from the vessel with optimum monitor elevation.

A second Classification Society subsequently produced further guidance, this time in the form of Rules for the

Classification of Firefighting Vessels[2] and these contained broadly the same division of water capacities as above. This has been followed by an extension by the first Classification Authority of their requirements to cover a third category, namely:

- Firefighter III with a total capacity not less than 9600m^3/h, with jet height and range performance of at least the standard laid down for Firefighter II[3];

and these Notes now form the basis of this particular Authority's Rules for the Classification of this type of vessel.

There is as yet no uniform set of rules or requirements defining the oil industry's needs in terms of, for instance:

- the quantity of water required related to platform surface area or maximum rate of oil or gas production;
- the type of jet required e.g. spray or "solid" jet; degree of dispersion of spray jet required or assumed in the calculation of water quantities, etc.;
- the jet trajectories required, including the need for an "up-and-under" ability to reach the underside of the platform;

although a number of specific studies have been carried out by the industry for particular platforms or particular vessels.

CHARACTERISTICS OF A VESSEL SUITABLE FOR INSTALLATION OF FIREFIGHTING SYSTEM

An offshore vessel suitable for the installation of such a firefighting system has the following characteristics:

1) the operational role and location of its main sphere of operation are such that a large proportion of its operating time is spent in close proximity to the structures it may be called upon to protect. The longer the lapse of time between detection of the fire and arrival of the vessel at the structure, the greater the opportunity for the fire to take hold or spread, with even greater danger and prospective disaster;
2) its primary operational role is normally some duty other than firefighting, such as diving support, structure maintenance or platform standby. (The concept of a purpose-built offshore fire patrol and firefighting vessel has been examined in detail by a number of authorities, and the predominant finding has been that the expense of such a single-purpose vessel, which, hopefully, would never be required for anything other than standby and training, cannot be justified; particularly when, to provide adequate coverage of a widespread series of structures, several such vessels would be required.)
3) the vessel's propulsion and manoeuvring equipment is adequate, in terms of both power and speed of reaction, to maintain it on station when firefighting in the face of the external forces on the vessel due to:
   - wind and waves up to the predetermined operational weather limitations for the vessel in the firefighting role;
   - thrust from the water monitors, which may act in a wide range of directions due to the ability of the monitor to train over a wide range of bearing and elevation. The thrust must also be evaluated in relation to the vessel's stability, particularly if the monitors are mounted relatively high on the superstructure.

   The total thrust reaction from the monitors in an installation complying with the Firefighter II classification referred to may be as high as 10 to 12 tonnes.

Some of the equipment or design features which may be necessary on such a vessel include:

i) bow and stern thrust units, manoeuvring propellers, or other manoeuvring devices;
ii) a dynamic positioning system to provide automatic control of main propulsion and manoeuvring equipment to maintain a preselected position. This facility is of particular importance on those vessels intended for combatting fires or blowouts as the second line of defence, when the vessel may have to stand off the structure for long periods and when the problems of operator strain and fatigue in a prolonged emergency situation assume major significance.

TYPES OF VESSEL SUITABLE FOR INSTALLATION OF A HIGH CAPACITY FIREFIGHTING SYSTEM

The types of vessel on which the turbine driven system described in this paper is already fitted include:

1) offshore maintenance and support semi-submersible. This type of vessel is well suited for the system because:
   i) its operational role keeps it in the area for long periods;
   ii) its size and semi-submerged configuration provide a stable platform in a wide range of adverse weather conditions;
   iii) its stability, coupled with extensive manoeuvring equipment and a dynamic positioning system, provides the ideal location for the positioning of the firefighting equipment adjacent to the burning structure.

   The capital cost of the vessel, however, is high.
2) an offshore multi-purpose service vessel (monohull) for, for instance, diving support, has the same advantage of proximity to the structures during the majority of its charter period, although in some cases the limited size of the vessel imposes a constraint on the provision of firefighting equipment in addition to the basic "payload".
3) the offshore supply vessel can also be provided with firefighting equipment, but is limited by the nature of its operation in that it is often away from the immediate area of the structure as part of its supply duty.
4) the platform standby vessel is an ideal choice insofar as it is statutorily required to remain in the immediate vicinity of the platform to provide a rescue and refuge facility for the personnel on the platform. However, the normal size of these vessels limits the capacity of firefighting equipment which can be adequately accommodated. Furthermore, since the primary role of these vessels in such an emergency is to rescue personnel and remove them to safety and perhaps to hospital, the firefighting function itself can only be carried out for as long as it assists, or at least does not hinder, that primary role.

In the operational framework which has developed for the North Sea, the first line of defence of off-platform firefighting is a supply vessel or diving support vessel which spends the majority of its time relatively close to the platform. This is backed-up by a larger-capacity installation on a vessel serving a larger area containing several platforms or groups of platforms: this vessel is often a semi-submersible and which may combine diving support and other maintenance duties with its emergency service duties, and is made available to assist in any major emergency in its predetermined area of responsibility by a co-operation agreement between the platform operators, the vessel owner, and the charterer.

THE REQUIRED CHARACTERISTICS FOR A LARGE CAPACITY FIREFIGHTING SYSTEM

The characteristics of the component items of equipment comprising an offshore firefighting system may be summarized as:

1) small size and weight for the required capacity, not only to facilitate the installation of the equipment in the confined space available but also to enable as large a proportion of the vessel as possible to be devoted to the everyday functions carried out to earn revenue.
2) high starting and running reliability;
3) low maintenance: both to maintain the equipment in readiness and to keep it operational during the emergency;
4) capability of virtually continuous operation for periods as long as several months when required in an emergency such as a wellhead blowout.

TURBINE DRIVEN HIGH CAPACITY SYSTEM FITTED TO AN OFFSHORE MULTI-PURPOSE SERVICE VESSEL

A brief description of an offshore service vessel fitted with this firefighting system follows. (See Fig. 1).

Seaway Falcon is a multi-purpose offshore vessel approximately 80m overall with a propulsion engine power 4200 hp and capable of 14.5 knots. She is fitted with extensive equipment for offshore maintenance and repair including heavy lifting gear (100 tonne capacity), diving equipment (300m depth) and observation chamber (500m). She has four side thrusters, two forward, two aft, with a total side thrust of 20 to 30 tonnes. The firecontrol requirement is to provide a water flow of 8000 tonnes/hour (35,000 U.S. gallons/min. or 132,500 litres/min.) of water in jets capable of reaching a height of around 50m with a horizontal range of around 150m; this is achieved with four monitors, located on the after sides of the two funnels and electrohydraulically controlled by joysticks located in the wheel house.

Two pump sets, each capable of 4000 tonnes/h, individually supply one pair of monitors. The pump is a single stage horizontal centrifugal pump and is, in fact, an adaptation of a standard marine cargo pump. The prime mover is a 2200 hp marine gas turbine driving through an air operated clutch. The pump discharge pressure is approximately 11.5 bar giving a pressure at the monitor of the order of 10.5 bar (Fig. 2).

The grounds for the selection of a gas turbine as the prime mover conform closely with the required characteristics for such a system outlined in the previous

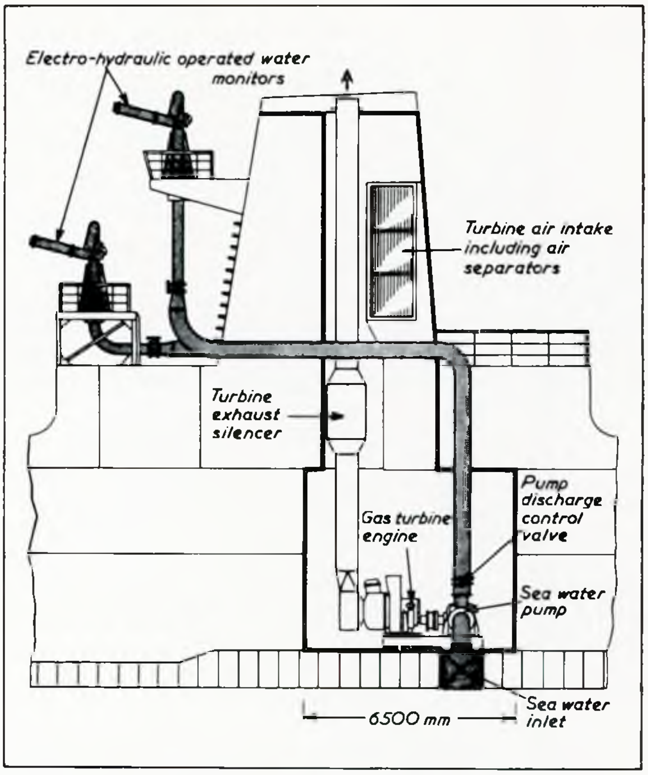


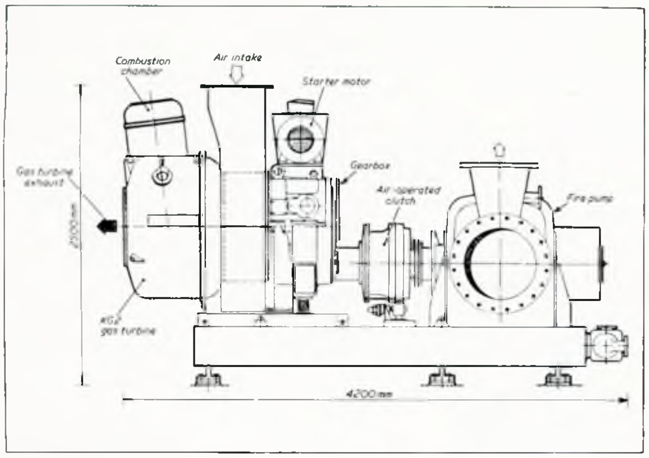
FIG. 1. Typical installation in machinery room (m/v *Seaway Falcon*)

section. A brief description of the essential characteristics of this particular gas turbine can be found in Refs 5 and 6; the principles of operation are shown in Fig. 3.

In summary, the manner in which the gas turbine meets the requirement is:

1) size and weight: the skid mounted pump set capable of producing 4000 tonnes/h weighs 7.5 tonnes and 4.2m long;
2) starting and running reliability: the inherent simplicity of the single shaft radial gas turbine contributes to its high starting reliability, even after relatively long periods of inactivity. Its low thermal inertia and small lubricating oil capacity result in no prior warming through being required, and recorded starting reliability of over 99.9% has been experienced. Reliability in operation is the outcome of the steadily increasing experience of this particular machine in some 500 installations covering a wide variety of marine and industrial applications since the first engine in 1969;
3) low maintenance: again the inherent simplicity contributes to the basic 8000h-between-overhaul/16000h-between-major-overhaul maintenance schedule. But perhaps more important is the minimal routine work required to keep the machine on standby;
4) capacity for continuous operation has been widely demonstrated in base load generating duties on a number of offshore platform installations.

One aspect of the gas turbine's suitability for the role of prime mover in an offshore firefighting system which is of obvious concern, is its capability for sustained operation in an environment which has the added problem of the heavy spray concentrations caused by the fire



Note: Above figure already reproduced by I Mar E. as Fig. 12 in paper "Marine Auxiliary Gas Turbines" delivered 1.2.77.

FIG. 2. Gas turbine driven pump set for up to 4000 tonnes/h output

monitors as well as the normal salt-in-air concentrations experienced by standard marine equipment. The radial gas turbine described above operates at a considerably lower maximum cycle temperature (around 825°C) than, for instance, current propulsion gas turbines, and is therefore able to tolerate a greater contamination of the intake air with salt in terms of its susceptibility to hot end corrosion. Furthermore, the larger air passages in the radial compressor compared with an axial flow machine result in a smaller loss in performance due to compressor fouling. Nevertheless, air intake filtration is obviously necessary, and here it is possible to benefit

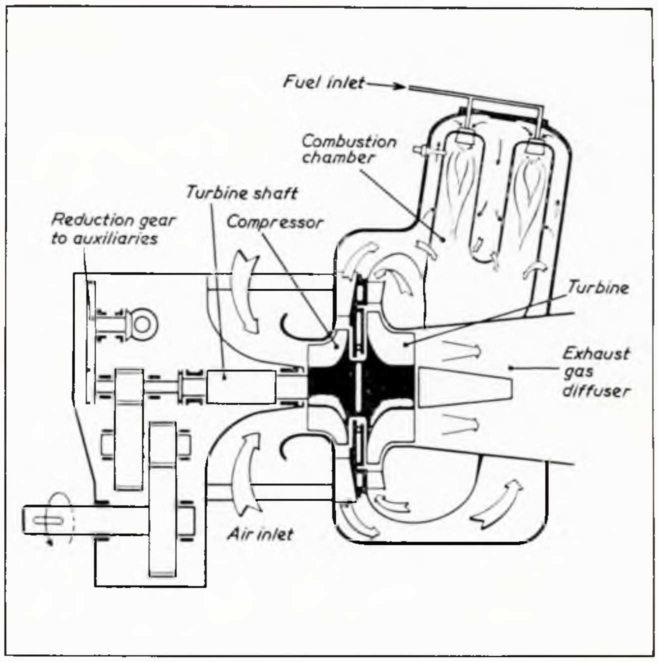


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FIG. 3. Principles of operation of the all-radial gas turbine

from the extensive research carried out into salt spray removal devices for warship propulsion gas turbines. The resultant three-stage separator system which has been developed, and is now fitted to propulsion gas turbines in British, Dutch, U.S. and many other navies, offers a compact, simple and relatively inexpensive system with a separation efficiency which is in practice more than sufficient for the modestly-rated firepump gas turbine. The filter panel (See Fig. 4) is constructed in modular form: the first stage removes the large spray droplets by inertial separation, the second stage coalesces the fine droplets into larger ones, and the third stage removes these larger droplets. The separation system has proved itself repeatedly in service, not excluding the dense spray concentrations sometimes experienced if the monitors are directed into or near the wind, the only proviso being the care that must be taken to ensure air-tightness of the intake duct and around the filter panel, and adequate drainage arrangements for the separated water.

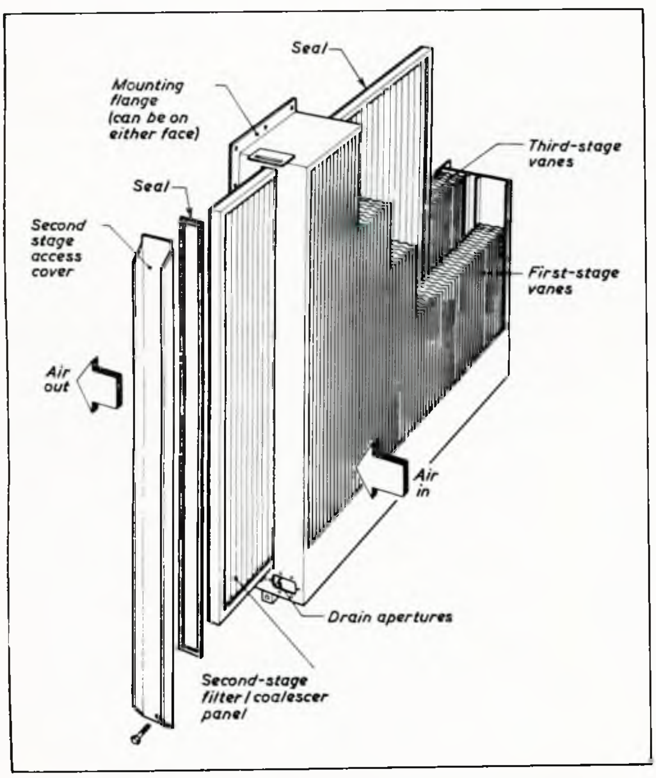

FIG. 4. Typical arrangement of 3-stage air inlet separator module for removal of salt spray from gas turbine intake air

VARIOUS ALTERNATIVES IN THE BASIC FIREFIGHTING SYSTEM

The components of the basic system are:

1) skid mounted gas turbine driven pump set;
2) remotely (pneumatically) operated pump discharge valve;
3) one or more monitors mounted on the ship structure;
4) control instrumentation cabinets for the gas turbine, pump, and monitor electrohydraulic actuation system;
5) joystick consoles (fixed or portable) for directional control of each of the monitors for remote location at a convenient vantage point.

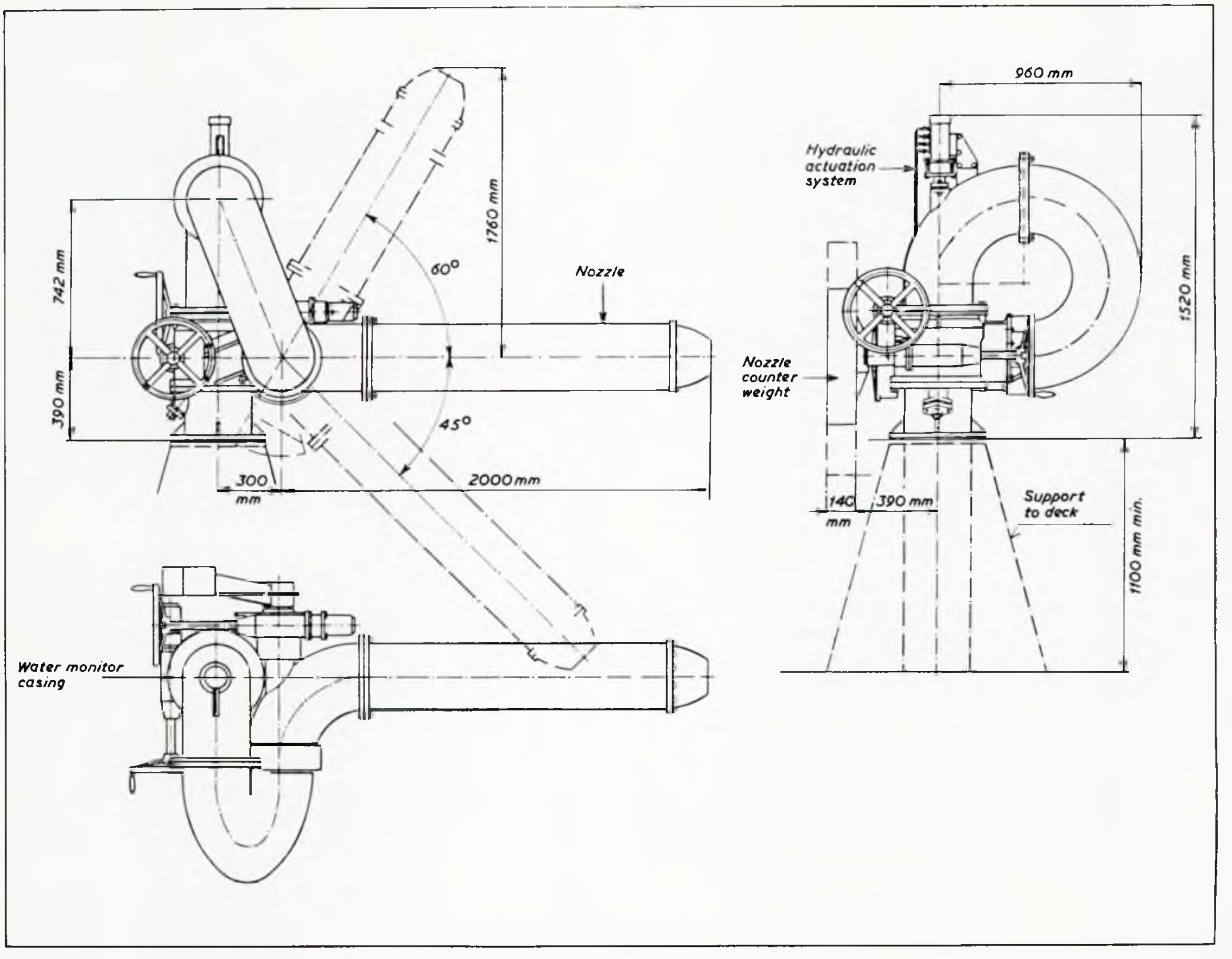

FIG. 5. Basic water monitor suitable for 2000 tonnes/h

With reference to the monitors (see Fig. 5), the choices available, in ascending order of capital cost, for each type of directional control are;

i) manual control by handwheel on the monitor. Although naturally a little inconvenient and slow, this direct control can halve the cost of the monitor equipment by eliminating the electrohydraulic system, and has been used on a vessel such as a semi-submersible, which has itself considerable positional control and in-built stability. For classification as a firefighting vessel, however, most authorities require operation of the monitors to be from a central protected position;

ii) joystick control, with constant speed of monitor response to joystick movement;

iii) joystick control, with variable speed of response according to the degree of displacement of the joystick;

iv) stabilized water monitor control by which, once the monitor has been adjusted to the required elevation and heading by manual operation of the joystick, the system then provides automatic compensation for pitch, roll and heave movements of the vessel.

Fittings can also be provided to enable the basic water monitor to produce a dispersed spray instead of the standard jet.

The trajectory of the jet produced by the monitor, in terms of the height it can reach and the range of which it is capable, is obviously important in relation to the geometry of the structure to be protected. There is only limited published data on the influence of:

- water pressure at the monitor nozzle;
- water flow rate to the monitor;
- nozzle diameter and shape;
- monitor elevation;

on the height, range and degree of dispersion of the jet from monitors with nozzle diameters large enough for these capacities, i.e. around 115 to 140mm dia. Considerable further work is necessary to obtain a clear

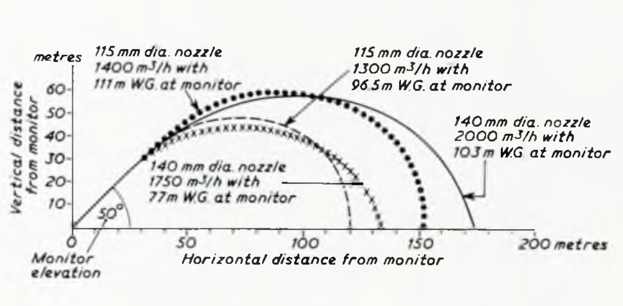

FIG. 6. Summary of *Seaway Falcon* monitor trials, 1975, showing variation in target range with various nozzle diameters, water flows and pressures

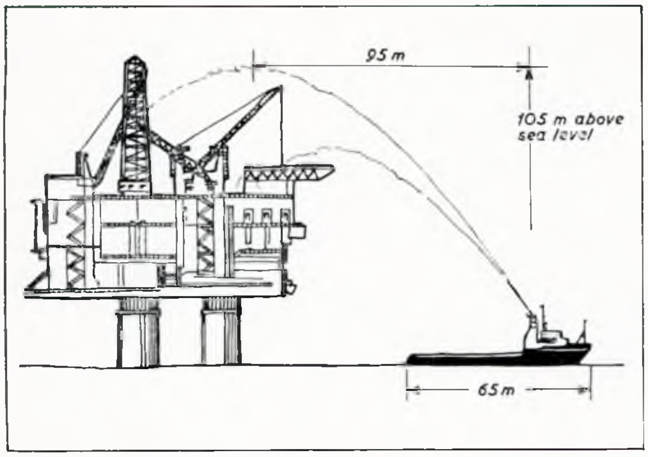

FIG. 7. Sketch of modern offshore firefighting facility: *Stad Sea*

picture of the effects of varying the above parameters in adverse weather conditions.

A modest set of trials, carried out in far-from-ideal conditions, on the vessel *Seaway Falcon* referred to above are summarized in Fig. 6 and indicate that the height and range are clearly a function of mass flow and pressure at the monitor, and that progressive increase of the monitor pressure alone will not necessarily improve performance.

A measure of the extent to which the system has been developed is provided by a comparison of these results, which were achieved in 1975[4], with the sketch shown in Fig. 7 based on recent trials of a supply and service vessel related to one of the major platforms it is designed to protect. The overall length of the vessel shown is 65m, so it is capable of directing the jets approximately 105m above water level at a distance of 95m from the monitors, and the need for this order of performance is illustrated by the relationship of this trajectory to the platform in question.

However, in addition to the variations that are possible to the components of the system (including those for the gas turbine such as choice of fuel type, starting system, etc.) the arrangement of the system in the ship can be varied to suit the vessel and its operational role.

CONTAINERIZED ALTERNATIVE TO 'TWEEN-DECK MOUNTING FOR THE FIRE PUMP SET

The compactness of the single shaft radial gas turbine has, in past applications led to its utilization in:

- marine containerized gas turbogenerator installations where a 1.5 MW generator set and its controls are installed in a container conforming to the ISO 20ft x 8ft x 8ft requirements.
- mobile gas turbogenerator installations of basically the same equipment, suitable for road transportation to remote locations requiring on-site electrical power.

The same design philosophy can be extended to the gas turbine driven firefighting equipment package. In this type of package, a diagrammatic sketch of which is at Fig. 8, the main container houses the gas turbine driven pump set, and the electrohydraulic module for the monitor actuation. A separate control room, which can either be bolted onto the container or located remotely as dictated by the vessel arrangement, houses the control and instrumentation cabinets for the gas turbine, pump and monitor systems. The air intake and filtration system is housed on top of the container and the turbine exhaust silencer and duct mounted on one end. The monitor or monitors can either be mounted on the container structure, or on the vessel structure if the vessel arrangement makes this preferable.

The remotely operated pump discharge valve is located in the discharge pipe between the pump and the monitor(s). This type of containerized gas turbine/pump set arrangement is utilized when one or more of the following conditions applies:

i) space below decks on an existing vessel is insufficient for the satisfactory accommodation of a skid mounted pump set;

ii) the vessel owner does not want, or have time for, the disruption of breaching the hull or deck plating in order to install the equipment below deck;

iii) the vessel owner wants to be able to transfer the firefighting equipment between different vessels in his fleet to provide himself with flexibility of deployment of the vessels for different charters;

iv) the oil company, or platform operating company, wants to purchase and own the firefighting equipment, but also wants to preserve some flexibility of choice of chartered vessels obtained to carry out the various supply or service tasks around the platform.

Preparatory work on board a vessel to make it ready to receive such a firefighting package normally includes:

a) provision of additional deck scantlings and fixings in way of the container (if the monitor is mounted on the container the fixings must be adequate to withstand the thrust reaction from the monitor);

b) provision of the external services required. These can usually be tailored to match the availability and supply particulars of the services of the vessel, but typical requirements are:
   - small intermittent compressed air supply for clutch and pump discharge valve actuation;
   - salt water for gas turbine lube oil cooler and fire pump priming system;
   - a.c. electric supply for gas turbine start motor (intermittent) and monitor hydraulic pump drive;

c) provision of a sea suction pipe connection with the shipside valve for the fire pump. Portable over-the-side suction arrangements are feasible in certain applications but are not favoured where there is any likelihood of damage from other vessels, equipment or heavy weather.

OPERATIONAL EXPERIENCE

It is not easy to draw clear conclusions regarding improvements to the current design of large capacity fire control systems from occasions when existing systems have been operated in emergencies, because the circumstances of each fire or blowout are different, and occurrences have been thankfully few.

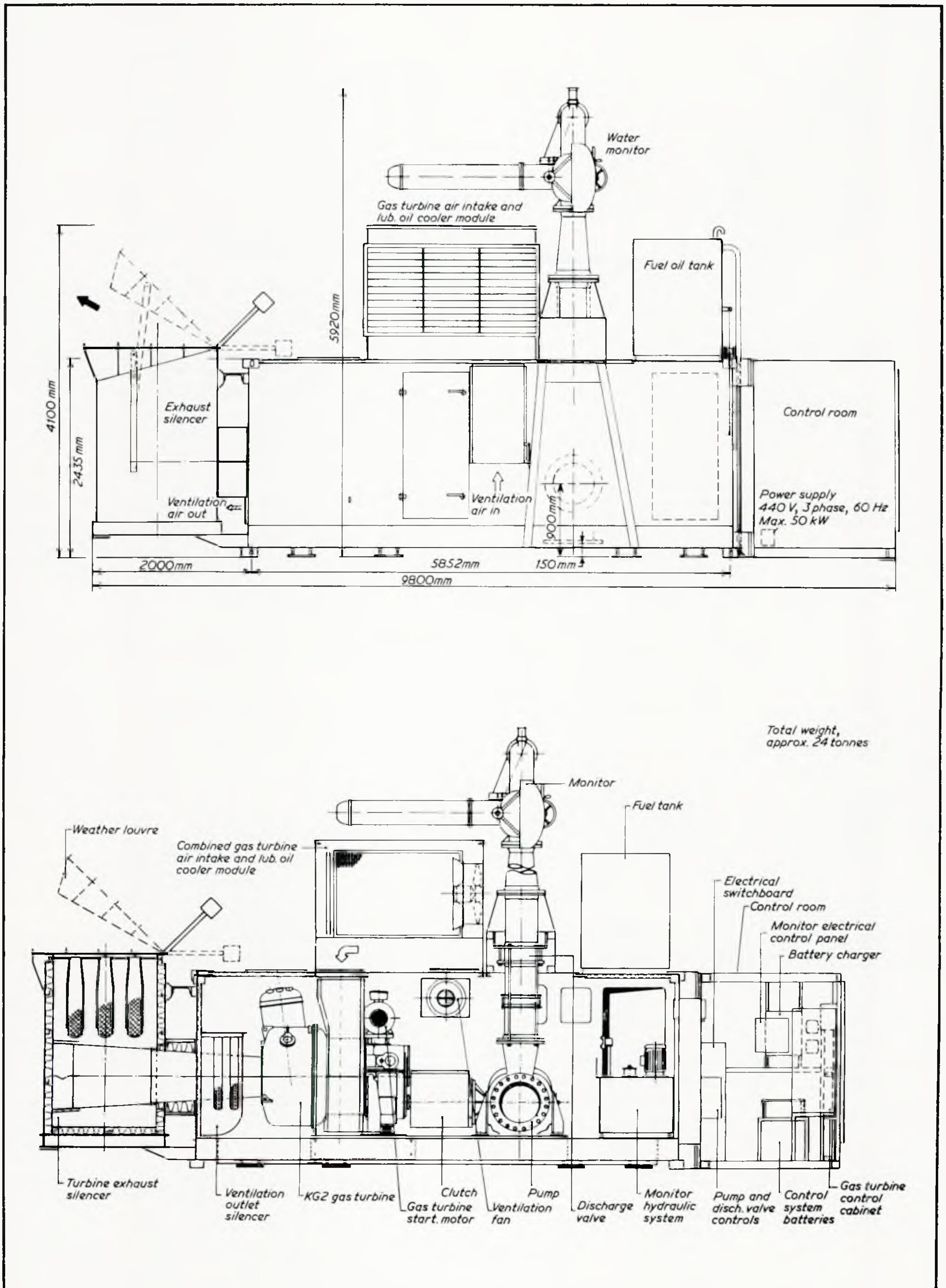

FIG. 8. Containerized firefighting package, external and sectional view

Seaway Falcon, for instance, has been in major firefighting operations three times since entering service in 1975:

i) *Ekofisk Alpha* platform fire, October 1975. A gas test pipe leak ignited and set fire to the platform. The vessel arrived within 15 minutes, the fire was extinguished in less than an hour, and in all nearly 30,000 tonnes of water were projected including precautionary spraying after extinction of the fire. The water damage to electrical wiring, furnishings etc. was considerable, but there was little or no structural deformation and the platform was out of full operation for less than five months.

ii) *Ekofisk Bravo* blowout, April 1977. Again the vessel was quite close at hand and provided a continuous water curtain, usually using two of its monitors over the platform to lessen the risk of explosion and ignition for the 10 days it took to cap the well. Approximately a million tonnes of sea water were pumped.

iii) Jack-up rig *Maersk Explorer* blowout and fire, October 1977. The vessel was called to this fire in the Danish sector of the North Sea from her normal station in the Ekofisk field. The fire was quickly extinguished and the vessel withdrew leaving another smaller capacity vessel to continue precautionary spray.

All these occurrences were in relatively good weather, and none required the continuous platform cooling duties, for perhaps months, which are often predicted as the maximum duty when specifying the firefighting requirements.

Lessons which can be learned from these outbreaks are:

a) proximity of the vessel or, alternatively, speed of passage to the fire, is of the utmost importance.

b) large capacity water dousing can prevent structural deformation even in the face of quite extensive fire, and can also prevent ignition of a lengthy well blowout.

c) the gas turbine has proved a satisfactory means of driving the firefighting system in terms of speed of response, reliability and acceptability to the operators.

AREAS REQUIRING FURTHER STUDY

Although the modification of existing vessels to accommodate a firefighting facility on board continues to provide the oil industry with a number of firefighting vessels more swiftly than would be possible from a new building, a growing number of new vessels of different types are now being fitted with large capacity systems as part of their original equipment. There is obviously a temptation for the machinery installation designer to economize on the power plant required for propulsion, for conventional auxiliary power demands and for firefighting, by combining the systems, by such means as:

- firefighting pump drive from a power offtake or its reduction gearbox;
- electrically driven firepumps with electric power supplied from the vessel's main generators, particularly in diesel-electric propulsion systems.

Considerable care is required in the evaluation of such systems, and among the factors which must be considered, and which may point to the fitting of an independent source of power for the firefighting system are:

i) the relative size of the power required for propulsion and that for firefighting results in a large increase in the main power plant to be installed if a combined system is envisaged, unless a considerable reduction in the power available for propulsion is to be accepted when the vessel is firefighting. This reduction is a problem from the point of view of accurate station keeping in an emergency situation, and this is particularly relevant on dynamically positioned vessels where, to gain the full advantage offered by such a system in speed of response and accuracy of location, the full propulsion and positioning power should be available.

ii) in any combined system, the possibility of a failure in one part of the system incapacitating the whole system must be considered. On a semi-submersible, for instance, with a diesel-electric central power generation plant supplying main propulsion, manoeuvring propellers and firefighting system, considerable safeguards must be provided to limit starting currents and prospective fault levels, to provide automatic isolation of different switchboard sections, and in general to ensure that a fault or an overload in, say, the firefighting system, does not black-out the entire installation. The alternative, of choosing for the firefighting equipment an independent prime mover which can operate in isolation from the rest of the vessel's systems, is therefore an attractive one, and is an application for which the radial gas turbine can be used with advantage in view of its capability for almost self-contained operation.

An additional alternative, when the concept of the separate power supplies for the propulsion/manoeuvring system and the firefighting system has been accepted, is to consider the gas turbine driven units in a dual firefighting/emergency generator role, by fitting combination pump/generator units. In such a unit, one of which has been in service on the semi-submersible *Seaway Swan*, the standard gas turbine driven pump set as shown in Fig. 2 is modified to become, in effect, a gas turbine driven alternator with the clutch drive to the pump mounted on the "free" end of the alternator. In the *Seaway Swan* installation the set operates either as a 1500kw gas turbo-alternator with the clutch disconnected, or as a 4000m^3/h firefighting pump set with the generators electrically isolated, but alternatively the set can be arranged to supply power to both the generator and the pump simultaneously. Fig. 9 shows an arrangement for a semi-submersible requiring a capability of 9200m^3/h, where the set also provides the electrical power necessary to drive the water supply pumps located in the vessel's lower pontoons which lift the water to working deck level. With the clutch pump disconnected each set can also operate as a gas

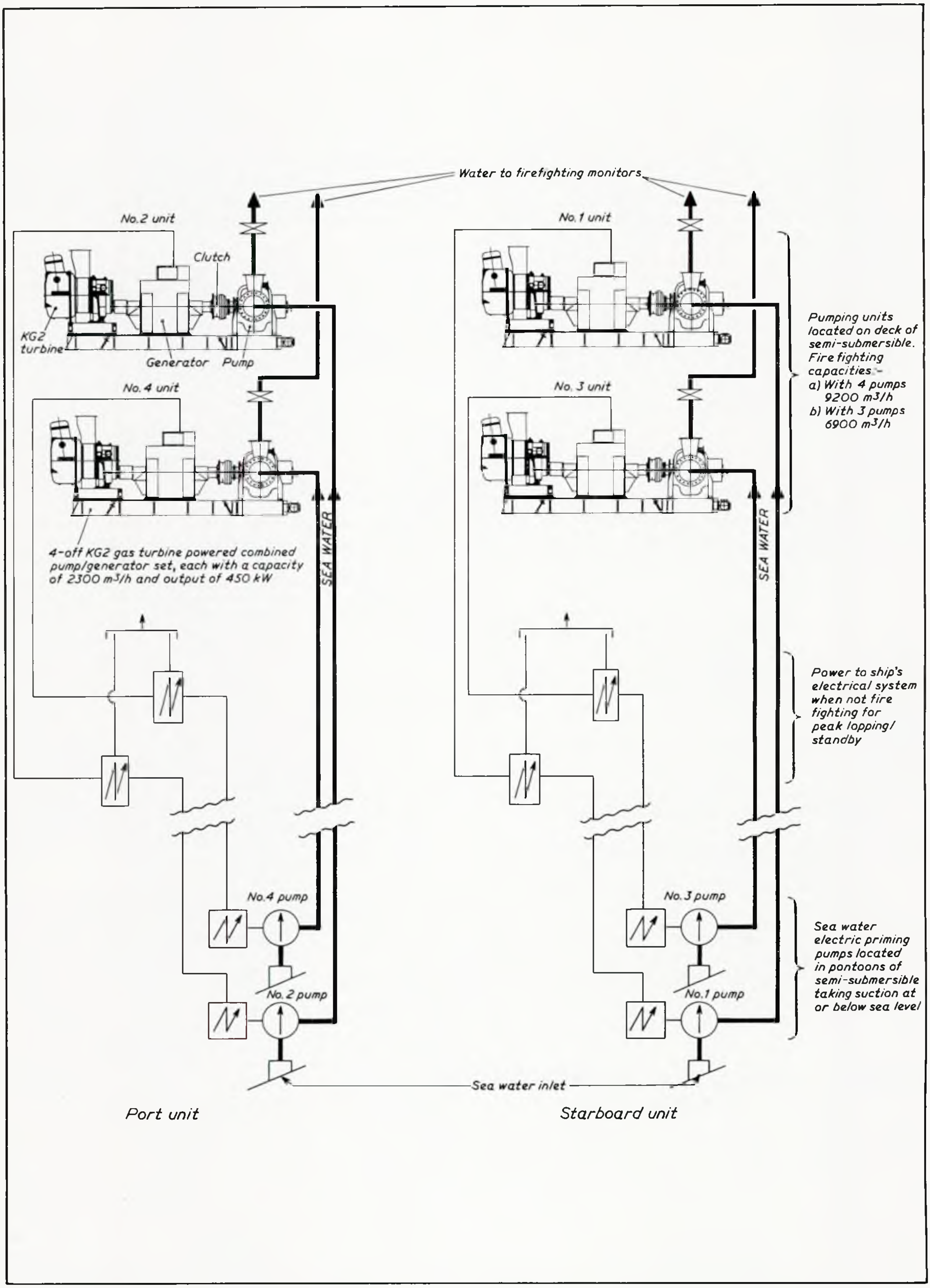

FIG. 9. Application of the combined gas turbo-alternator/pump set to a semi-submersible firefighting system

turbo-alternator to supply emergency power to the vessel's main distribution system.

Among other areas worthy of further study and evaluation in the field of offshore firefighting systems are:

a) identification for the operator of where the water is actually falling. Although careful choice of the position of the central monitor control point can assist in minimizing the extent to which the random spray from the jets obscures the view of the target area, further assistance to the operator may be necessary. Among the facilities which have been considered and which in some cases are already in operation in the field are:
   - closed circuit television from a suitable elevated vantage point back to the central control position;
   - computer simulation and display of the jet trajectory on, for instance, the dynamic positioning system display screen;
   - motorised spotlights mounted adjacent to the monitors and controlled to follow automatically the path of the jet, to show up the target area, particularly, for instance, when fighting an un-ignited blowout at night.

b) more detailed and specialized training of the operators in the emergency procedures, the firefighting theory and the actual operation of the equipment at their disposal on board.

c) further consideration, as the size of the vessel on which firefighting systems are located increases, of the positioning of the monitors in relation to the direction in which the vessel will normally lie when firefighting. If the monitors are located approximately at the mid length, with the vessel upwind of the fire and head to wind, there is a considerable proportion of the vessel lying between the monitors and the fire, and this must be considered from the two viewpoints:
   - at least one of the Classification Authorities requires the range of the jet from the monitor to be measured not from the monitor itself but from the nearest point on the vessel to the point of impact of the water.
   - both major Classification Authorities specify self-spraying capabilities to be provided onboard, the capacity of which is calculated on the vessel's vertical surface area, but with, say, a supply vessel lying stern to the fire there may be a considerable expanse of deck projecting towards the fire which may need additional protection.

CONCLUSION

The utilization of the marine radial gas turbine as the prime mover for a shipborne offshore firefighting system has made possible the provision of a compact and reliable system with the maximum practicable capacity from a given space on board the vessel.

REFERENCES

1. Guidelines for the Construction and Classification of ships intended for firefighting in offshore structures and other facilities, May 1977. *Det Norske Veritas.*

2. Rules for the Construction and Classification of Firefighting Ships; Part 7, Chapter 3. *Lloyds Register of Shipping.* Issued 1979.

3. Revised Guidelines for the Construction and Classification of ships intended for firefighting in offshore structures and other facilities. Draft issued June 1979. *Det Norske Veritas.*

4. Fire control system tests on board *Seaway Falcon.* Report G77/2-8319. *Published by A/S Kongsberg Vaapenfabrikk.*

5. Dunton, S. H., 1976. "Design and Application of an All-Radial Industrial Gas Turbine". *Diesel Engineers and Users Association, London.*

6. Buchanan, G. I., 1977. Marine Auxiliary Gas Turbines. *Trans I Mar E, Vol.* 89, *pp.* 122 *to* 144.

Discussion

MR. K. J. RUTHERFORD, BSc, CEng, FIMarE (BP Tanker Company Ltd.) commented that the author had described the developing area of offshore firefighting with particular reference to monohull vessels having gas turbines as the fire pump prime movers.

He supported the author's comments on the need for more published data on monitor performance, especially in adverse weather conditions. The monitor manufacturers had now been made aware of the desirable performance parameters for large fire monitors and some had actually demonstrated their capabilities. Unfortunately, such demonstrations had not settled the debate whether high nozzle pressures or high monitor throughputs, or both, were the important factors in obtaining reasonable drenching of a stricken installation in winds up to Beaufort Force 8 or 9.

Many fire monitor installations currently available to oilfield operators required the vessel to stand in very close to the production platform in order to drench the drill floor areas effectively. In realistic sea conditions, that required either good dynamic positioning capability or a Master with an iron nerve. Where the fire monitors were mounted on monohull vessels, manual control of the monitors could place a great strain on the operator and in such applications, an automatic targeting system could usefully be applied to monitor control.

Little provision was made in many firefighting vessel installations for water to be adequately directed under the platform lower deck to cool the supporting structure and risers. It was those areas, rather than the modules, which required preservation in the long term.

Many existing firefighting vessels were not adequately equipped to face the possible magnitude of the heat radiated from an oil fire, even with the vessel upwind of the fire; or of the likely existence of gases evolved from the blow-out, most of which were heavier than air. The oil platforms shut down when a blow-out occurred, but firefighting vessels were expected to go in to rescue the platform personnel and to provide drenching of the structure.

He would, therefore, value the author's comments on the provisions made in the design of the containerized unit discussed in the paper, in the following areas:

1) ***Operation radiant heat:*** what was the effect of high ambient air temperature on the turbine output? What provision had been made for external drenching of the container and to prevent water ingress from the vessel's drenching mains into the container ventilation system and into the turbine air intakes?

2) ***Operation in a potentially explosive environment:*** the gases expected to be evolved from a blow-out had self-ignition temperatures in the region above 200°C. What provision had been made for cooling the exhaust at exit from the container, and for keeping all exposed surfaces within the container to below 200°C?

   How was turbine speed controlled, and shut-down effected, when high concentrations of petroleum gas had been ingested? By what means could the container be made gas-tight and what provision was made for gas detection? Were the electrical components of the package suitably certified for use in a petroleum gas environment?

3) ***General comments:*** the fuel consumption had not been mentioned in the paper, could the author give an indication of fuel consumption at sustained half load and full load, and also state which grades of fuel would be burned?

   Was an internal fire detection and extinguishing system installed? Were any means provided for taking alarms and engine control to a remote position, or did the container have to be continually attended?

Mr. Rutherford's own investigations had led him to believe that, in general, built-in gas turbine pumping or generating sets offered fewer advantages than diesel-driven units for anything other than vessel emergency sets, despite the well-known disadvantages of diesel engines. When compared with diesel engine installations, gas turbines required increased size of air intakes and exhaust trunking; had increased fuel consumption and, therefore, required increased tankage; and had increased exhaust gas temperature and volume, making waste heat recovery desirable but difficult. When taken overall, a gas turbine did not show a significant weight saving over a diesel engine installation.

MR. G. COGGON (Lloyd's Register of Shipping) felt that the choice of subject had been timely since, under the pressure of the possibility of a major catastrophe in the North Sea, the development of firefighting ships had been proceeding rapidly.

Lloyd's Register had produced Rules for two classes of firefighting ships, but had since realized that Rules for a third and larger capacity vessel were necessary. To that end they were consulting with the industry in order to produce requirements which would be both helpful and realistic.

The paper had been concise and easy to read, but could have been improved by the inclusion of a definition of the conditions in which the ships were required to operate, e.g. what heat might be expected to be radiated from a blow-out fire and what concentrations of flammable and toxic gases might be expected. That was very important because those conditions governed the choice of equipment required.

It was Lloyd's opinion that, to be really effective, a firefighting ship should be provided with a water-spray system over all the vertical and some horizontal surfaces. The author had mentioned that, but had not passed any opinion. Such an opinion would be most welcome.

The author had mentioned dynamic positioning. In Mr. Coggon's view that would be almost, if not altogether, essential if one was constantly to hit the target with a jet of water at a range of 100 to 200 m with the ship moving in all weather conditions, by both day and night. He would be glad if the author would comment on that.

The author had also referred to the means of controlling the monitors, but had not passed an opinion as to whether or not they should be remotely controlled. Mr. Coggon believed they should be remotely controlled in order to enable the vessel to approach a burning or gas-surrounded platform to rescue personnel or to deal with an Ekofisk type situation.

The use of containerized firefighting packages suggested interesting possibilities involving flexibility, provided care was exercised regarding the strength of the deck on which they were to be placed. However, the unit illustrated in Fig. 8 could be hazardous in a gas-dangerous area, since the unit exhausted directly to atmosphere.

It seemed a pity that the paper had been based to such a large extent on *Seaway Falcon*, including the results of tests held in 1975. Many developments had taken place since that date and it would have been more interesting to hear of the latest developments in the much larger semi-submersible type facilities.

DR. A. P. HATTON, FIMechE (UMIST) wished to comment on the influence of water pressure, flow rate, nozzle diameter etc., on the trajectories of large water jets. The author had rightly stated that further work was necessary to elucidate those effects but Dr. Hatton would like to draw attention to some recent work which had attempted to answer those questions.

In a recent paper* by himself and Dr. M. J. Osborne of Knowsley Engineering Ltd., a computer simulation of jet behaviour had been described which used empirical drag information obtained from other workers' experiments on vertical jets. The analysis showed that, for maximum range, an optimum pressure existed for a given flow rate. That effect was caused by the increase of drag per unit of flow as the jet diameter reduced with pressure increase. The smaller diameter, high speed jet lost its momentum more rapidly and would not carry as far as a larger diameter jet at the optimum pressure. Wind effects had also been investigated and a survey of earlier experimental work had been presented.

With regard to nozzle shape, that had been a perennial subject for argument since Freeman had presented his classic paper on fire streams in 1889†. In order to throw further light on that question, to verify the simulation and, in addition, to prove a commercial advanced monitor design, a comprehensive test programme was recently carried out by Knowsley Engineering Ltd. and Worthington Simpson Ltd., in conjunction with UMIST and BSRA. A total of 270 runs were made with jet trajectories measured photographically against a surveyed background. Many nozzle shapes were tested, amongst them the design proposed by Hunter Rouse† when he carried out his extensive tests for the US Coast Guard in 1951. That nozzle had consisted of a circular arc convergence to a 60° included angle cone exit. It was claimed that the resulting acceleration from the nozzle exit to the *vena contracta* would iron out the turbulence and any boundary layer effects. There was evidence that the nozzle gave improved performance at low pressure (<3 bar), but the tests at BSRA showed the Rouse design to be markedly inferior to other designs with regard to both range and coherence. Most of the earlier work† had been carried out on small jets (up to 1 in dia.) and it could be shown that it could not be extrapolated to jets of the sizes recently tested at BSRA (over 6 in dia.). It was hoped to report those tests in due course, although certain of the results achieved were currently confidential.

* HATTON, A. P. and OSBORNE, M. J., 1979, "The Trajectories of Large Firefighting Jets", *Int Jnl of Heat and Fluid Flow (I Mech E) Vol* 1, *p* 37.
† Details of these references appear in Hatton and Osborne.

MR. I. SUTHERLAND (Gilbert Gilkes & Gordon Ltd.) had several questions to ask:

1) As there were no pump curves included in the paper, could the author indicate:
   a) concerning pump rotational speed, if there was a gearbox between the pump and turbine;
   b) at the design point where the pump was operating on its performance curve relative to the best efficiency point;
   c) what the turbine's continuous output rating at the design operating speed was, and how that compared with the pump-absorbed power at that speed?
2) What was the fuel consumption of the turbine for 24 hours' operation at the pump's design point?
3) What was the time taken to obtain design output from the pump when starting with a cold turbine?
4) Were vessels of the *Seaway Falcon* type sufficiently stable in average North Sea conditions to keep the water jet on target?
5) Was there any conflict with the firefighting role of a vessel which also had divers in saturation? The divers might be dependent on the vessel for life support for up to five days depending on their working pressure, etc.

Author's Reply

The author was indebted to Mr. Rutherford for his valuable contribution and comments on the design requirements for a firefighting vessel, particularly in view of his own Company's involvement in platform operation and in the construction at present of a major semi-submersible with a powerful firefighting capability, which had been described in Mr. Rutherford's paper on the Platform Emergency and Support Vessel.*

With reference to Mr. Rutherford's remarks on fire monitor automatic stabilization, it would be appreciated that the mention in the same paragraph of the advantages of a dynamic positioning system was significant. The capability of providing monitor stabilization already existed (and, indeed, the author's Company was currently involved in vessels which would be fitted with such a system) and the provision of the necessary data to the monitor stabilization system, such as pitch, roll, lateral movement etc., was simplified on a dynamically-positioned vessel, where those parameters were already being monitored. Further interfacing of the water monitor and dynamic positioning system could also be effected by the provision of monitor thrust compensation, whereby the vessel's thruster allocation would be automatically adapted to counteract the thrust reaction from the monitors before it could push the vessel off station.

Turning now to the specific queries raised by Mr. Rutherford, the effect of high ambient air temperature on turbine performance was, of course, well established and all gas turbine manufacturers published graphs or tables showing the reduction in power for the turbine with increased ambient air temperature. That performance loss was a thermodynamic fact of life, experienced by all internal combustion engines, although the gas turbine's high air/fuel ratio made it more susceptible. There were some measures that could be adopted to minimize that effect, which in the case of the 1670 kW gas turbine referred to in the paper amounted approximately to a loss of 9 kW for every one degree centigrade rise in ambient. Those measures included:

1) Arranging the gas turbine air intake to face away from the direction in which it was most likely that the effect of the radiant heat from the fire would be felt. The case of the containerized unit described in the paper, which might be mounted on the vessel in a variety of attitudes, such as fore-and-aft, athwartships, or diagonally, involved some assumptions on the most likely ultimate position and on the likely positioning of the vessel when firefighting.
2) Paying careful attention to the rating of the gas turbine and to the selection of pump type, speed and characteristic, to provide flexibility in the ambient conditions in which the unit was capable of meeting the specified performance. It would be folly, for instance, to select for a given duty, a gas turbine capable of developing the required power only at a low ambient, or to select a pump speed and characteristic that resulted in a steep loss of performance off the specified design point. Consequently, it was the practice in the author's Company to calculate gas turbine ratings for firefighting applications at a higher ambient than for other applications and to study the pump characteristics to ensure that marginal loss in gas turbine output would not result in disproportionate fall off in pump performance. Quotation of specific figures was difficult unless the sphere and type of operation was accurately known, but in some recent North Sea applications, where 15° would be the normal ambient for evaluating gas turbine rating, 25°C was used for the firefighting equipment.

External drenching of the surface of the containerized unit could be provided and had been fitted on some installations. It consisted essentially of a perforated spraybar running round the top edge of the container structure with the hole size and pressure in the pipe calculated to provide the water flow/m^2 of exposed area recommended by the Classification Societies. It was preferable to supply this water from a source on board other than the containerized water pump because

i) The pressure required in the spraybar was considerably lower than that required for the firefighting monitor.
ii) There might be instances where external drenching of the container surfaces, together with other parts of the ship's superstructure, was required when the main firefighting monitors were not, such as when taking the vessel in close to a structure to rescue personnel.

Ingress of the drenching water into the gas turbine air intake, the ventilation system, and the container itself, was prevented by

a) careful positioning of the spraybar and its holes;
b) provision of adequate weather louvres on the intake openings;

c) provision of the modular air intake water separation panels described in the paper.

It must be appreciated that those containerized fire-pump installations were successors to a number of containerized gas turbine generator installations on which considerable experience had been gained in successful operation in a salt spray environment. The additional spray present in a firefighting application, coming from the monitors themselves, had also been experienced for some years now, so that the additional water from the drenching system did not pose too much of a problem.

With reference to the questions raised by Mr. Rutherford regarding operation in a potentially explosive environment, there were two distinct areas referred to:

a) ignition of an explosive atmosphere by hot exhaust gas or a hot surface;

b) the threat of gas turbine run-away due to ingestion of combustible gas in the air intake.

No special measures were taken to cool the exhaust gas flow. In fact, experience showed that, due to a combination of the exhaust silencer configuration and the rapid cooling which took place on efflux from the silencer (due to what was, in effect, swirl mixing with the colder air), the temperature a relatively short distance from the exit from the silencer had dropped to a level which rendered it safe even for adjacent personnel. That was illustrated by the exhaust arrangement on many containerized installations in which the exhaust gases were released at little more than head height on the working deck, often ducted almost horizontally, with no adverse effect on the personnel on the working deck. Furthermore, the containerized generator set installations at sea were cleared for open deck operations on tankers where potentially explosive atmospheres, particularly during tank cleaning, might exist. An added feature was that such was the clarity of the exhaust and so complete the absence of carbon carry-over that operation of the equipment in those sensitive conditions without spark arrestors was also approved by the Classification Societies.

A stagnant gas mixture which contained significant quantities of heavy hydrocarbons could have auto-ignition temperatures in the region of 200°C, as mentioned by Mr. Rutherford.

The ignition temperatures for most natural gases were appreciably higher, typically in the range 400 to 600°C. In gas turbine installations ventilation was provided and that further increased the ignition temperature.

In the author's opinion, no prime mover could be expected to operate safely in an explosive environment if the combustion air had to be ingested from the explosive gas-air mixture and exhaust gases exited into the explosive atmosphere. However, a special installation could be engineered such that, even if the turbine were situated in an explosive atmosphere, the combustion and ventilation air could be taken from a "safe" area and the unit could be operated safely. It might also be noted that in nearly all situations involving a gas blow-out it would be possible to shut down the gas turbine in a controlled manner without any damage.

The details of the gas turbine performance at various loads had been covered in a previous paper† but for guidance the fire control package described in the paper consumed approximately 0.8 tonnes/h of fuel for an output typically of 3000 tonnes/h of water against a head at the monitor of 120 m w.g. Part load figures were of course not relevant in a firefighting application, since the gas turbine had only three steady-state conditions in such applications: stopped, idling when declutched from the pump, and full pumping output against a constant head.

As far as the acceptable grades of fuel were concerned the full range of distillable fuels were satisfactory, down to Marine Diesel Class B2, which often contained mixed residuals. The turbine in summary normally operated satisfactorily on the same fuel as that consumed by the vessel's diesel generators (except on those relatively rare vessels where the generators were arranged to operate on residual fuels). On specific applications, the turbine could be arranged to operate on residual fuel with suitable derating and adjustment to overhaul times but, in general, for marine firefighting applications it had been found that the standard fuel already available on board for other uses was well within the turbine fuel specification.

An internal fire extinguishing system was not fitted in the container as standard but could be without difficulty, and some existing containerized applications were fitted with such a system. Typically, the system comprised both rate-of-temperature rise and infra-red detecting units in the machinery compartment, with infra-red detection in the control room. Detectors were cross-coupled to ensure that two were necessary to set off the system automatically, one detector only operating the alarm. Halon 1301 was a typical extinguishing medium, stored in a bottle located in a convenient position such as the control room. The ventilation openings into the container were fitted with spring-loaded shut-off doors which shut automatically on discharge of the extinguishing system to prevent egress of the medium. Alarms were provided internally to ensure that any personnel in the compartments were warned of the operation of the system, and externally to notify personnel elsewhere that it had operated.

The container did not have to be continually attended in operation and provision could be made for varying degrees of remote control and indication ranging from local starting with a single remote group alarm indication, to remote start/stop and alarm indication.

Whilst noting Mr. Rutherford's concluding summary of his views on the application of gas turbines for both marine generation and pumping applications, it should also be pointed out that of the 500-plus applications of the specific gas turbine referred to in the paper, approximately 120 of those were on board ship for generating or pump duties. Whilst the author agreed that application to marine baseload power generation of that type of prime mover was seldom practicable, the above installations bore witness to the feasibility of utilizing the machine with advantage for standby, peak lopping or emergency applications on a wide variety of vessel types, details of which were described in a previous paper.†

With reference to the specific objections listed by Mr. Rutherford:

1) The effect of the size of the air intake and exhaust equipment was second order in machines of the power range in question, and could be minimized by attention to machinery location e.g. location higher in the vessel made possible by reduced auxiliary system requirements and reduced weight.

2) The fuel consumption was undoubtedly higher than a comparable diesel engine and, while that was important, it assumed a lower level in the order of priorities for standby or emergency equipment.

3) Utilization of the exhaust heat could have, and had, been effectively carried out with that machine and

could achieve overall efficiencies in the range of 70 to 80 per cent. Exhaust heat utilization of that type was seldom feasible in a marine application because:

i) the requirements for auxiliary steam were usually better correlated with main engine power variations than those of auxiliary electric power;

ii) with the auxiliary gas turbine cast in a standby or emergency role, its utilization did not justify the provision of the ancillary waste heat system.

The gas turbine under consideration in the paper showed weight and space savings for the applications in question when compared with any diesel engines of commensurate power. The savings of course decreased as the speed, complexity and degree of supercharging of the diesel being used as comparison increased.

A typical diesel engine put forward on a number of occasions for the firefighting duty, for which the Kongsberg Ku-2 frame size of gas turbine had been used, had the following characteristics: 16 cylinders, four valves per head, Vee form, running at 1500 rev/min, with an output of 2240 metric h.p. When comparing dimensions, the results were:

	Length (m)	Height (m)	Width (m)	Weight (kg)
Gas turbine	2.0	2.2	1.4	2600 wet
Diesel engine	3.1	2.4	1.7	8400 dry

The diesel engine was relatively highly rated, had two turbochargers and an intercooler, and represented a basically different philosophy of design, in terms of:

- complexity and, therefore, reliability;
- acceptability of fuel type variation;
- overhaul time and skill required;

compared with a single-stage radial gas turbine in which nothing had been done to compromise its basic aims of simplicity and reliability.

Turning to Dr. Hatton's contribution, it was very encouraging to find that systematic and scientific investigation was being concentrated on the question of large capacity water monitors, and the author was grateful to Dr. Hatton for his summary of current progress. He looked forward with interest to the publishing of the results of the UMIST/BSRA trials. That work would fill a gap in the available knowledge of the topic and hopefully remove the responsibility assumed by the author's Company for investigating monitor/pump set performance in the mid-1970s, since it was a task better suited to the manufacturers and designers of the monitors than those of the prime movers for such a system.

With reference to Mr. Coggon's comments, the participation by the Classification Societies in the offshore firefighting discussion was welcomed in that, by establishing a series of classification levels for firefighting vessels, they had simplified the prospective shipowner's task in specifying the vessel he required, and also the vessel charterer's task in defining the capacity and type of firefighting capability he needed for his platform.

Whilst accepting Mr. Coggon's comment that the paper had not included a definition of the conditions in which the ships were required to operate, it could be argued that, as equipment designers and suppliers, they could justifiably look for such a definition either to the oil companies and platform operators who wanted the vessels to protect their investment, or to the Classification Societies who laid down the criteria by which firefighting vessels were to be evaluated. The fact was that, apart from the standard requirements for any offshore service vessel operating throughout the year in the North Sea, there were no commonly agreed criteria covering the emergency situation of a blow-out or large-scale platform fire and detailing radiant heat levels, gas concentrations etc. Therefore any contributions from, for instance, the oil companies' offshore safety managers, to provide such data would be very useful to all those involved in the design, equipping, and classification of the vessels to operate in that environment. With reference to Mr. Coggon's request for an opinion on the necessity of water spraying over exposed superstructure, he again felt that was more a question for the fire engineers or for the platform operators who might have some first-hand experience of the conditions likely to be experienced. However, although in those instances where the equipment described in the paper had been used in dealing with real life emergencies, no spraying of the superstructures was required (and in fact was not fitted), it nevertheless seemed a prudent provision requiring minimal additional cost. An additional consideration, particularly on those vessels with superstructure well forward and monitors mounted on the superstructure pointing aft, was that there was a large expanse of deck projecting towards the fire and it might be felt necessary to provide spraying of the deck surface as well, as had been fitted on at least one of the vessels with the equipment described in the paper.

As far as the necessity for dynamic positioning was concerned, the author must of course declare his interest in that his Company was also very much involved in the design and installation of dynamic positioning systems, several installations being on vessels with firefighting systems. The provision of a DP system simplified the problem of reaching and maintaining station for the vessel, and could, by combining DP with monitor stabilization, greatly increase the accuracy of monitor aiming. It was also possible to have a "stand-alone" monitor stabilization system. One should not, however, decry the usefulness as a first-aid vessel fitted perhaps with a containerized firefighting system, which, because of its everyday role was not fitted with DP but which nevertheless could carry out an effective and essential task as a stop gap, until the larger firefighting vessel arrived to provide long-term water spraying.

Remote operation of the monitors had been more often provided in the past because of the physical difficulties in manually operating the large handwheels, two per monitor, than from a desire to remove the operator from the vicinity of the monitor. It followed, however, that the central grouping of the monitor controls at a well-protected vantage point, preferably close to the vessel's control room or wheelhouse, led to a more effective system. It must also be mentioned that the provision of an electro-hydraulic remote control system doubled the cost of the monitor, and that at least one major British semi-submersible operating as a multi-purpose offshore service vessel had large-capacity, manually-controlled monitors. It could well be argued that, from the aspect of operator safety, large capacity monitors on a semi-submersible with a jet range of 200 m represented a basically different operator environment from smaller capacity monitors on a monohull vessel which might have to position itself considerably closer to the fire to be within range of the monitors. It therefore followed that it was not realistic to predicate a single requirement on remote control to cover the full range of possibilities for size and manoeuvrability of the vessel and the capacity and range of monitors.

Mr. Coggon's comment on the gas turbine exhaust in the context of the hazard of an explosive atmosphere was covered in the reply to Mr. Rutherford. The criticism of the use of data from *Sea Falcon* in 1975 was noted. Those trials were to his knowledge the first carried out with monitors of that size at sea, and the conclusions drawn from them had formed the basis of all the designs of subsequent installations of that type of equipment. Similar trials had subsequently been carried out, and the results published to the industry, on a number of vessels including *Capalonga* (1976), *Smit Lloyd 2* (1977) and *Stad Sea* (1978) for a variety of combinations of water flow and monitor pressure. Those results extended, but in no way contradicted, the principles formulated after the *Seaway Falcon* trials. Those four sets of trials still represented, to his knowledge, the only widely-published records of extensive performance trials on actual firefighting installations.

Mr. Sutherland had raised a series of succinct technical queries, some of which had been touched on by previous contributors but which the author would attempt to answer in their order of presentation.

1a) ***Pump rotational speed***—this depended on the capacity and type, and also whether it was necessary to drop the speed to enhance the suction lift capabilities for on-deck installations. The range of pump speeds of the specific applications covered in the paper was from 1145 to 1800 rev/min. There was a reduction gearbox as an integral part of the gas turbines—the turbine rotor speed was 18,000 rev/min which was reduced by that gearbox to the required pump speed.

1b) ***Pump design point.*** In selecting the pump design point, and indeed the pump frame size itself, it was necessary to optimize between capacity, power required, pressure head, and suction capability, so the selection of a design point exactly on the peak of the efficiency curve was not always practicable. However, in the majority of cases the selected point represented a divergence of less than 3 per cent from maximum efficiency, since the pump efficiency curve was fortuitously fairly flat for the single-stage centrifugal pumps in question.

1c) ***Relationship between turbine power and pump power required.*** The continuous rating of the turbine was, for broad specification purposes expressed as:

- 1670 kW at 15°C ambient and no intake or exhaust losses for utilization up to 1500 h/yr;
- 1470 kW at the same ambient and no losses for over 1500 h/yr;

the actual power calculated to be available for the pump included allowances for:

- intake and exhaust pressure loss in the specific installation;
- derating to allow for increased ambient temperature due to radiant heat from the fire;
- a straightforward contingency margin in recognition of the essential and emergency nature of the application;

and for a typical installation in a temperate environment would result in an available power at the pump of about 1373 kW.

2) ***Fuel consumption*** for 24 hours at full output on one pump set was about 19 tonnes. Depending on the capacity/head relationship for the specific pump that could represent between 54,000 and 96,000 tonnes of water during that period.

3) ***Time to develop full output.*** Using the normal starting routine for remote operation:

- initiate gas turbine start and run up to approximately 75 per cent speed;
- engage pump clutch;
- open pump discharge valve;

full output from the pump would be available within 60 seconds.

4) ***Target accuracy of jets*** from a vessel such as *Seaway Falcon*. It of course depended on Mr. Sutherland's definition of "sufficient", on the size of the target and on the dexterity of the man on the joysticks controlling the monitors. In those fires in which *Seaway Falcon* had been involved, the accuracy had been more than adequate, but in each case the weather at the time was, by North Sea standards, relatively calm. For the *Ekofisk Bravo* blow-out incident, not only was the weather calm but the vessel's role in any case was to provide an all-enveloping spray to dampen the entire structure and atmosphere, so a degree of monitor swaying would have been acceptable.

5) ***Possible conflict between firefighting and diving.*** The only prospective conflict in the installation design was in the demands of the firefighting systems and the diving support system on the auxiliary power generating capabilities of the vessel, assuming that steps had been taken to retrieve the divers and locate them on board as soon as the fire emergency was signalled. The outstanding advantage of the gas turbine driven pump sets described in the paper was the small requirements of the gas turbine in terms of the auxiliary services needed to start and run the pump sets when related to the power developed. There should, therefore, be no conflict when operating the firefighting system, with the divers' life support system or, indeed, with any other of the vessel's essential services in the emergency situation. Several such firefighting systems were fitted on vessels arranged for diving support duties for saturation diving. There was, however, a prospective operational conflict between the diving support duty and the firefighting duty. On the one hand, if the fire emergency occurred while divers were working from the ship there would be an inevitable delay in deploying the vessel as a fire-fighting ship while the divers and their gear were retrieved and relocated on board. Additionally, if divers were in the decompression chamber on board there must be a question mark over the advisability or acceptability of deploying the vessel in a potentially hazardous environment for fire-fighting while the divers were thus incarcerated. There was no easy solution to such a situation: transfer of the divers of the vessel while still under compression was a possibility, but the potential coincidence of a fire on a platform with those diving operations represented one disadvantage in the comparison of the diving support vessel with other vessels when evaluating which vessel type to select as the vessel for the "first aid" firefighting equipment.

The author would like to thank all those who contributed to the discussion of the paper, and several colleagues in Kongsberg who contributed not only to the preparation of the paper but to the answers in the discussion.

* RUTHERFORD, K. J. and GIBBONS, D. J., 1980, "Machinery System Design for a Platform Emergency and Support Vessel", *Trans I Mar E (TM)*, *Vol* 92, *Paper* 10.

† BUCHANAN, G. I., 1977, "Marine Auxiliary Gas Turbines", *Trans I Mar E*, *Vol* 89, *Series A*, *Part* 4, *Paper* 2, *pp* 122-44.

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