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TRANSACTIONS (TM)

THE ENGLISH STAR CLASS OF REFRIGERATED CARGO VESSELS

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The *English Star* Class of Refrigerated Cargo Vessels

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SYNOPSIS

This paper deals with the evolution of the English Star *class of refrigerated cargo vessels. The commercial background which led to the technical decisions on capacity, dimensions, layout and performance characteristics is outlined. The close relationship between the naval architectural and marine engineering features is described. These features are mostly evolutionary rather than revolutionary in character and represent a significant step forward in the 'efficient ship' concept in terms of manning, operation, fuel consumption and performance. A detailed description is given of the refrigeration and machinery installations, followed by particulars of trials performance and a commentary on the experience gained with the first vessel of the class during its initial year in service.*

INTRODUCTION

The concept

The commercial requirements of the specialized reefer trades cover a wide range of factors which demand difficult decisions from both the shipowner and the shipbuilder when designing a new class of vessel.

The optimum ship size, in terms of minimum costs per ton mile, needs to be balanced between servicing the deep-water automated ports on the one hand and the restricted shallow-draught ports of the tropical fruit sector on the other. A principal requirement is an economic service speed, but the vessel must have reserves of power for the trade in high-value perishable products, which needs both the grower's loading schedules and the shipper's commercial deadlines to be met with absolute reliability.

The refrigeration capacity must be designed to provide the safe carriage of different products with flexibility and precise temperature control. It must be capable of quickly reducing the temperature of fruit loaded at a high ambient temperature to the carrying temperature with a large margin of system redundancy.

All these objectives, within the equally important framework of least capital and ongoing operating costs, require compromises, but compromises in which reliable service to both the trades and the shipper must always take priority.

H. E. Tune served an Engineering Apprenticeship with Pilkington Brothers of St Helens, Lancashire, and in 1943 went to sea with Bibby Line and Blue Star Line, gaining his first class combined certificates. Mr Tune was appointed to Blue Star Line's Superintendents Department as Assistant Superintendent Engineer in 1951. Following progressive appointments as Superintendent Engineer and Deputy Chief Superintendent, in 1971 he took up his present position of Chief Superintendent with General Management responsibility for all Group newbuilding and projects and Fleet Technical Operations.

S. M. Tennant served an apprenticeship at the Caledon Shipbuilding and Engineering Company at Dundee. He graduated with first class honours in Naval Architecture from Kings College, Newcastle upon Tyne after which he was employed by Fairfield Shipyard and Engineering Company, becoming Technical Manager. He joined Harland and Wolff in 1967 as Shipbuilding Manager. In 1973 he became Director and General Manager of the Caledon Shipyard in Dundee before returning to Harland and Wolff in 1975 as Shipbuilding Director. He is now Technical Director and is responsible for all design and technical work with Harland and Wolff.

Principal parameters and arrangement

The owner's targets were the achievement of the specified cubic capacity within the most efficient ship and with the least number of hatches, each of which is to be optimized for the shortest loading and discharge times. The specified 450 000 ft^3 cargo capacity was determined after commercial research as being best suited to meet the optimum growing/loading schedules and port draughts of the tropical sector. The significant volume from an owner's point of view is the payload in pallets that can be achieved in the maximum vertical deck area, with the least possible loss of space caused by shipside flare and under deckhead coamings and ceilings.

Carriage of containers in the hatch trunks and on hatch covers was regarded as a useful side element of the owner's trades. This required hatch cover sizes which balanced the necessity for large opening areas for 'all under hook' working against the retention of cover for refrigerated cargo and banana working. It was achieved by a combination of independent multiple-hatch panels.

Speed

A normal service speed of 18–19 knots over a range of operating draughts, with reserves to 20 knots for the banana trade and ballast positioning passages, was decided upon, with 17.5 knots being the requirement at maximum draught with frozen cargoes. Care was taken with the initial engine selection to identify a balance between propeller diameter vs shaft speed and MCR vs MSR so as to provide a favourable 'maximum fuel efficient' flat partial-load fuel performance curve over all the various conditions.

A unifuel concept was aimed at, with the main engine and generators capable of operating on 600 cSt fuel, serviced by the latest centrifuging, blending and fuel conditioning equipment.

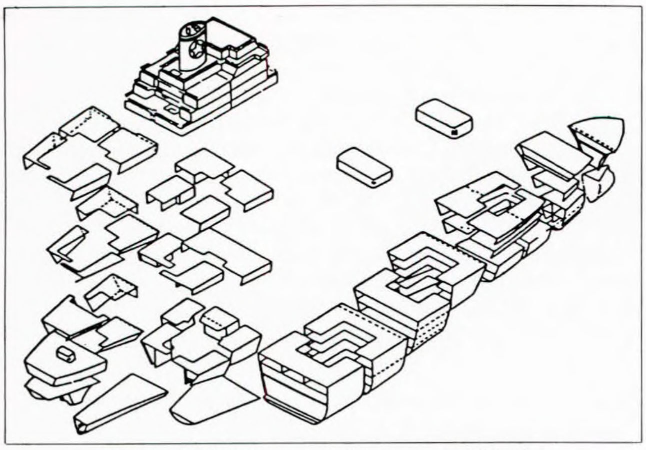

FIG. 2: Prefabricated weldments and blocks

being sub-divided into four tween decks between the tank top and the main deck. Nos 1 and 4 holds are sub-divided into three tween decks between the deep oil fuel tanks and the main deck.

In the final development stage it was decided that the engine room would be 21.75 m long, which gives a compact yet spacious arrangement of the main and auxiliary machinery. The refrigeration compressors and brine room are situated on the second flat level forward above the main machinery with the control room on the flat directly above.

Because of the owner's requirement for a minimum number of hatches with the associated cranes arranged so as to require the minimum number of stevedores, the sizes of the holds and locations of the cranes were chosen with great care. Nos 2 and 3 cargo holds were fixed at about 23 and 25 m long, respectively, inside the steel bulkheads, giving each a capacity of about 150 000 ft^3. Nos 1 and 4 cargo holds were each about 30 m long with capacities of about 65 000 and 100 000 ft^3, respectively.

Superstructure

A five tier superstructure block situated over the machinery spaces is designed to accommodate a crew of 21 comprising 11 officers and 10 ratings, this being the reduced manning agreed with the MNOA and NUS. Accommodation is also provided for two cadets, four shore contractors, two pilots and a super cargo. The middle three superstructure decks are given over entirely to living and recreation spaces for the officers and crew, with the bridge deck as navigation centre accommodating the wheelhouse, chart room, radio room etc.

The catering arrangements on the main deck are based on the cafeteria system with separate officer and crew dining rooms situated on each side of the galley. The boat deck is fitted with two 40 man motor lifeboats stowed in davits, supported by the usual complement of liferafts and life-saving apparatus.

Deck equipment

The deck machinery is electrically driven by Ward Leonard motor generating sets, and comprises two self-contained winch/windlass units forward and two self-tensioning mooring winches aft.

The cargo hatches are as large as practicable. Nos 2, 3 and 4 hatch covers are of similar size, giving an opening 12.9 m long by 10 m wide. No 1 hatch, because of the fine hull lines forward, is of necessity smaller (9.05 m long by 7.00 m wide). The hatches are designed for fast operation, going from fully open to fully closed (or vice versa) in 3–4 min. Each hatch can be worked with one half of the cover in place in order to protect the cargo in inclement weather conditions. Under these circumstances the covers can be closed even faster.

The hatch covers on the weather deck are hydraulically operated with an automatic cleating system and have removable hinge pins to enable the end leaves only to be raised while the centre leaves remain closed. The hatches can be further split transversely to allow several configurations of part opening. They are designed to accept one tier of 20.0 ft ISO containers on each hatch. They will operate with a 5° list and 2° trim. The control panels are mounted on the hatch sides. The hatches are insulated and provided with thermal sealing arrangements for refrigeration purposes as well as watertight seals.

The tween deck hatches are non-watertight and are arranged to allow opening of either end bay only by disconnecting the link mechanism between the end pairs of covers. They are designed to take 6.0 t fork lift truck loads. The covers on the third deck are insulated and fitted with thermal seals. The covers over the lower hold space are designed to support two tiers of 20.0 ft ISO containers.

Shipside loading doors are fitted in the shell in the upper tween decks on both sides of the four cargo holds.

There are four electric deck cranes, each of 5 t SWL (arranged for double working of nos 2 and 3 hatches), driven by Ward Leonard controllers. The crane serving no 4 hold can also plumb the engine room hatch.

Electro-hydraulic twin ram type steering gear, to the latest IMO standards, is fitted and has two independent control systems.

A 1 t electrically operated stores crane is fitted on the after deck stores servicing position, supported by one of the 5 t cargo crane for container storage of the ship's supplies.

A general arrangement of the ship is shown in Figure 1.

Ship construction

The ship is of conventional transverse-framed construction with longitudinal deck girders at the hatch sides supported on wide spaced pillars, which are carefully positioned to ensure minimum interference with cargo stowage.

These vessels, with their multi-flat configuration, provided convenient weldment breaks at each flat level and at mid-hold length for steel work prefabrication (see Figure 2). Nos 2 and 3 holds consist of individual weldments blocked together. The block extends from base to upper deck, from hold bulkhead to mid-length of hold and the full width of the ship. Each hold therefore comprises two blocks.

The block arrangement in nos 1 and 4 holds is slightly different. The blocks were again built of individual weldments split at mid-hold, but are much smaller, extending only to the lowest flat level and incorporating deep tanks and oil fuel tanks. Above these flats, because of the ship's shape, weldments were erected as single units.

The engine room consists of a double bottom block of two weldments, the after weldment being the larger of the two as it incorporates the main engine seating on one weldment. Above the tank top, the weldments were erected as single units.

The bow and stern sections consist of two blocks, each of the individual weldments being blocked in the large build-up shop to achieve this. Individual units of the superstructure were erected at the head of the building dock to form one large block which was then lifted by the Goliath crane onto the main hull.

Nos 2 and 3 holds were first into the dock, with work then moving on to the engine room because of its large outfitting requirement. Nos 1 and 4 holds were next, these sections being erected at approximately the same time. Finally the superstructure with machinery casing was placed onboard. Smaller units such as crane houses and upper deck hatch coamings followed.

All weldments and blocks underwent the maximum possible amount of outfitting before erection, and the engine room included many pipe and machinery modules.

DESIGN FOR REDUCED MANNING

Philosophy

The owners had been undertaking internal studies of the potential for labour saving and operational efficiency since the 1970s. They can be achieved by combining technological advances in equipment with innovative ship design. The four principal areas where rationalizations were sought and incorporated in the design were:

1. Navigational and central operations.
2. Mooring and handling in port.
3. Engine room arrangement and technical operations.
4. Catering and administration.

As part of the emphasis on human factors, collaborative discussions were held with unions and other interested parties on improvements in safety and convenience by the use of non-skid surfaces, the avoidance of unnecessary level differentials, access, ladder and handrail sizing and siting etc.

Navigational and central operations

At sea, the bridge assumes command of all navigational and international communications and ship handling. There is comprehensive array of worldwide WT, VHF, Telex, satellite navigation and other navigational aids, including anti-collision and ARPA radar together with adaptive auto-steering etc. The Watch Officer is supported by bridge to engine controls and by all the machinery and UMS console information, along with alarms, internal telephones and over-all address systems.

Weather facsimile recording is provided, and all the base systems for Satcom are installed, allowing easy retrofit when the full complement of earth stations is established and this unit is seen by the owners as being economic.

The main operational work centre for all the ship's routines and administration, either at sea or in port, is situated on the main deck. All stores and ship's equipment are landed directly by pallet or container on the starboard side and moved mechanically directly into centralized deck stores or the ship's catering stores within the accommodation. Daily catering supplies are drawn directly into the central galley (forward) and further self-service catering is drawn directly from the galley outlets into officers' and ratings' saloons, which are to port and starboard on the same level.

The port side of the accommodation on the main deck is given over to an intercommunicating administrative office complex for the Master, Chief Engineer and Catering Officer, together with a general office. Communicating shower and changing rooms with direct engine room access and a port stevedore's office and deck toilet are also incorporated in this complex. The general office retains all the ship's documentation and is supported by an IBM XT microcomputer system ruggedized by BSRA. All the ship's administration, both at sea and in port, is centred within this complex, the higher levels of accommodation being strictly reserved for the private living quarters of the ship's staff.

Within the three decks of the living quarters there are officers' and crews' bars and smoke rooms, a gymnasium and a swimming pool. All cabins have an individual shower and toilet, with the accommodation so arranged that wives can accompany their husbands. The furnishings, which include fitted carpets throughout, are of the highest standards.

Mooring and handling in port

Pending the cost-effective development of a remote and fully automated ship mooring system, the *English Star* class is fitted with the latest anchor windlass and self-tensioning equipment. Improvements have concentrated on the detailed layout and centralized control, to allow minimum manning for berthing and unattended port surveillance.

Hatch covers are mechanized throughout for one man operation at all deck stations. Within the cargo holds virtually self-maintaining materials, easily portable deck gratings and air- and water-cleaning systems are provided.

Particular attention was paid to weather deck and hatch coaming geometry to eliminate all external appendages and to reduce water retention and corrosion sensitivity, in combination with a programme of modular construction of the steel hull, which was shot-blasted and painted under cover. Paints are high-quality vinyl epoxies (including in the engine room), with topcoats of orthodox acrylic materials because of their improved tolerance to epoxies and to provide easier maintenance by the ship's crews.

Engine room arrangement and technical operations

With UMS now accepted, the engineering requirements concentrated on improved reliability and having the minimum number of labour-intensive operations. This was established in the following broad areas:

1. Simple systems throughout, using the latest equipment of proven reliability and so having longer periods between overhauls.
2. Plant arrangements to facilitate ready access and overhaul with mechanical tools in support.
3. Control systems using the latest developments in electronics for improved reliability, and with standby fall-back systems.
4. Introduction of new methods and equipment to reduce manual (and unrewarding) labour routines to the minimum.
5. Careful thought to environmental space utilization for both machinery and men to produce self-inducing cleanliness of spaces and reduced noise and vibration levels.
6. Centralization of all important technical functions in the control room, coupled with ready visual observation of all important machinery including the central refrigeration systems.

Catering and administration

The principal concept followed was centralized servicing and messing arrangements, together with the use of labour-saving materials, fitted carpets, ceramics etc. throughout the accommodation. The cabins are readily maintainable by the occupants. Self-contained laundries are provided for all ranks together with self-service pantries on all decks, changing rooms at all engine room access levels and a communal duty mess to support the theme of self-dependence.

Word-processing facilities and software covering all the ship's administration routines, spares, catering, stores, accountancy, ship stability, loading programmes, and engineering technical data, including progress into machinery monitoring and Lloyd's condition monitoring survey programmes, are provided within the IBM XT microcomputer system in the general office.

REFRIGERATION

Insulation

The insulation of the cargo holds, refrigerating machinery and brine room was carried out by Cape Contracts Ltd, who were required to produce a system giving an average heat leakage over the ship not exceeding 0.4 kcal/m^2hK. Heat design consultants were employed by the contractor.

The insulation medium is generally fibreglass Crown 125 slabs covered with tongued and grooved birch plywood fastened to wood grounds. All the timber materials are rot-proofed throughout. Wood grounds on the ship's sides and bulkheads were fitted horizontally so that contacts between the ground and the frame occur only where the ground crosses the vertical frame. This means that the heat-leakage path to the structure is minimized.

Polyurethane slab insulation is used on tank tops over heated fuel oil double bottom tanks and in way of other high-temperature areas.

A feature of the system is the thickness of the insulation ribands around the periphery of the intermediate uninsulated decks. These are 200 mm thick at the ship's side tapering to 25 mm at the face of the air screen to allow for efficient air circulation. Some indication of the efficiency of these ribands could be deduced during the cooling trials (which took place over a period of very high humidity and fairly low ambient temperatures) by the marked absence of a condensation line at the intermediate decks.

Considerable care was taken in selection of the plywood for the insulation linings, air screens and deck gratings. After consultation between the owners, builders and Cape Contracts' technical staff, Finnish birch plywood was selected. This requires no painting maintenance, is easily cleaned, is not subject to rot, is to the highest clinical standards and is faced on the hold side with a light blue epoxy coating and on the reverse side with a phenolic resin. The edges of the plywood sheets are tongued and grooved to provide efficient air sealing at the joints.

The shipside air ducting system, with graduated transverse air flow under gratings, allows a low grating section height and gives improvements in grating strength and stability when fork lift working is taking place.

The deck gratings are mounted on wooden bearers about 100 mm deep providing efficient air flow up through the cargo for the cooling air. The plywood is pierced with holes of graduated size and spacing as required to provide balanced air circulation throughout. They support 6 t laden weight fork lift trucks and are arranged in hinged sections to simplify cleaning underneath them. Portable sections of gratings are fixed to the tween deck hatches with easily removable fasteners. Gratings on the hatches are designed to lift as an integral part of the cover when the hatches are opened.

Particular attention was given to the insulation and sealing of the hatches in order to ensure that this potentially sensitive insulation point was efficient. The shipside loading doors are insulated plug doors with special attention paid to sealing arrangements. Portable sections are provided to give access through the doors for easy cargo working.

The design of the shipside air screens is such that whilst the areas through the ducts give the required air circulation for cooling purposes, the screens in way of the pronounced shipside flare in nos 1 and 4 holds are kept as nearly vertical as possible in order to assist the stowage of pallets. In way of the areas of greatest flare, hinged 'squaring off' panels are fitted and can be locked in the upright position in order to provide vertical surfaces when palletized cargoes are carried.

Stevedore access hatches are provided in each hold and have sloped ladders with insulated stringers to meet the requirements of the Australian Waterfront Workers Association.

The air circulation in the crowns of the weatherdeck hatches was designed to ensure adequate cooling of the cargo in this area.

Refrigerating machinery and brine system

The refrigerating machinery, supplied and installed by APV Hall International, is situated on the second flat forward in the engine room with the brine room alongside the compressors. The system is based on three Hallscrew single-rotor screw compressors with R.22 as the refrigerant. Each unit is arranged with its own primary refrigeration circuit, including a sea-water-cooled condenser and brine chiller/evaporator operating on the dry superheated gas expansion system. Each system is connected into a common liquid receiver which is normally isolated and acts as a pump-down unit for system maintenance.

The plant is designed to operate with sea water circulated at 32 °C and an ambient temperature of 35 °C with two units working and one on standby. All three machines can be in operation when cooling fruit. The plant is capable of the following:

1. Cooling a full load of bananas (about 3770 t) from the loading temperature of 28 °C to the carrying temperature of 12 °C within 72 h of completion of loading.
2. Cooling a frozen cargo loaded at −15 °C to −25 °C within 72 h of loading.
3. Maintaining a full deep freeze cargo at −25 °C with one compressor unit on standby.
4. Maintaining a full banana cargo at 12 °C or fruit at 1.7 °C with one compressor on standby.
5. Operating at any selected temperature to suit the full range of refrigerated cargo requirements.

The three Hallscrew single-rotor screw compressors are driven at about 3550 rev/min by 250 kW two-pole electric motors and are capable of capacity unloading down to about 10%.

Three sea-water-cooled horizontal shell and tube condensers are each operated by a vertical centrifugal sea-water pump capable of delivering 129 m^3/h, which is the requirement of one condenser. To maintain the optimum sea-water temperature in the condenser, a recirculation valve is fitted in order to optimize plant efficiency.

Three uninsulated direct expansion shell and tube evaporators (brine chillers) together with brine pumps, pipe systems valve headers etc. are fitted in an insulated brine room adjacent to the refrigerating machinery on the starboard side of the refrigeration flat. The brine system is designed for the circulation of brine at three different temperatures (two cooling temperatures and one defrost/heating temperature) to any of the main space groups.

There are three main vertically mounted centrifugal brine pumps, each capable of delivering 160 m^3/h of chilled brine at 3.5 bar. A similar pump capable of delivering 68 m^3/h is provided for defrosting and heating duties. A small positive-displacement pump is also provided for making and mixing the brine.

Cargo air circulation

Each cargo space is equipped with two brine-circulated air cooling batteries designed for vertically downwards air flow, with a battery of axial flow air circulating fans mounted on a plenum chamber fitted over the cooling battery.

Electrically operated brine modulating valves of advanced design are controlled automatically by the delivery air temperature and are mounted in the cooler room. They control the flow of brine to the coolers of each individual insulated space. All the coolers of any insulated space group can be connected to any of the three brine circulation temperatures in the brine room.

Air refreshing system

When carrying fruit, and especially bananas, the ripening process generates considerable quantities of carbon dioxide, as well as other undesirable gases. This means that the air in the holds must be changed frequently in order to get rid of these odours. In the case of bananas at 12 °C two air changes per hour are required and with citrus and deciduous fruits one change every two hours. This causes a major load on the refrigerating plant. To minimise this load and conserve energy, the exhausted cold air is taken through an efficient heat-exchanger unit which helps to cool the fresh air being drawn into the spaces.

Carbon dioxide gas analysers are fitted in the air refreshing unit in conjunction with the air changing system, with the

CO_2 monitoring cubicle mounted in the refrigeration control room. Ozone generators are also provided for injection of ozone into the air stream going to each space. The CO_2 analysers also monitor the relative humidity of the atmosphere in the cargo holds.

Remote automatic control and logger system

Automatic control functions are provided for the refrigerating machinery and brine systems. They control loading/unloading of the compressors, brine temperature injection, brine chiller valves and motorised control valves on the return path from the coolers.

An automatic logging system records at pre-selected time intervals and is designed to comply with the requirements of the United States Department of Agriculture (USDA), thus enabling all spaces loaded with USDA cargoes to be monitored on demand. A facility is incorporated into the equipment to give an alarm in the event of logger failure, thermometer failure or if any parameter is beyond the USDA limits.

Two thermometers in each space monitor the temperature at fixed positions remote from the cooling battery and a series of thermometers is provided for measuring the temperature of the fruit flesh. These flesh thermometers can be used as air thermometers when USDA cargoes are not being carried. Cooled-air delivery and return temperatures are logged along with the CO_2 concentration and relative humidity.

The system uses microprocessor modules in remote outstations adjacent to the individual cargo holds. One outstation monitors the logged air delivery and return temperatures and the other monitors the air delivery temperature for control purposes and the space temperatures for USDA logging/alarm monitoring. Two independent data highways are used to link the outstations and common master station in the control room, and one links the logging outstations and the machinery outstations.

In order to meet the classification and USDA requirements for standby facilities, each of the pairs of outstations monitoring a hold is electrically independent so that if one should fail then the other will still be capable of displaying the temperatures on its own control panel. Each outstation has its associated valve housing containing solenoids to control the brine valves and the CO_2 analysis valves.

The master station, along with a visual display unit and two logging printers, is housed in a console situated in the machinery control room. A touch-sensitive keyboard and control panel is also provided to allow the operator to change alarm limits, temperature controls, set points etc. and to demand display of temperatures and CO_2 levels and also to permit manual operation of brine valves etc.

The complete refrigeration installation was designed, manufactured and installed under survey to the requirements of Lloyd's Register of Shipping to give class +100A1+LMC, UMS+RMC. The installation complies fully with the USDA requirements for fruit and other perishable cargoes, and also meets the requirements of the Israeli Ministry of Transport, The Citrus Marketing Board of Israel, South African Perishable Products Exports Control Board and the California Fruit Growers Exchange.

PROPULSION AND AUXILIARY MACHINERY

Machinery installation

The installation of the main machinery of these vessels (see Figure 3) might seem conventional to the uninitiated, but in fact has an unusual blend of features to please naval architects, marine engineers, shipyard production engineers and the owners and their operating staff. It is not always easy to satisfy this combination of interests!

The overall objectives ideally required a main engine of limited overall height to minimise encroachment upwards into areas to be used for refrigeration machinery and for the main deck level operational centre, comprising the stores complex with mechanized handling and the ship's catering and management offices. The performance parameters required an engine capable of propelling the ship fast when required (up to 20.5 knots) yet which should spend most of its life at 18–19 knots, and therefore be at its most economic at these speeds. Draught restrictions, which included a banana draught of 7.08 m, a citrus draught of 7.89 m and a ballast draught of 4.39 m (mean), defined the upper limits of the propeller's diameter which could safely be used without jeopardising performance and/or vibration characteristics and suggested an optimum shaft speed of 115–125 rev/min.

These criteria seemed to be admirably matched by the H & W–MAN–B & W 7L67GBE engine, with a nominal MCR of 15 200 bhp at 123 rev/min. The LGBE was the latest development of the B & W uniflow scavenged two-stroke engine, the second generation of the series which started with the GFC and marked a change to the principle of long strokes and constant-pressure turbocharging. The 'E for Economy' version had the quoted potential of a specific fuel consumption of 126 g/bhp h at 80% MCR, a figure which was comfortably achieved by all the engines of the class on shop test, one even recording a remarkable 123 g/bhp h.

Alternative engines

At the time the decision on this engine was made, the MAN–B & W MC/MCE range was on the point of announcement, with nominally even lower specific fuel consumptions. Thorough evaluations were then made to see if their potential could be used to advantage. However, the GB/GBE range was supplemented rather than superseded by the MC/MCE range, and exploitation of the latter's economy would have entailed unacceptable sacrifices of major aspects of the overall concept, either because of their increased height or because of their dependence on large and slow-turning propellers.

Generating machinery

The choice of generating capacity involved a complex set of variables. The owner's predictions of the electrical loads likely to be encountered in port and at sea with different cargoes ranged from as little as 400 kW in ballast to 2000 kW when cooling down a newly loaded banana cargo. Another consideration, particularly important as it was intended to run the generators on heavy fuel, was to ensure that all the likely permutations could be met without any single unit running for prolonged periods on light load.

This virtually dictated that a multi-unit installation of four generators would be required, with a further differentiation into two at 880 kW and two at 660 kW to maximise flexibility. This combination could be met by MAN–B & W T23LH diesel engines in eight and six cylinder forms, respectively, with the added advantages of commonality of spares and inherently good balance in both cases.

The ¾-aft machinery space afforded the opportunity, dear to naval architects and seafarers but usually denied in all-aft installations, of siting all generators on the tanktop where they are least likely to telegraph noise and vibration to the ship's structure. The artifice of turning the sets end to end, so that the alternators faced each other and shared common rotor withdrawal space, was necessary because of the engine room length limitation, especially on the port side. Concern for shipboard housekeeping problems meant that special measures were taken to ensure that oily spillages from the forward pair of diesels did not run back under their alternators when the ship had a stern trim and introduce oil mist to the windings.

A shaft-driven alternator was considered at one stage but

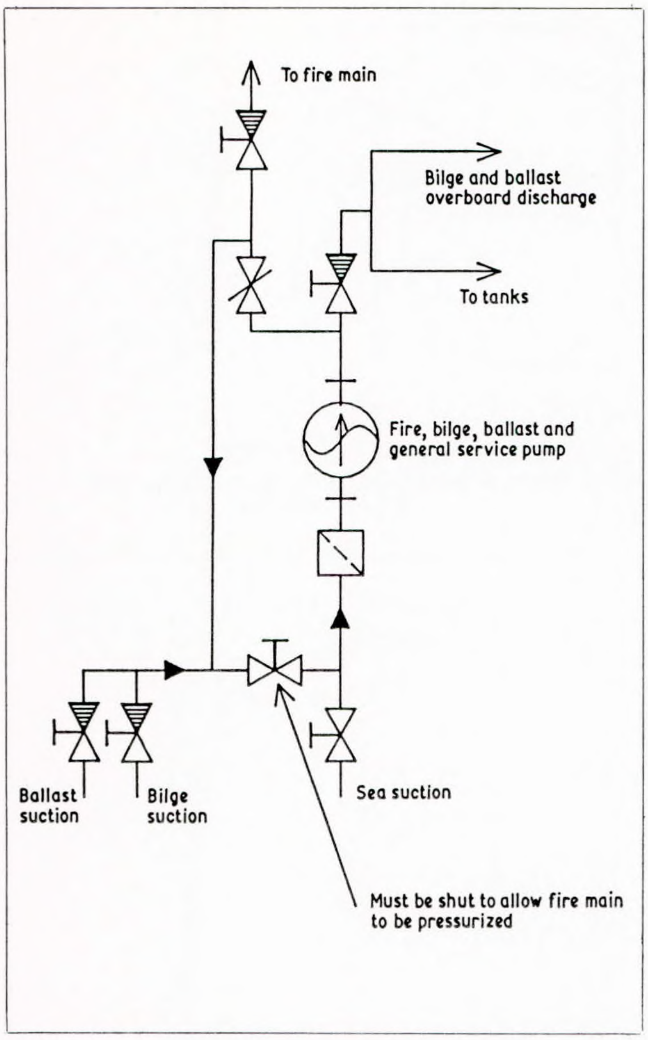

FIG. 6: Layout of multi-purpose sea-water pumping system

The Grazebrook Spanner Swirlyflo vertical oil-fired boiler is supplemented or replaced at sea by a Grazebrook exhaust gas boiler, control being by an integral modulating gas bypass damper. This arrangement is favoured by the owners in preference to the builder's general practice of control by steam dumping because of the reductions in pipework and the number of pumps required.

SEA TRIALS AND SERVICE EXPERIENCE

Speed trials

For the sea trials the vessels were run at draughts corresponding to those used for the predictions from the model test results. They were carried out over the Arran Mile in very nearly ideal conditions with calm sea and wind force 2–3, four double runs being made with the main engine at 35%, 60%, 80% and 100% of the maximum continuous rating.

The results for *Scottish Star* are plotted in Figure 7, and show very close agreement with the predictions from the model test. In view of the agreement it was confidently expected that the predicted performance at the design draught, on which the contract was based, and at the other cargo draughts tested would be achieved by all vessels in service.

Turning-circle and crash-stop tests were also carried out during sea trials and indicated very satisfactory results for a vessel of this type (see Figures 8 and 9).

Noise and vibration

Noise predictions had been carried out for the owner's earlier *A* class vessels by BSRA and comparison with the new design indicated that the noise levels laid down by the Department of Transport guidelines should be generally achieved. This was confirmed during sea trials when extensive readings were taken throughout each vessel. These readings showed that with only one or two minor exceptions the guidelines were comfortably met in all cases (see Table I for sample results).

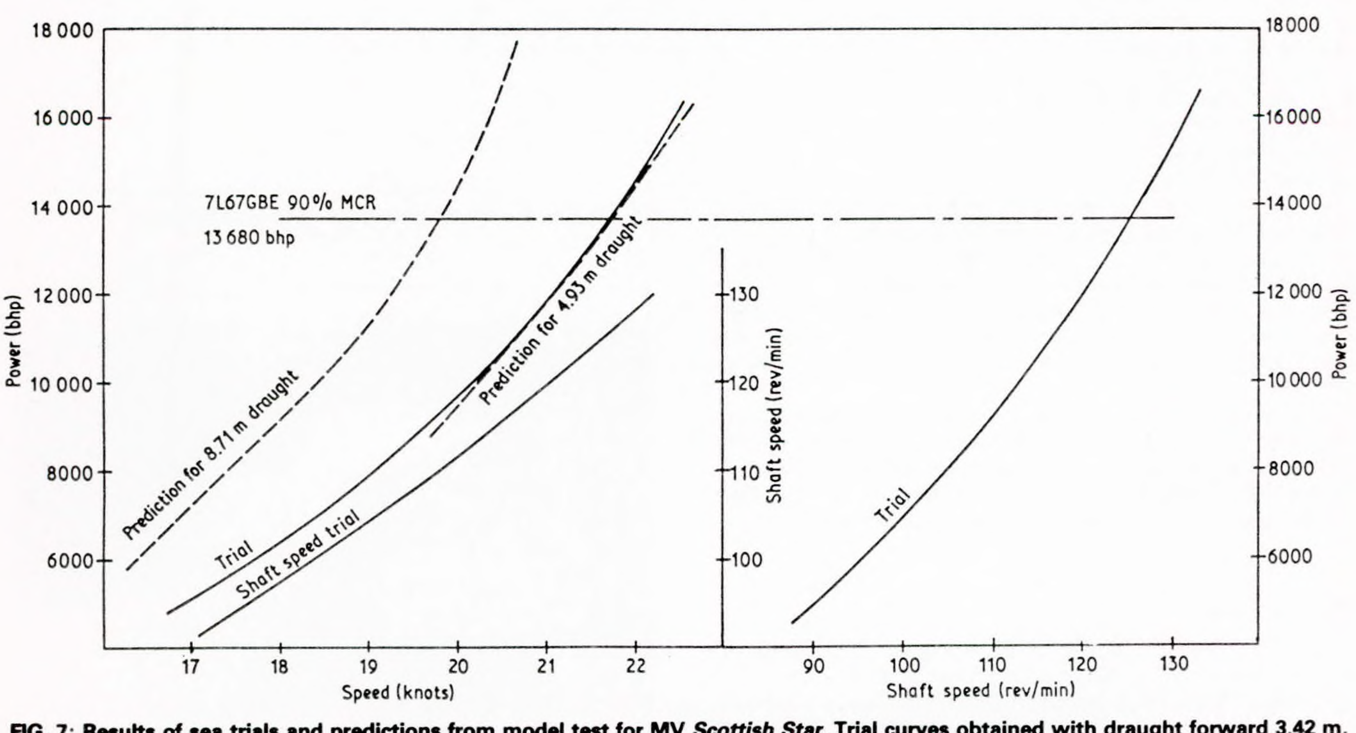

FIG. 7: Results of sea trials and predictions from model test for MV *Scottish Star*. Trial curves obtained with draught forward 3.42 m, draught aft 5.33 m (trim by stern 1.89 m) and displacement 7818 t

Even though the vessel was operating at a very shallow draught, with the propeller not fully immersed, measurements indicated very low levels of vibration throughout, this being particularly noticeable at the aft end and in the steering gear compartment.

Sea-keeping and crew comfort

On its initial voyage the first ship sailed in ballast for Venezuela and experienced wind force 5–12 throughout, enforcing reduced speeds. Although arrival was delayed by 5 days, the overall voyage itinerary was recovered thanks to the vessel's capacity for 20 knots on the homeward leg. This meant that the delivery deadlines in Marseilles and Genoa to meet the Easter holiday markets were achieved.

In such extreme conditions the ship's sea behaviour was reported to be excellent and the decks remained very dry, with no shipping of green water (see Figure 10). The comfort of the onboard environment both in heavy weather and under full-power steaming was said to be excellent and the ship was remarkably free from vibration and noise. This is a vindication of the choice of the ¾-aft machinery and superstructure location.

Machinery service experience

The propelling and refrigerating machinery have performed with a minimum of incident, the only two items of interest occurring during the fourth and fifth voyages.

Voyage no. 4

Blackout and complete loss of power occurred because of leakage of salt water from a fractured heat exchanger in a diesel alternator's nozzle cooling system into the fuel supply line. All essential systems were operational within 30 s by auto-start of the emergency generator, with full power restored and the ship back on passage within 5 min.

Voyage no. 5

The steering gear failed while moving astern into the harbour basin at Zeebrugge when the rudder did not stabilize at the called-for half-helm position and continued towards the full position. The fault was ultimately found to be a small broken pilot valve spring in the telemotor, but it is instructive to see how incorrect but understandable crew reactions exacerbated the problem.

The bridge correctly deduced the situation as being caused by some failure of the working motor unit and switched the bridge selector switch to the standby unit, which has an independent telemotor and would therefore have been expected to clear the problem.

However, the motor hand/auto change switchgear incorporates a latched relay which inhibits the standby unit from starting until the working unit is sensed as being stopped. In haste the bridge had passed straight through the 'stop' position, and when the standby unit was observed as having failed to respond to the 'start' order, a major steering problem was suspected and assistance from the still attached tugs was requested.

Had a simple hand reverse corrective helm been applied the incident would have been cleared. The lesson of this obscure but just conceivably repeatable mishap has been enshrined in a prominent wheelhouse notice, and the operating staff's confidence in the IMO standards has been restored.

Fuel problems

The HFO bunkers used so far have been of 420 cSt nominal viscosity but have exhibited widely varying operational characteristics. Some fuels have produced temporary problems when used undiluted in the 720 rev/min diesel alternators.

On the third voyage, exhaust valve hangup threatened

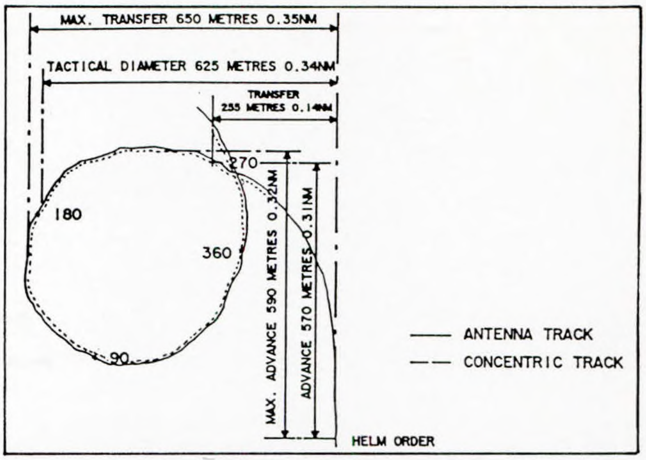

FIG. 8: Result of full ahead – hard to port turning circle test for MV *Scottish Star*

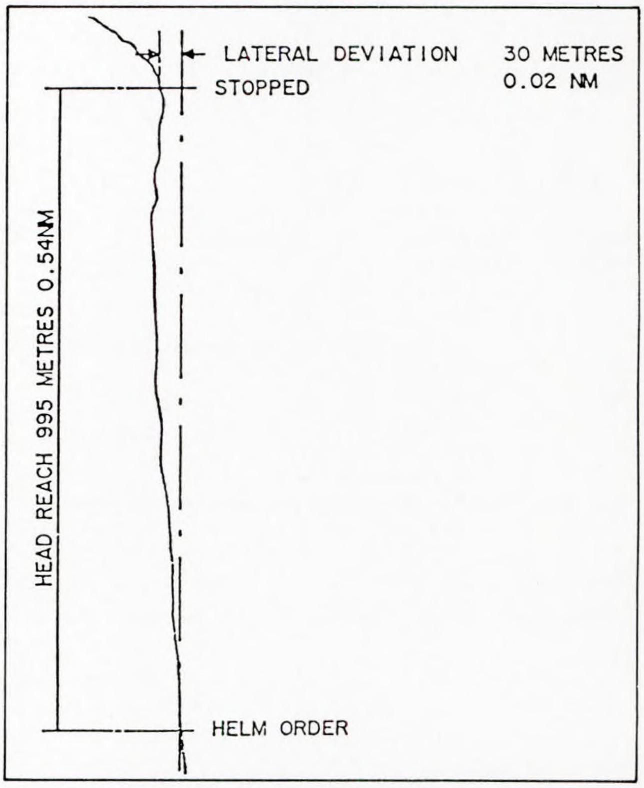

FIG. 9: Result of crash stop from full ahead test for MV *Scottish Star*

FIG. 10: View forward, showing behaviour under extreme conditions

Table 1 : Noise readings taken during sea trials of MV *Scottish Star*

Location	*Recommended maximum noise* (dB)	*Recorded noise* (dB)	*Octave band mid-frequency* (Hz) 31.5	63	125	250	500	1k	2k	4k	8k	*NR*
1st superstructure deck												
Open deck aft port	75	71										
Crew 3	60	58										
Passage port	80	63										
Crew's lounge	65	61										
Bosun	60	57										
Contractors B	60	62	84	73	71	63	58	58	51	41	28	58
2nd superstructure deck												
Open deck port	75	70										
Electrician	60	57										
2nd engineer's bedroom	60	53										
2nd engineer's dayroom	65	51										
Officers' lounge	65	53										
Officers' laundry	80	64										
3rd superstructure deck												
Passage cl	80	55										
Captain's dayroom	65	52										
Captain's bedroom	60	52										
Hobby room	65	63										
Open deck starboard	75	78	92	85	82	84	74	74	68	62		76

Measurement equipment : Bruel & Kjaer type 2203
Weather conditions slight, power 13 700 bhp, speed 21 knots.

UMS operations and the Sea Star unit was recommissioned in its blender role to maintain a 50:50 HFO/MDO blend until the problem was diagnosed. High asphaltenes had caused carbon fouling on the valve stems. A modified valve stem has since been introduced by the engine builders and has overcome the problem.

On a later voyage a more puzzling phenomenon was experienced when engine rail viscosities could not be sustained despite extensive experiments with heater temperatures. Consequent nozzle and blower fouling problems were again alleviated by resort to 50:50 or 70:30 blending ratios until the offending charge was consumed. No satisfactory explanation of this fuel batch's behaviour has been found despite extensive laboratory analysis.

These cases illustrate that the operation of medium-speed engines on heavy fuel may still hold some surprises and underline the wisdom of retaining a blending facility in reserve, especially when the future quality of such fuel is so doubtful. Even the sludge produced from purification of some of these fuels created its own problems and high wear rates were found on the gear-type circulating pump in the Seacrap sludge conditioning module. Modification to a Comet-type heavy-duty pump is now standard.

THE EFFICIENT SHIP OF TODAY

With union collaboration on rating interchangeability on demand (IDF), the *English Star* class manning scale was agreed at 21. This approximates closely to the 18 man target of several of the international 'efficient ship' and 'ship of the future' concepts, including the recently announced British project.

Pending the social and legislative progress necessary before dual certificated watchkeepers are available, and given that extra manning is appropriate to a sophisticated high-powered vessel with a specialized cargo, it is reasonable to suggest that the *English Star* class represents today's state of the art of the 'efficient ship'. This means that these ships will be able to take advantage of any further progress in legal and administrative arrangements occurring within their lifetimes.

These 'efficient ships' have been achieved through close cooperation between owners, operating unions and builders in applying their combined empirical knowledge to the production of a design where attention to labour-saving detail and the judicious use of advanced technology complements a harmonious and evolutionary concept. The in-service results obtained so far have been an encouraging reward to those involved.

ACKNOWLEDGEMENTS

The authors thank the Boards of Blue Star Line Ltd and Harland & Wolff plc for their support in the preparation of this paper, and Mr T Riddell, now retired from the design staff of Harland & Wolff plc for his assistance in gathering together the detailed information contained in the paper.

APPENDIX

General particulars of machinery

Classification: Lloyd's Register of Shipping Class + 100A1 + L.M.C., U.M.S. + R.M.C.

Main engine: H&W, MAN, B&W low-speed, single-acting, two-stroke, direct-reversing, crosshead marine diesel.

Makers	Harland and Wolff
Type	7L 67 GBE
Bore	670 mm
Stroke	1700 mm
Maximum continuous rating	15 200 bhp at 123 rev/min

Equipment	*No fitted*	*Manufacturer*
Main-engine turbo blowers	2	British Brown Boveri
Main-engine air coolers	2	Vestas
Stern glands		Simplex-Turbulo
Main-engine camshaft lub oil pumps	2 (1 working, 1 standby)	Hamworthy
Main-engine lub oil pumps	2 (1 working, 1 standby)	Hamworthy
Cylinder oil supply pump	1	Hamworthy
Lubricating oil cooler	1	Serck Heat Transfer
Camshaft lub oil cooler	1	Serck Heat Transfer
Lub oil fine filter	1	Scamco
Lub oil coarse filter	1	Scamco
Main-engine camshaft lub oil filter	1	Boll & Kirch

Equipment	*No fitted*	*Manufacturer*
CJC pump	1	Anderson & Groot
Main-engine lub oil heater	1	Swinney Engineering
Main-engine lub oil	1	Alfa-Laval
Main fresh-water circulating pumps	2	Hamworthy
Main fresh-water cooler	1	Alfa-Laval
Sea-water pumps	1	Alfa-Laval
Sea-water pumps	2 (1 working, 1 standby)	Hamworthy
Auxiliary sea-water circulating pumps (DA)	1	Hamworthy
HFO/DO transfer and standby oily-water pumps	2	Hamworthy
Fuel oil service pumps	2 (1 working, 1 standby)	Hamworthy
Boiler fuel supply pumps	2 (1 working, 1 standby)	Alfa-Laval
Purifier heavy fuel oil supply pumps	2 (1 working, 1 standby)	Alfa-Laval
Main-engine fuel oil supply pumps	2	Hamworthy
Main-engine fuel oil filter	1	Scamco
Fuel oil heaters (heavy grade fuel at main engines)	1	Swinney Engineering
Fuel oil heaters (heavy grade fuel before purifier)	2	Swinney Engineering
Fuel oil purifiers (heavy grade fuel oil)	2	Alfa-Laval
Fuel oil purifiers (diesel grade fuel oil)	1	Alfa-Laval
Exhaust gas boiler	1	M&W Grazebrook
Feed pumps	2	Ryaland
Fresh-water generator	1	Caird & Rayner
Sea-water feed and ejector pump	1	Hamworthy
Oily-water separator	1	Hamworthy
Bilge ballast and fire pump	2	Hamworthy
Fire and general service pump	2	Hamworthy
Auxiliary bilge and oily water pump	1	Thom, Lamont
Sludge pump	1	Comet Marine
Fuel oil blending module	1	Star Engineering Applications
Sludge conditioning module	1	Star Engineering Applications
Main starting air compressor	2	Hamworthy
General service and control air compressor	1	Howden
Topping-up air compressor	1	Hamworthy
Main alternator engines	2	MAN-B&W T23LH, 720 rev/min
Emergency diesel alternator	1	Hawker Siddeley
Lub oil renovating unit (alternator engines)	1	Star Engineering Applications
Oil-fired boiler	1	M&W Grazebrook
Domestic fresh-water pumps	2	Hamworthy
Engine room ventilation fans	4	Davidson & Co Ltd
Extractor fan, purifier space	1	Davidson & Co Ltd
Ventilation fan, crankspace	1	Davidson & Co Ltd
Engine room crane	1	Clayton Crane & Hoist Co
Steering gear		John Hastie & Co
Anchor windlass	2	NEI Clarke Chapman Marine
Air-conditioning and ventilation equipment		APV Hall International
Cargo cranes	4	NEI Clarke Chapman
Hatch covers	86 (43 pairs)	MacGregor Navire UK
Emergency fire pump	1	Hamworthy
Refrigerating plant		APV Hall International
Fire-extinguishing equipment		Walter Kidde
Vacuum sewage plant		Evak
Tank gauging		Chadburn Bloctube
Indicating controllers		Foxboro
Alarm system		Victor Automation
Viscosity transmitter, main engine and blender		Elwâ
Pneumatic control valves		Fisher
Self-acting control valves		Spirax Sarco

Discussion

G. R. SCRINE (Shipowners Refrigerated Cargo Research Association): First, the insulation coefficient of 0.4 kcal/m^{2}h K is equivalent to 0.082 in Imperial units, which is about 10% higher than the traditional figure of 0.075. Does this include the deck edge leakage, for which I note the decks have been well ribbanded.

The use of polyurethane foam on tank tops was first tried out on Shaw Savill's *Icenic* many years ago. In view of the problems of water uptake by polyurethane foam it would be interesting to know how the insulating contractors have sealed the foam against moisture ingress. We have measured insulation deterioration factors of 5–6% per annum and can quote even worse figures for an LPG carrier.

There is no doubt that on any type of ship the tank top is the area most vulnerable to water damage, but the problem remains. We are currently investigating the rate of water uptake in foam insulation to fill in some of the gaps following the basic investigations by ICI some years ago.

I would also like Messrs Tune and Tennant to comment on the reason for using portable squaring-off panels rather than air bags at the ship's side where the flare is most pronounced. Although we have not investigated this in detail, it has been brought to our notice that air can bypass pallets adjacent to these panels.

Considering the air circulation system, the paper does not give the number of air changes. I know this is rather an emotive subject and there may well be an upper limit above which additional air volume produces an unwelcome increase in fan horsepower and refrigeration capacity. Some investigations with bananas several years ago suggested that 80–90 air changes was quite sufficient but 55–60 was on the low side to meet the specified cooling requirement at the time. On the other hand 110–120 changes per hour only produced a marginal improvement in cooling rate over the 80–90 figure, and for the vessels in question the latter figure was adopted.

Some of our more recent work has centred upon the cooling or heating of bananas on pallets, the latter process usually requiring redistribution of cartons on the pallet. Heat transfer from pallet loads of produce under operational conditions is not well documented and we will carry out some laboratory and sea trials when the opportunity presents itself.

I was pleased to see that the air freshening figures have been reduced from 2.5 changes for bananas and one change for citrus fruit which were prevalent about 10 years ago.

Could Messrs Tune and Tennant give some detail of the air to air heat exchangers of the air freshening system. The paper also mentions remote measuring and monitoring of CO_2 and relative humidity, both of which are difficult and expensive. Could details of these devices please be given and do they offer any advantage over some of the earlier systems?

On ventilation is there a case for automatic ventilation based on the commodity and its temperature? The metabolic activity of fruit, although variable at a constant temperature, appears to have defined maximum values. We are considering the benefit or otherwise of ventilation on a time basis which is related to the known maximum CO_2 production of the commodity. One could say that many cargoes are over-ventilated and we know of certain trades where fresh air ventilation is deliberately suppressed to save fuel.

The use of a remote master station to monitor and operate plant is a step forward to a total plant management system which can be programmed according to the commodity, its point of loading and the carriage requirements including ventilation. It would be possible to incorporate various cooling regimes and temperature control to meet special requirements such as in-transit quarantine and, most important, refrigeration plant management.

With a reduced complement in the future, it would be interesting to consider the extent to which the ship's engineers will continue to control and monitor plant. Future plant design is difficult to forecast. There could well be an increase in the use of single-screw compressors and further refinements in cooler and fan design. It is perhaps worth pointing out that the process of carrying cargo at sea has not changed materially since 1935 or thereabouts when *Port Jackson* was fitted with what was known as a forced air fan and battery system. UK owners have on the whole remained faithful to the secondary refrigerant system whereas the continental lines have generally favoured direct expansion.

There has, I think, been a fear that a leak in a direct expansion system could cause a major problem whereas a brine leak would not necessarily cause problems. However, the protagonists of direct expansion systems claim that there are few operational problems and that they are more economical to run. One possible advantage is in defrosting, which can be automated using a simple valve arrangement. The brine system requires a number of valves to achieve the same objective. It has also been suggested that reverse cycle is more rapid but I have no evidence to support this.

Until the recent fall in oil prices there has been an impetus towards energy-saving installations, for example when a ship is part loaded. Two-speed fans are now quite common and capacity control of screw compressors has been developed to a high level but not necessarily with sufficient energy saving. The single-screw machine may improve this situation, but in general the marine industry has not adopted the concept of fitting plant that will cope efficiently with both large and small loads, mainly because of increased capital cost.

As the fuel consumption of the main propulsion unit continues to fall, the proportion of that used by generators for refrigeration as a percentage of the total will rise unless particular attention is paid to energy saving. Speed controllers for auxiliary motors are becoming more practicable but again their capital cost is high. There are, however, circumstances where the pay-back time can be quite short depending on the use of the motor in question.

We have carried out some preliminary investigations on speed control for small semi-hermetic reciprocating and rotary vane compressors. The controllers has been coupled to a temperature controller whose sensing element is located in the air stream from the cooler. Temperature control to ±0.25 °C has been achieved in container refrigeration systems at a similar power consumption to on/off operation of the same compressor. Given a reasonable cost for the combined temperature and speed controller, the system has the potential to offer some advantage over current hot-gas injection or suction throttling methods. There is, however, much to learn about the evaporator performance at low gas flows and the conditions under which the compressor operates.

Finally a word about commodities. People often say to me, why are you still interested in marine refrigeration, surely it has all been done before. Taking the more simple case of frozen cargo, the principles are well developed but unfortunately there are many occasions when cargoes are not loaded at the carrying temperature. It is not unknown for highly perishable foods such as prawns to be only partly frozen at the catching and processing stage and then frozen down hard in transit. Meat and butter from New Zealand for example are not always loaded at −18 °C, and current EEC proposals for frozen food are causing a certain amount of disquiet. There is a greater awareness of the cold chain and in-transit temperatures, particularly for the most perishable frozen foods such as shellfish and vegetables.

It is, however, with chilled commodities that the majority of problems arise and even countries which have well developed facilities are not exempt. Problems still arise from poor pre-cooling, mixing of incompatible cargoes, and developing countries wishing to export produce whose harvesting and pre-shipment practices require further expertise. There are also changes in packaging and handling, and the *English Star* exemplifies a modern pallet-friendly ship whose rate of loading and unloading is very competitive with some container ports.

Improved temperature control has enabled the ship operator to maintain the condition of produce for longer than appeared practical some years ago. The limitation of storage life is still likely to depend on the condition of the fruit, the loading temperature and packaging. The modern fruit carrier has an installed capacity theoretically to cool cargoes at a very rapid rate, but as yet it is difficult, if not impossible, to devise an economical system which is as rapid as the pressure cooling system. In theory, given perfect stowage, the modern refrigerated ship should behave in this way, but the inhibiting features are as likely to be the spacing of cartons on the pallet or the spacing of the pallets in the cargo space. However, rapid cooling is not necessarily the answer to good storage but it does remove many problems at an early stage.

This contribution would not be complete without a passing reference to controlled atmospheres, which have re-emerged on this occasion in container services from New Zealand to Europe. First used in the pre-war years for carriage of chilled beef with a 10% concentration of CO_2, it is now being applied to meat cargoes at 25% CO_2 and for fruit in specially modified integral containers. To date apples are the main cargo to Europe but stone fruit has also been sent to the USA and elsewhere. One cannot envisage this type of transport extending to conventional ships in the short term but increasing competition amongst the Southern Hemisphere exporting countries may well change this view.

B. A. PHILLIMORE (APV Hall International Ltd): First I should like to congratulate Messrs Tune and Tennant on their paper. A description of the operational philosophy, design and development of the refrigerated cargo vessel is a subject which, in the past, has received inadequate attention and it is many years since a paper has been presented to the Institute covering this not insignificant element of the marine industry. Secondly, it is appropriate to congratulate Harland & Wolff on their 125th anniversary, of which the present paper and the ships themselves can be regarded an appropriate record of the occasion.

It might be worthwhile considering that in the combined disciplines of refrigeration, shipbuilding and ship operation, the present vessels are the result of a total of three hundred years deep involvement in these activities by the participants. On an historical note, it is interesting to turn the clock backwards and examine records of the earliest Blue Star refrigerated vessels which are available to me.

SS *Broderick* was purchased from Shaw Savill and was in fact built by Harland & Wolff as their Ship 409. As compared with the present vessels, *Broderick* had five hatches with a total of 339 000 ft^3, cooled by a refrigeration installation comprising one horizontal Duplex steam-driven CO compressor, with brine circulation to grid cooling pipes on bulkheads, sides and deckheads. Blue Star Line Ltd are best able to establish the exact number of refrigerated vessels constructed on their behalf since incorporation. My own records indicate a steady rate of construction of at least one ship per year over the forty years from the end of the World War II, all primarily designed for the carriage of refrigerated cargoes.

I would like to comment on certain aspects of the design of refrigeration system installed on the vessels. The following design criteria were stated in the building specification:

1. Seawater temperature: maximum 32 °C (not 37 °C as stated in the paper).
2. Overall heat-transfer coefficient: 0.4 kcal/m^2h K (this is a slightly better coefficient than the conventional 0.45 kcal/m^2h K frequently specified).
3. Temperature requirements: (a) to cool a full cargo of bananas to 12.2 °C, (b) to maintain the full chill cargo at 1.7 °C, (c) to cool frozen cargo loaded at −15 °C within 72 h and (d) to maintain frozen cargo at −24 °C.
4. Operating method: Conditions 3(b) and 3(d) to be achieved with one machine inoperative.
5. Air refreshing: An air refreshing system capable of a maximum of three changes per hour to be installed.

As the design of the vessel developed consideration had to be given to the comparative capacities of the various holds so that an even loading and discharge time could be achieved. This balancing of capacities improved the overall cooling down time as it produced a more even demand on the refrigerating machinery as the spaces were closed. Figure D1 shows the relatively even increments of demand for cooling as the spaces are loaded and closed, reaching a peak of 1450 kW at the end of the 36 h loading period. The load figures allow for two fresh air changes being maintained throughout the period of loading and during the time from hour 36 to hour 76 while the pulp in all compartments is being pulled down to the specified carrying temperature of 12.2 °C.

By close co-operation between the owners, the builders and my company, the design was developed with particular reference to equipment selection to achieve maximum power savings. Air circulation fan powers and duct sizes were chosen to produce no adverse effect on the nett carrying capacities in the compartments in which an air circulation rate of 80–90 changes per hour was established to meet current shippers requirements.

Economy was always a primary consideration in the design of the plant and particular emphasis was given to the air refreshing side. The owners requirement for three changes of fresh air for general cargo but only two or less for refrigerated cargoes meant there could be excessive power input into the refrigeration system and demand on the alternators, but to reduce this the air refreshing units are fitted with two-speed fans with motors running at full and two-thirds speed.

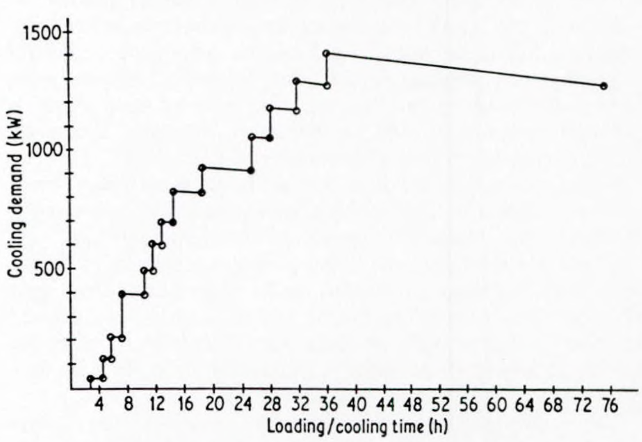

FIG. D1: Load when cooling a full cargo of bananas

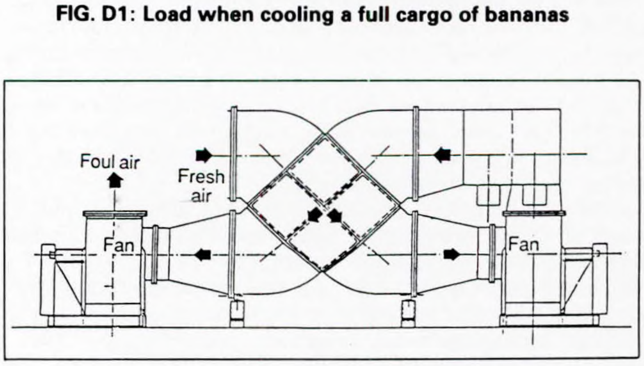

FIG. D2: Air flows with the plate heat exchanger

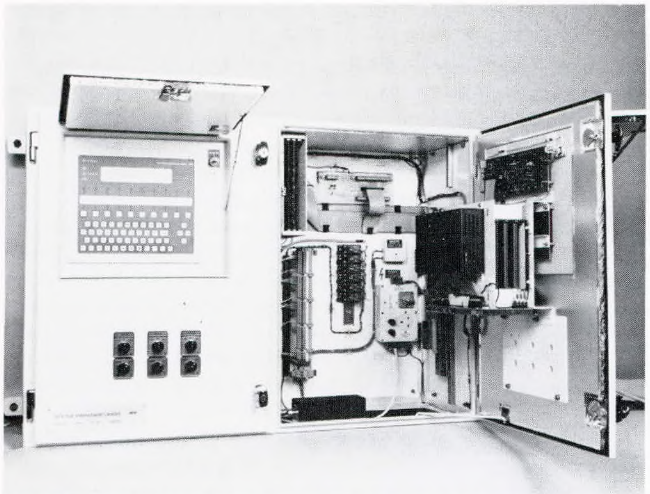

FIG. D3: Control and monitoring equipment for the refrigeration system

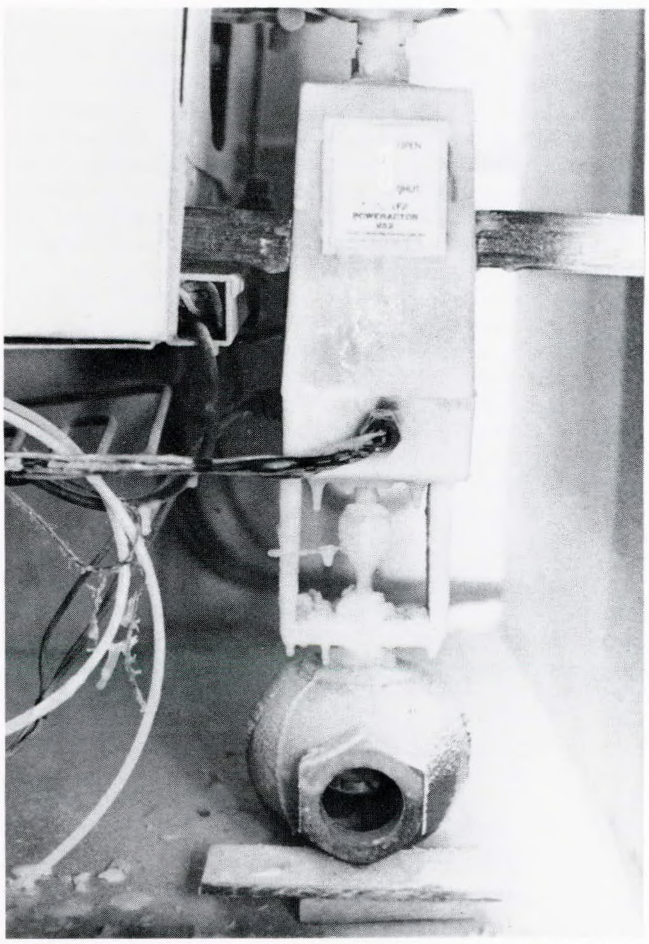

FIG. D4: Electrically operated brine valve under low-temperature test

The other significant feature of the air refreshing system is the plate heat exchanger (see Figure D2), incorporated to prevent any possibility of cross taint between cargoes. As there are two entirely separate air streams there is no likelihood of migration or deposit such as might occur on the wheel-type exchanger. It is anticipated that by the use of the heat exchanger in the fresh air system the demand on the refrigeration system will be reduced by about 60 kW when fully loaded with bananas (160 kW refrigeration only).

The owners required a very high degree of standby for the logger and control system (see Figure D3) on the basis that, unlike a container ship, in adverse conditions it is not always possible to move across decks and obtain access to forward spaces. To achieve these ends, the following factors were incorporated:

1. It has been the practice in the past to put all thermometer points (airstream and space) on a single data logger with, as standby, a separate indicator connected only to airstream thermometers. For these vessels each hatch has a dual outstation, one section of which is connected to half the air and space thermometers in the particular group of compartments and in turn transmits data to the central control/monitoring equipment (see Figure D3) by a dedicated highway. The remaining thermometer points in each hatch are connected to the second section of the outstation and signals are transmitted from there through a second data highway. The connections between thermometer points and the outstations are arranged in staggered fashion such that each section/highway can give a general coverage of the compartments served. Each half section of the outstation has its own keyboard and visual indicator to enable control points to be set and conditions monitored locally.
2. A dual highway is incorporated. In the unlikely event of both highways being faulty, control and temperature readings can be made at the outstation.
3. A master station with duplicate typewriter outputs is fitted and this in turn may be arranged to operate on only one highway if necessary.
4. As well as the normal logging function and printout there is a cassette recorder taking standard tapes for mailing back to head office for later analysis of the logs should it be necessary.
5. The total control system is electrical as the owner wished to get away from the problems associated with keeping control air dry. The valve body employed is well established as is the electric actuator. However, the special requirements required by the application of fail-safe closure and hand operation features resulted in a new top being designed. Extensive trials were undertaken on these in an environmental chamber in our works and those of the manufacturer of the actuator (see Figure D4).

I should now like to comment on certain aspects of Mr Scrine's contribution to this paper.

The specified heat-transfer coefficient of 0.4 kcal/m^{2}h K is in fact a composite figure and has been used for many years, particularly in Europe, and combines the surface and deck edge coefficients identified many years ago as separate elements in a paper presented to this Institute by Hales and Farmer (Insulation of a Refrigerated Cargo Liner). Decks were heavily ribanded and the heat-transfer figures for surfaces took into account improvements over the years in insulating materials. Having said this the ability of a shipyard or insulating contractor to achieve an overall heat-transfer coefficient of any value must primarily depend on the quality of the workmanship rather than the conductivity of the materials.

I believe I may have answered Mr Scrine's question about the rate of air circulation within the cargo spaces, and I have also commented on the arrangements for air refreshing and would like to re-affirm that the system is designed to avoid any risk of cross taint between fresh and foul air.

The paper and Mr Scrine's comments refer to CO_2 and humidity sampling. Facilities for this have been provided and consist of instrumentation in the spaces with data transmitted through the highways to the central data processing/logging installation. The instruments involved are delicate but have been operating since the vessels entered service. The need for monitoring of CO_2 has been recognised for many years with particular reference to fruit cargoes. The need for humidity monitoring is a more recent requirement and can be taken in certain cases as being a reflection on the design of the refrigeration installation where reductions in air heat exchanger sizes can produce dramatic reductions in first cost but lead to an excessively high temperature difference between the cooler surface and air with a consequent high risk of product dehydration.

Similarly, inexperienced engineers operating with too low refrigerant or brine temperatures can produce potentially disastrous effects on the cargo. Humidity measurements and certainly any attempt at control of humidity are expensive and should be compared with equipment cost and education of operating staff.

L. J. GLOVER (Gateway Shipping Ltd): My company is acting as consultants to foreign owners for the construction of two vessels of similar size in the Far East. Consequently, this paper is very timely and I would like to thank Messrs Tune and Tennant and their colleagues for their efforts in the preparation of this paper which is concise, descriptive and worthy of our congratulations.

Bearing in mind that we are competitors in the same business, our marketing information coupled with our operational experience led us to the conclusion that an all-aft configuration would be desirable. Also, by extending the fo'csle head aft, we could have four decks in each hold with roughly the same capacity to give quick turnabouts at European discharge ports. Even with these variations, the vessels' principal dimensions are to within a few percent of the Blue Star ships for the same carrying capacity of 450 000 ft^3.

It is noted that unlike so many of our Far Eastern competitors, Messrs Tune and Tennant have preferred to remain with the Robson side duct for distribution of air to the cargo holds. In addition to other opinions in the paper, have they experience of the ductless system of distribution which supplies the air through gratings in the longitudinal direction from immediately below the brine coolers? We believe there is very little difference in these two methods of distributing air providing the cargo stowage is at a reasonable level of competence. However, the Robson system materially reduces the floor area with its subsequent loss of revenue.

To avoid the use of portable pallet boards as mentioned in the paper, we consider it is preferable to square off the ship's flare where the deckhead line exceeds the deck baseline by more than 8 inches.

I would appreciate the views of Messrs Tune and Tennant and further response to the following:

1. Could they explain their system of storing on the starboard side of the accommodation block. I refer specifically to their statement on page 6 'all stores and equipment are landed directly by pallet or container on the starboard side and moved mechanically directly into centralised deck stores or ship's catering stores within the accommodation'. This system has been used previously for much larger vessels, but from the GA drawing (Figure 1), access to the provision rooms is only via internal or external alleyways. By 'mechanically moved' do they mean mechanical rollers, for example.

2. In the efforts to reduce labour-intensive operations in the engine room, was a centralised cooling system considered, utilising plate coolers on the primary circuit? This may increase overall power requirements slightly, but in my opinion it does materially reduce maintenance.

3. Similarly, were two-speed motors considered for the principal saltwater pumps to reduce the electrical loading? Did they consider fitting three pumps of 50% of the maximum capacity on the main saltwater systems, with one of these pumps being two speed? The combinations are quite good and improve efficiency in reducing the electrical load.

4. I note with interest the block construction of the vessels as shown in Figure 2. Did this materially reduce the construction period, ie from laying the first block until flotation? This may be difficult to resolve with four vessels being built in one dock.

5. On the same theme, was there any particular reason for commencing the construction at the head of the dock rather than close to the gate? It would appear to us that this would simplify the float out.

6. Finally, in the light of hindsight and their operational experience, would Messrs Tune and Tennant change any of the concepts from their completed design as described in the paper?

M. M. THOMSON (IMPAC Offshore Engineering UK Ltd): I should like to congratulate Messrs Tune and Tennant on an interesting paper about a subject that one rarely hears about. My comments/observations on the paper are as follows:

1. It is noted that the hatch covers are designed to accept only one tier of 20 ft ISO containers. Many ships today are sailing with three and even four tiers of containers on the weather deck hatches. What was the reason for this limitation?

2. The arrangement whereby the end leaves can be disconnected from the centre leaves of the hatch covers is of particular interest for it is understood that problems in alignment, cleating and watertightness can arise when reconnecting the end leaves to the centre leaves, particularly if the centre leaves take up their natural deflection with loaded containers on top. I would be interested to know what the operators experience has been to date with this arrangement. Could Messrs Tune and Tennant also explain the method by which the weather deck hatches 'can be further split transversely' or are they referring in this instance to the tween deck hatches.

3. Although modern hatches are 'designed' for one man operation, the number of times this can be implemented on hydraulically operated covers is rather limited. Electrically operated covers can be controlled from a portable console with a wandering lead, but hydraulic control panels must be fixed in one position. Inevitably the control panels are mounted mid-length on the hatch coamings. Operation of the tween deck covers is generally obscured by one end of the weather deck covers remaining closed, or as previously described the centre leaves being left in the closed position during cargo handling. From the safety point of view it is not advisable to close tween deck covers from a remote position without one person being in the tween deck giving instructions to the operator. It would not be the first time a cover has jammed, come off the rails, fallen down the hatch or toppled over because of the absence of an extra person in the tween deck. For the designers to call the system 'one man operated' can be misleading. It is true that one man operates the controls, but in practice a minimum of two men should be present to avoid accidents.

4. From the number of units erected in the building dock a considerable number of manhours have apparently been wasted. The UK's foreign competitors make more use of shop fabrication to cut down the amount of dock/berth work. One of our German competitors with a lower craneage capacity to that of H & W erected a 7000 dwt cargo ship in 8 units including the deck house. I would appreciate the builders comments on selecting the number of units.

Dr B. BAXTER: My questions are concerned with the stability of the vessel. What is the maximum GZ and the range of stability in the load departure and load arrival conditions, and what are the corresponding angles of downflooding?

In the relatively short sea life of the class it would be interesting to know what maximum wave heights have been encountered whilst at sea. How is such information assessed and recorded by the ships and then later reported to the owners?

Authors' reply

We are grateful to Mr Philimore for conveniently answering many of Mr Scrine's queries on points of design incorporated within the refrigeration systems of the *English Star* class. This leaves us with little to add, other than a few minor comments.

As always, in attempting to achieve a balance between first costs and fuel use, the overall heat-transfer coefficient (*K* factor) of 0.4 kcal/m^2 h K remains an ideal norm. However, the quality of the workmanship in the actual insulation outfitting is also important.

Blue Star Line have carried out several investigations over the years of ship construction geometry intended to reduce the labour-intensive operations involved in insulating, with consequent benefits both to ship first cost and quality control. Innovative arrangements, however, remain speculative and improvements are constrained to ultra-detailed attention to steel disbursement and optimum frame module. The use of computers and CADCAM helps in these respects, and the *English Star* class ships contain many of these improvements.

Both Mr Scrine and Mr Philimore mention air circulation rates and air refreshing, both of which are considered very carefully in terms of power and *K* factor, but always within the margins for reliable cargo carriage. As a further comment on air circulation, temperature gradients within the stowed cargo either in block hatch or broken-parcel part stows are important criteria, as Mr Scrine infers. This emphasizes the requirement of a graduated positive distribution throughout the spaces rather than an overall maximum air circulation rate, as is often quoted. For this reason the *English Star* class follows the side-ducting Robson principle.

The problems of water uptake on polyurethane foam are well documented in the work of SRCRA amongst others. Unfortunately water in holds, from weather and accidents, is a fact of life and there are many ships where a water-penetrated tanktop has demanded a great deal of attention.

The rather alarming figures on an apparent average annual deterioration basis quoted by Mr Scrine do not seem to have caused any measurable problem in ships, some now 15 years old, with this type of construction. Accordingly we believe that well fitted slab polyurethane, free from specific loadings, has many advantages.

Nevertheless, water in insulation of any type is something to be avoided as far as practically possible. The polyurethane tank top slabs are sealed and bonded between bearers, and the 19 mm Warkhaus tongued and grooved tank top sheet plating is sealed at the joints and around the periphery with glass fibre resin-bonded cloth.

The choice of direct expansion vis-à-vis brine refrigerating systems is of course a balance between first cost and ongoing operations. It is difficult to establish figures but for the larger installation we believe that the difference in energy consumption in comparative earlier plants represented marginal premiums in favour of direct expansion. With modern brine systems the differences between them and direct expansion systems are virtually non-existent.

Several container ships in the Blue Star fleet with refrigerated cells located conveniently adjacent to the central refrigerating plant room have operated very satisfactorily for years on direct expansion, as does the modern concept of vertical stack refrigerated container systems with adjacent compressors.

In our experience the majority of problems with refrigeration of any type concern the 'hot' gas system. With brine these are disposed of on short lines within the machine room with brine 'cold sink' reserves and standby cargo circulation unhampered whilst any technical malfunction can be recovered. The situation in container ships with short gas lines approximates to these conditions of ready access.

In our view, the extension of direct expansion 'hot' lines and recovery systems through the considerable length of all hatches in a breakbulk reefer is much less attractive in terms of incident probability. The occurrence of a gas line leakage within the loaded ship would disrupt the schedules and could have a disastrous effect on the cargo. Thus we regard brine systems to be worthwhile investments for breakbulk reefers because of the reserves of capacity, the temperature transient timescale, and their simple operation.

Air bags are in fact used in *English Star* class vessels in conjunction with the hinged portable side panels at the hatch ends, and also for trimming the hatch square load in pallets or in broken stows. Air connections are led throughout all spaces for this purpose and air bags are a most efficient and useful development.

We note the comment that air bypass of support side panels has been experienced with certain types of side panel construction. The arrangements giving rise to this do not exist with the portable side panel configurations in *English Star* class vessels and so this problem does not arise.

Finally Mr Scrine's speculations on auto-control of ventilation, increased plant automation and control, and also on the general terms of commodity carriage and development, are of continuing interest and most welcome as an authoritative addition to the paper, as regards both the present state of art and achievements yet to come. We are fortunate to be privy to much of Mr Scrine's work within our mutual associations. Suffice it to say that we look forward to continued discussion and progression concerning many of the points he has raised.

Mr Phillimore comments on the number of Blue Star Line ships, and as a result of several years work summarizing the rather complex archives we can now give detailed answers.

The first ship appears as *Brodmore* and was built as *Rangatira* for Shaw Savill in 1890 by Wm. Gray & Co. of West Hartlepool. By a diverse route she was eventually acquired as *Brodmore* by Vestey Group Associates in 1912, emerging under Blue Star's house flag in 1917. Homeward bound in the Mediterranean with frozen meat, she was torpedoed and sank off Tripoli in that year.

Broderick, the second ship, also arrived with Group associates in 1912, finding her way to Blue Star in April 1918. She suffered the same fate as *Brodmore* on passage from London to Venezuela later in that year.

From these records the present count of principally refrigerated vessels under the Blue Star house flag from that day to completion of the *English Star* class stands at just 200, an interesting and graphic example of the changing face of marine technology across the years.

We are grateful to Mr Phillimore for pointing out the error in that the maximum refrigerated system sea water design point is 32 °C and not 37 °C as incorrectly stated in the preprint. This has been corrected. We also thank him for the comprehensive summary of the design of the refrigeration systems.

The concentration on optimising all energy aspects of the refrigerated plant and cargo cooling system resulted in a downward shift of 30% from original estimates of installed power. This not withstanding, experience in all vessels in various cargo modes is producing figures that are encouragingly, and perhaps unexpectedly, inside even these reductions in expected targets. More experience is yet required, but we consider that these improvements over hitherto traditional levels of energy requirement are probably due not only to the benefits of the latest developments in single-screw compressors, air freshening heat-exchange systems etc. and air distribution, but also to the advanced cooler modulation and control functions associated with the degree of automated monitoring and control adopted in these vessels. Experience to date is promising and bodes well for future advances.

On the points raised concerning monitoring and recording the relative humidity, our development continues towards a totally reliable instrumentation system capable of recovering this important task from the traditional methods of regular manual recording. We can only agree, however, with Mr Phillimore's closing comments on this subject.

We note Mr Glover's comments with regard to his company's final selection of the all-aft configuration for two vessels of similar cubic capacity.

Continuity of hatch working for minimum full ship overall loading/discharging rates is achieved in the *English Star* class with a combination of crane double working, ie the no 1 crane being turned over to assist nos 2 and 3 on the larger 2 and 3 hatches on earlier completion of the loading of no 1 hold. In recent experience full ship loadings and discharges (ca. 4000 pallets) have been achieved within 14 h, a rate which, within the logistics of port supporting operations in this type of trade, seems difficult to better and indeed approaches the fastest rates of our experience.

Over the years several vessels incorporating fore deck no 1 hatches with extended forecastle decks have been built and seen service in the Blue Star Line fleet. However, disadvantages with stability/ballast relationships for this arrangement across the spectrum of the various commodities to be carried have caused us to look for the lowest cargo/tonne mile cost solution in balanced hold proportions, as adopted for the *English Star* class.

We have considerable previous experience of the ductless systems of air distribution leading to our preference for the Robson system. The reasons for this are outlined in the paper and in the comments of Messrs Scrine and Phillimore and our replies to them.

In our opinion the theoretical advantages in deck space implied by the ductless system are marginal rather than material and in practice doubtful in terms of realistic revenue. For new-buildings considerations regarding maximising deck areas for pallets and the overall cubic payload can be dealt with effectively in the design stage.

We are not clear as to Mr Glover's advice with regard to vertical squaring off of all shipside flare in excess of 8 inches over the deck baseline, unless this refers to a purely pallet carrier. As noted, the ducted system achieves this by utilising the volume contained within the squared off shipside flare for air circulation with deck areas maximised to shipside deck edge. In areas of more extreme flare forward, hinged portable vertical squaring off boards are provided.

We apologise for the insufficient clarity on mechanised ship storing. The arrangements provide for either forklift pallet trucking direct from the starboard after deck into the internal handling room and various storerooms (the principal operation) or by container breakdown from no 5 hatch cover via portable roller trackway.

Centralised cooling systems are attractive and their use was evaluated. In the event all the considerations between energy requirements and reliable simplicity were considered to be optimised in the arrangements selected, which comprise a co-ordinated arrangement of pump size and uses in combination with plate coolers. As noted, the results in terms of reduced kW loadings is quite promising.

Block construction is a feature of shipbuilding at Belfast as it allows the maximum amount of work to be carried out in shops under cover. It is the aim also to reduce dock time. In the case of these vesels the requirement was to deliver four ships in rapid succession so the logistical problems were different from those normally encountered.

The first vessels were built at the head of the dock behind the intermediate gate because the seaward end of the dock was at that time being used to construct a 173 000 dwt bulk carrier.

In all circumstances it is of course possible, with hindsight, to improve on past endeavours, but as the service life of the vessels increases, all the design objectives derived from exhaustive discussions and planning now appear to be emerging. Such improvements as have been identified relate to consolidation of new principles and have been applied to the shipboard operational management.

Such changes as we might foresee for the future are likely to lie with further longer-term developments in this area and in manning, and have hopefully been anticipated within these ships for ready appliction when the opportunities arise.

In reply to Mr Thomson's contribution, deck container carriage of three or four tiers high is very much the practice in our company's container services, but with *English Star* class vessels the carriage of containers is seen as a secondary facility to the ships' main role as breakbulk reefer vessels.

In the complement of 106 containers, one tier on deck falls very conveniently within the stability spectrum for reefer commodities. The extra first costs in hatch cover strengths and extra ballasting facilities for further tiers is not seen as attractive. This is simply a matter of commercial economics for this type of trade.

As the weather deck hatch covers on these vessels consist of only four panels, the opening variations are limited to the natural centre opening and also the end panels by first removing large link pins and drawing back these panels, leaving the centre panels in position. The tween deck hatch covers can consist of up to eight panels and can, with difficulty, be split in quite a variety of ways.

As far as the *English Star* class vessels are concerned the hatch covers at each deck level are only operable from control positions at their own levels, therefore the question of impaired visibiity from one deck level to another does not arise. The system could thus be termed 'one man' operation.

The decision on the number of units and blocks to be used in a vessel's construction must always be a matter of compromise. In the centre portion of the vessel large blocks forming a ring structure were used because the blocks were self-forming and easily supported on the ship trolleys. In addition, by using trolleys which are movable, they could be matched to each other. At the ends of the vessel, because of shape, this was not possible and to ensure the retention of ship form by good fairing the construction was by smaller weldments.

The German competitor may have had only one slip and it therefore was necessary to build large blocks adjacent to the ship to reduce berth time. In our case, with a much reduced order book and ample dock space, it was not sensible for us to do this.

In reply to Dr Baxter, for load departure conditions the maximum GZ is 1.42 m with a range of stability of 98° and an angle of downflooding of 77°. For load arrival conditions the maximum GZ is 0.96 m with a range of stability of 88° and an angle of downfalling of 78°.

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