



# THE MERCHANT SHIPPING ACT, 1894

## REPORT OF COURT (No. 7951)

### m.v. "Reina del Pacifico" O.N. 162339

In the matter of a Formal Investigation held at the County Courthouse, Crumlin Road, Belfast, on the 20th, 21st, 22nd, 23rd, 26th, 27th, 28th, 29th, and 30th days of April, 1948, and the 1st, 3rd, 4th, 5th, 6th, 7th, 8th, 10th, 11th, 12th, and 13th days of May, 1948, before J. H. Campbell, Esq., K.C., R.M., assisted by John Lamb, Esq., O.B.E., A.M.I.M.E., F.I.P., W. L. Nelson, Esq., O.B.E., M.I. Mar. E., and Ivor J. Gray, Esq., A.M.I.N.A., M.I. Mar. E., into the circumstances attending the explosion in the machinery space of the Motor Vessel "Reina del Pacifico," which occurred on the 11th of September, 1947, while the vessel was undergoing sea trials in the Irish Sea and Firth of Clyde.

The Court, having carefully inquired into the circumstances attending the above-mentioned shipping casualty, finds, for the reasons stated in the annex hereto, that the primary cause of the explosion in the main machinery space of the "Reina del Pacifico" was due to the piston of No. 2 port outer engine overheating and igniting an inflammable mixture present in the crank chamber of said engine.

Dated this 5th day of June, 1948.

J. H. CAMPBELL, *Judge.*

We concur in the above Report.

JOHN LAMB

W. L. NELSON

IVOR J. GRAY

} *Assessors.*

#### QUESTIONS AND ANSWERS.

The Court's answers to the questions submitted by the Ministry of Transport are as follows:—

- Q. 1. By whom was the vessel owned?  
A. Pacific Steam Navigation Company, of Liverpool.
- Q. 2. How long had the vessel been so owned?  
A. Seventeen years.
- Q. 3. (a) By whom was the vessel built?  
A. Messrs. Harland & Wolff, Limited, Belfast.  
(b) By whom were the engines designed, built and fitted?  
A. Messrs. Harland & Wolff's adaptation of Burmeister & Wain design; built and fitted by Messrs. Harland & Wolff, Limited, Belfast.
- Q. 4. Where and when was the vessel built?  
A. At Belfast, in the year 1931.

- Q. 5. Was the vessel disabled by explosion in the main machinery space at approximately 4.46 p.m. B.S.T. on the 11th day of September, 1947?  
A. Yes.
- Q. 6. Did such explosion, if any, occur when the vessel was approximately 7 miles N.E. of Copeland Island in North Channel, Irish Sea?  
A. Yes.
- Q. 7. Was the vessel undergoing sea trials when the explosion occurred?  
A. Yes.
- Q. 8. (a) When did the vessel last leave port before the explosion occurred?  
A. Vessel sailed on intended trial voyage at 7.15 a.m. on the 10th September, 1947.  
(b) What port did she so leave?  
A. Belfast.  
(c) Was the vessel in good and seaworthy condition when she last left port?  
A. Yes.
- Q. 9. How many persons lost their lives as the result of the explosion?  
A. Twenty-eight.
- Q. 10. For approximately 12 months prior to the date of the explosion had the "Reina del Pacifico" been undergoing a complete refit together with machinery overhaul at Belfast?  
A. The ship did not undergo a "complete" refit during the twelve months prior to date of the explosion. The reconditioning was confined to that set out in the repair list dated 27th September, 1946.
- Q. 11. Did such refit and overhaul follow a period of employment as a troopship on war service?  
A. Yes.
- Q. 12. Prior to the war had the "Reina del Pacifico" been employed as a passenger liner between the United Kingdom and the West Coast of South America?  
A. Yes.
- Q. 13. Had any explosion similar to the one which is the subject of the Inquiry occurred on board the vessel previously?  
A. No.
- Q. 14. Are there any records of any parts of the main engines overheating prior to the refit and overhaul referred to in Question 10? If so, what action was taken thereon?

- A. Yes. Lubricating oil was applied by hand to the overheated parts, and fuel was either cut off the cylinder concerned, or the engine control lever was brought to the "stop position."
- Q. 15. Had the main engines of the vessel given satisfaction during the service as a liner and as a troopship?
- A. Yes.
- Q. 16. Was a sea trial commenced on the 2nd day of September, 1947?
- A. Yes.
- Q. 17. When was such trial (a) commenced, (b) abandoned; and (c) for what reason was it abandoned?
- A. (a) 2nd September, 1947.  
(b) 2nd September, 1947.  
(c) Owing to serious overheating of piston and cylinder of No. 6 starboard outer, No. 11 port outer, and No. 2 port outer to a lesser degree.
- Q. 18. What defects, if any, were discovered in the vessel's main engines as a result of such trial? What action was taken with regard to such defects?
- A. (a) Port outer No. 11 piston and cylinder liner badly scored; starboard outer No. 6 cylinder jacket cracked; piston and cylinder liner badly scored; port outer No. 2 cylinder liner and piston found in good order.  
(b) Port outer No. 11 cylinder liner and piston renewed; starboard outer No. 6 cylinder jacket, liner and piston renewed; port outer No. 2 thoroughly cleaned, carefully examined and no renewals or repairs effected.
- Q. 19. When the second trial was commenced on the 10th day of September, 1947,
- (a) Who was in command of the vessel?
- A. The Master, viz. John Whitehouse, who was on the ship's register on the second trials.
- (b) Who was responsible for the manning and running of the machinery (other than main engines)?
- A. Having regard to paragraph 3 of Exhibit "T," which document was proved by Robert T. Oxburgh, the manning and running of the machinery (other than the main engines) was the joint responsibility of the owners and repairers.
- (c) Who was responsible for the manning and running of the main engines?
- A. Witnesses on behalf of the Pacific Steam Navigation Company, stated, and their Counsel contended, that no servant of the company was responsible for the manning and running of the main engines. It was submitted on behalf of the Pacific Steam Navigation Company, that the manning and running were the responsibility of Messrs. Harland & Wolff, Limited. Counsel on behalf of Messrs. Harland & Wolff, Limited, submitted that the responsibility was joint. The Assistant Head Foreman of Messrs. Harland & Wolff swore that the control and responsibility was that of the Owners. In these circumstances it would appear that when the second trials commenced on the 10th September, 1947, neither of the parties considered themselves exclusively responsible for the manning and running of the main engines.
- (d) Were the machinery and main engines adequately manned and were all proper precautions taken?
- A. In view of answer to (c) it is clear that an essential precaution (viz. that of having some official of one or other of the parties in control and responsible for the manning and running of the main engines), was lacking. Further, it is apparent that there was divided control and responsibility in the manning and running of the main engines, which in the circumstances was unsatisfactory.
- Q. 20. (a) Did any material defects in the machinery (including main engines) arise during the second trial?
- A. Yes.  
(b) If so, what were they, and what action was taken in respect of them?
- A. The fuel pump spill valve of No. 8 cylinder starboard outer engine not functioning; No. 2 cylinder liner of port outer engine overheating. Spill valve changed without desired improvement.  
No. 2 cylinder fuel valve of port outer engine by-passed, and in a short space of time control lever brought to "stop" position. Within four to five minutes later the control lever was put into "starting" position.
- Q. 21. (a) Were any such defects observed immediately prior to the explosion?
- A. Yes.  
(b) If so, in which part of the machinery including main engines were the defects, if any, observed?
- A. See answer to Question 20.  
(c) What were the defects?
- A. See answer to Question 20.  
(d) What action was taken in consequence of the discovery of such defects?
- A. See answer to Question 20.
- Q. 22. (a) At what speed, in revolutions, were the main engines running at the time of the explosion?
- A. The three engines, port inner, starboard inner, and starboard outer, were running at 128 to 130 revolutions per minute as far as could be ascertained from the evidence.  
With reference to the port outer engine, it is difficult to estimate with any degree of accuracy the revolutions at which this engine was running. However, it would appear from the evidence that the revolutions of this engine were, at the time of the explosion, approximately fifty per minute.  
(b) For how long had the main engines been running, and at what speeds?
- A. From 7.15 a.m. on the 10th September, 1947, until 4.40 p.m. on the 11th September, 1947, at varying speeds up to full speed.  
(c) Had the main engines been running at a higher speed at any time during the trial on which the explosion occurred?
- A. No accurate records of engine revolutions during any part of the trial were forthcoming, but there are indications that the main engines were operating at their maximum speed from noon on the 11th September.
- Q. 23. (a) Was the accident the result of one explosion or more than one?
- A. More than one.  
(b) If more than one explosion, how many?
- A. Four.  
(c) If more than one explosion, were the explosions simultaneous or separate?

- A. The explosions were separate, but according to the evidence were almost simultaneous.
- (d) If there were more explosions than one, were all the explosions the result of a common cause?
- A. Yes.
- Q. 24. Where did the explosion or explosions originate?
- A. The first explosion occurred in number two crank chamber of port outer engine. The other three explosions occurred in the crank cases of port inner, starboard inner, and starboard outer engines.
- Q. 25. (a) What were the causes of the primary explosion or explosions and any subsequent explosions?
- A. The primary explosion was caused by the overheating of No. 2 piston of the port outer engine. The other three explosions were due to the inflammable content of the crankcases being ignited.
- (b) What explosive mixtures were involved?
- A. A mixture of atomized or vapourised lubricating oil, and air.
- Q. 26. Were all four main engines involved in the explosion or explosions?
- A. Yes.
- Q. 27. What was the effect of the explosion or explosions,
- (a) on the ship's machinery, including main engines?
- A. Damage to the closing plates and covers of crankcases of all four engines.
- (b) On the ship's structure?
- A. Negligible damage to ship's structure; access ladders and lifting beams in engine room badly damaged.
- Q. 28. (a) Were any fires started in the vessel as a result of the explosion?
- A. Yes.
- (b) Was fire fighting promptly organised and applied?
- A. Yes.
- Q. 29. Were rescue and first-aid measures promptly organised and applied?
- A. Yes.
- Q. 30. Were such explosion or explosions connected with the fuel oil system or with the lubricating oil system?
- A. The lubricating oil system.
- Q. 31. Was the lubricating oil of proper quality, quantity and condition?
- A. Yes.
- Q. 32. Was the fuel oil of proper quality, quantity and condition?
- A. Yes.
- Q. 33. Was the lubricating oil in any of the crankcases found to be contaminated by fuel oil or any other substance? If so, did such contamination increase the danger of explosion?
- A. Yes, to a very slight degree. This contamination did not increase the danger of explosion.
- Q. 34. Were such explosion or explosions caused by or contributed to by any wrongful act or default or error of judgment of the owners of the vessel, The Pacific Steam Navigation Company, or any of their servants?
- A. In view of the conflicting nature of the evidence given, the Court is not prepared to hold that the explosion in port outer No. 2 was caused

by or contributed to by any wrongful act on the part of any servant of the Pacific Steam Navigation Company, except in so far as is disclosed in answer to Question 19 (c) and (d).

- Q. 35. Were such explosion or explosions caused or contributed to by any wrongful act or default or error of judgment of the repairers, Messrs. Harland & Wolff, Limited, or any of their servants?

A. In view of the conflicting nature of the evidence given, the Court is not prepared to hold that the explosion in port outer No. 2 was caused by or contributed to by any wrongful act on the part of any servant of Messrs. Harland & Wolff, Limited, Belfast, except in so far as is disclosed in answer to question nineteen (c) and (d).

This Inquiry was held in Belfast, on the 20th, 21st, 22nd, 23rd, 26th, 27th, 28th, 29th, and 30th days of April, 1948, and the 1st, 3rd, 4th, 5th, 6th, 7th, 8th, 10th, 11th, 12th, and 13th days of May, 1948.

L. E. Curran, Esq., K.C., M.P., His Majesty's Attorney General for Northern Ireland, and F. A. L. Harrison, Esq., Barrister-at-Law (instructed by John B. Getty, Esq., for Treasury Solicitor), appeared on behalf of the Ministry of Transport. K. S. Carpmael, Esq., K.C., W. W. B. Topping, Esq., K.C., M.P., and E. W. Jones, Esq., Barrister-at-Law (instructed by Messrs. C. & H. Jefferson for Messrs. Hill Dickinson and Company, Liverpool), appeared on behalf of Messrs. Harland and Wolff, Limited, Belfast, Contractors of the Repairers. C. L. Shiel, Esq., [K.C., and G. B. Hanna, Esq., K.C. (instructed by Messrs. McKinty and Wright for Messrs. Batesons and Company, Liverpool), appeared on behalf of the Owners of the "Reina del Pacifico" (The Pacific Steam Navigation Company).

James McSparran, Esq., K.C., M.P., and H. A. McVeigh, Esq., Barrister-at-Law (instructed by F. Hanna, Esq., M.P.) appeared on behalf of representatives of Edward McAllister, James E. Barnes, Robert Currie Ellis, William Mills, James McAllister, J. D. McBlain, Robert C. McClure, Wesley Patterson, John Redmond, Samuel Richmond, James Bernard Savage, and Thomas Wilson, deceased, and of Robert Robinson, William Magee, R. Downey, Wm. Morrison, George Crowe and Cyril Osberg, injured, all of whom were made parties to the proceedings on the application of Mr. McSparran.

Francis Hanna, Esq., M.P., Solicitor, appeared on behalf of representatives of Ferney B. Glenfield, deceased, and representatives of Patrick J. Dunn, deceased, and D. R. Martin, Esq., Solicitor for Messrs. Keightley Jenkins and Company, Meols, Cheshire, appeared on behalf of the representatives of Harold Fay, deceased, and on behalf of the Navigators and Engineer Officers' Union.

G. B. H. Currie, Esq., Barrister-at-Law, (instructed by Messrs. Percy Hughes and Roberts, Solicitors, Birkenhead) appeared on behalf of representatives of Frederick Johnston, deceased. Mr. Currie (instructed by R. J. Livesey, Solicitors, Liverpool), also appeared for the representatives of A. H. Jones, deceased, and both parties were made parties to the proceedings on the application of Mr. Currie.

J. I. P. McCracken, Esq., Barrister-at-Law (instructed by Messrs. George McCracken and Company), appeared on behalf of representatives of Charles Thompson, deceased, and representatives of Hugh Doherty, deceased.

W. P. E. Alexander, Esq., Solicitor, appeared on behalf of representatives of Robert J. Thompson, deceased.

The m.v. "Reina del Pacifico" is a quadruple screw motor passenger vessel of 17,702 gross tons, being 551.3 feet in length, 76.3 feet in beam and 37.9

feet in depth registered dimensions. The vessel was built and engined by Messrs. Harland and Wolff, Limited, in 1931, to the order of the Pacific Steam Navigation Company, with registered offices at Liverpool, and at which port she is registered and continuously owned by this Company to the present day. She has five decks, A. to E., E. deck being uppermost and surmounted by a boat deck, which in turn is surmounted by a house which forms accommodation and which carries the funnels. She has five lower holds for cargo.

The vessel was designed for passenger service between the United Kingdom and the West Coast of South America, and was so employed, excepting during the war, when she was on charter to H.M. Government for trooping purposes.

The assigned summer draught is 31 feet 2½ inches. At the time of the explosion, however, the draughts were 17 feet 11 inches forward and 26 feet 3 inches aft.

*Classification.* The vessel held the class of 100 A.1. with freeboard in Lloyd's Register Book and was undergoing periodical special survey of hull and machinery during reconditioning in association with a renewal survey for load line; and certificates for special survey of hull and machinery and for renewal of load line were to have been issued on the completion of satisfactory trials.

*Passenger certificates.* Since 1931 the vessel has held a Board of Trade or Ministry of Transport Passenger and Safety Certificate for International voyages, carrying 886 passengers and 301 crew. Her last certificate expired on the 5th October, 1946, at the time the vessel arrived for reconditioning at Belfast. She was surveyed during reconditioning, and a further twelve months certificate was to have been issued on the completion of satisfactory trials.

#### EQUIPMENT ON BOARD.

*Life-saving appliances.* These complied with the Ministry's requirements for a foreign-going passenger vessel of this size, and comprised the following:—

- 16 lifeboats including 1 motor boat and 1 boat with auxiliary motor, capable of carrying a total of 1,349 persons.
- 14 Buoyant apparatus for 308 persons.
- 1,402 Lifejackets.
- 18 Lifebuoys.

*Medical stores.* These were supplied in accordance with the Merchant Shipping Medical Scales, 1945, Scale III, except that the Laudanum, Morphine tablets and Omnopon were not included. Owing to the dangerous nature of these drugs they had been removed from the ship in Belfast to avoid accidents by pilfering.

There were available, however, the 16 first aid kits from the lifeboats together with 50 supplementary "A" kits, and these provided an ample supply of Morphine tablets under normal circumstances.

The ship, being on a coastal voyage, was not required to carry any medical stores beyond a first aid kit, but she was in fact amply provided for the numbers on board at the trial.

*Fire fighting equipment.* The fire fighting equipment on board at the time of the second sea trial on 10th and 11th September, complied with the Ministry's requirements for a foreign-going passenger motor vessel of this size except in regard to a second smoke helmet which had been damaged and was then ashore for repair. The fire fighting equipment comprised the following:—

- 2—95 ton vertical rotary fire pumps in engine room.
- 1—95 ton vertical rotary emergency fire pump in generator room.
- 2½ inch fire main on each side of each deck with valves and couplings at 90 to 100 feet intervals.

41—50 feet lengths of 2½ inch canvas hose.

Fireproof bulkheads on all decks.

51—2 gallon foam type extinguishers distributed throughout accommodation.

12—2 gallon foam type extinguishers distributed throughout machinery spaces.

12—1 quart carbon tetra chloride extinguishers at switch boards and cinema.

4 Foamite hopper type continuous foam generators, two in main engine room and two in generator room, each capable of discharging 400 gallons of foam per minute.

2—10 gallon foam extinguishers, one at waste heat boilers and one in generator room.

"Rich" fire detection and steam fire extinguishing installation for each cargo space.

1—Smoke helmet and equipment (see note above)

#### ARRANGEMENT AND DESCRIPTION OF MACHINERY

*Arrangement of machinery.* The machinery space is amidships and extends from water-tight bulkhead 35 forward to 49 aft, and is divided as follows:—

Watertight bulkhead 35 Forward to 13 Forward	Oil fuel bunkers and settling tanks.
Watertight bulkhead 13 Forward to 2 Aft	Auxiliary generator room.
Watertight bulkhead 2 Aft to 34 Aft	Main engine room.
Watertight bulkhead 34 Aft to 49 Aft	Refrigerating machinery.

The main engine room is 83 feet mean length by 76 feet breadth by 28 feet high with a light and air casing 40 feet long and 17 feet wide extending upwards to the skylight.

*Description of machinery.* The propelling machinery comprises four independent engines placed abreast, each driving its own propeller direct, and each having 12 cylinders 630 millimeters (24.8 inches) bore by 1,200 millimeters (47.24 inches) stroke, the total service power being 16,000 Brake Horse Power at 130 revolutions per minute, giving the vessel a service speed of about 19 knots. The engines are designed for 18,000 Brake Horse Power.

The engines are Harland and Wolff's adaptation of Burmeister and Wain's design, and are of the four stroke single acting trunk piston type, pressure charged by exhaust gas turbine driven air blowers.

The cam shaft is chain driven from the crankshaft between Nos. 6 and 7 cylinders. The fuel valves are of the airless injection type with a group of three fuel pumps on the inboard side of Nos. 2, 5, 8, and 11 cylinders of each engine.

All auxiliaries are electrically driven by power supplied by four Diesel engine-driven generators each of 350 kilowatts capacity. The Diesel engines driving these generators are of the four stroke, six cylinder, trunk piston, airless injection type of Harland and Wolff design.

*Exhaust and pressure charge system.* The exhaust gas from the 12 cylinders of each engine passes forward through the respective manifolds to turbines mounted opposite the forward end of each engine on a common flat 10 feet above the lower platform level. Each turbine drives a rotary blower which draws air from the engine room through a mesh-protected opening below the flat. The discharge from each blower is trunked aft, above and to the rear of each engine with distributing pipes into the cylinder air inlet valves. Arrangements are provided to by-pass the exhaust gas in an emergency.

*Waste heat boilers.* On a platform at "D" deck two waste heat boilers are each arranged to take the exhaust from two main engines. Each boiler has two oil burners for use when the exhaust is being by-passed direct to the silencers and funnel. Diesel fuel is supplied from an overhead tank to the burners

and is injected by air under pressure from electrically driven blowers. The steam is used to supply hot water for domestic purposes by means of calorifiers.

When the incident, which has been the subject of this Inquiry, took place, the boilers had been working on exhaust gas for about three hours with fuel completely shut off.

*Main engine fuel system.* Diesel fuel is fed by gravity from service tanks on the after bulkhead to two working and one stand-by electrically driven low pressure pumps of the rotary type. These pumps normally deliver direct to the fuel pumps at the front of the engines, which in turn deliver the fuel under high pressure to the fuel valves in the cylinder head.

Whilst manoeuvring, the low pressure pumps deliver to the boiler fuel tank. The engine fuel pumps in turn draw their supply by means of gravity from this tank. The timing and control of the fuel injection which determines the speed of the engine is arranged at the fuel pumps by means of a spill device, the pumps being main engine driven and located at approximately five feet above engine room platform.

The fuel pumps are mounted entirely outside the crankcase and there is no way in the event of leakage from these pumps, in which fuel can find its way into the crankcase.

The controls for the two port engines are brought to the forward end of the port inner engine, while those of the starboard engines are brought to the forward end of the starboard inner engine.

*Crankcases.* All crankcases are totally enclosed, the doors on the sides, both back and front, being readily removable, except those in way of the fuel pumps. The top of each crankcase is closed by cast iron diaphragm plates between the "A" frames. Cylinder liners project  $7\frac{1}{2}$  inches into the crankcases while the pistons, when at the end of their down-stroke, project  $16\frac{1}{2}$  inches below the liners. The bottom of each crankcase is oil-tight and has been described to the Court under the heading "drain tanks."

The crankcase doors are of comparatively light steel  $\frac{3}{32}$  inch thick, suitably stiffened round the edge, and secured by a special form of dog. The doors are 6 feet 3 inches high by 3 feet 3 inches wide and weigh 155 pounds each. There are, in addition, small doors 2 feet high by 3 feet 3 inches wide of similar construction situated below the fuel pumps. Each engine thus has 20 large and 4 small crankcase doors, also a back gear case door. The end doors are of cast iron one-half inch thick, suitably ribbed, and held by studs and nuts.

The crankcase is common to the 12 units by way of apertures about 3 feet high by 2 feet 10 inches wide above the main bearings, and 1 foot  $10\frac{1}{2}$  inches high by 7 feet 6 inches wide below the main bearing together with a  $4\frac{1}{2}$  inches by  $5\frac{1}{2}$  inches aperture in both upper corners of each "A" frame. In addition, the chain driving the cam and fuel pump shafts between Nos. 6 and 7 cylinders is totally enclosed in a cast iron casing 1 inch to  $\frac{1}{2}$  inch thick extending to the top of the engine, the whole of this casing being open to the crankcase at the bottom.

Sheet steel splash plates are fitted over each crank web to prevent oil being thrown up on to the cylinder liner.

*Crankcase vapour extraction system.* To obviate the fouling of the engine room atmosphere by leakage of fumes, an electrically driven fan is installed for each engine. The fans draw through  $3\frac{1}{2}$  inch bore pipes connected to the diaphragm plates at Nos. 3 and 10 cylinders, and a 4 inches bore pipe to the top of the chain drive gear case. The vapour is then led through a common 9 inches bore pipe to the fan which discharges through a sea water cooled oil

extractor and thence to the top of the funnel. The fans for the two inboard engines are on the blower flat forward, and those for the outboard engines are on an after flat. The discharges from the two starboard engines run into a common trunk at the base of the funnel and those from the two port engines are joined similarly. Although means are provided for draining off any oil collected by the coolers, there is no record of any appreciable amount being collected. Examination of the pipes and coolers after the occurrence showed the cooler tubes to be completely free from oil. The pipes leading from the crankcase to the fan were coated with oil. Oil was also found trapped in the collecting drum at the fan inlet, and finally by the fan impeller, the casing of which was provided with a drain. It would, therefore, seem that the oil mist is trapped mechanically and that any gases present pass through the cooler without condensing.

No special means are provided for the admission of air into the crankcase, but a certain amount can enter by way of the air pipe, and sump drain pipe described under "drain tanks," and through minor leaks at the bottom of the crankcase doors and between the lower ends of the cylinder liners and diaphragm plates.

On the crankcase covers, at the forward and after ends of each engine an explosion vent is provided. These vents are covered by perforated steel plates on the outside of which are fitted millboard discs 0.134 inches thick. This millboard is intended to burst in the event of an explosion in the crankcase.

*Lubricating oil system and drain tanks.* On the after port side of the engine room there is one working and one stand-by electrically driven rotary pump, one of which draws lubricating oil from one or other of the drain tanks under the port inner and port outer engines. These pumps deliver the oil through the cooler to distribution pipes on the back of the outer engine and the front of the inner engine.

For each unit there is one pipe which conveys the oil to the main bearing, crank pin, and gudgeon pin bearing, by way of holes in crankshaft and connecting rod. From these bearings the oil drains to the engine sump and thence to the drain tank.

At each unit a pipe conveys oil to a trombone pipe situated under each piston. This oil flows through the hollow piston for cooling purposes, and returns through a second trombone pipe into an outlet pipe located along the front, in the case of the outer engine, and the back of the inner engine. The oil returning from the pistons is led into the same drain tank which receives the oil from the bearings. The same system supplies oil to the chain drive.

A similar arrangement applies to the starboard inner and starboard outer engines with a pair of pumps on the starboard side aft.

The tank top is recessed 2 feet 5 inches deep throughout the length of each engine to form an oil sump, and between Nos. 6 and 7 cylinders two valve controlled outlets of 6 inches bore allow the oil to drain into one or other of the oil drain tanks formed in the double bottom below the sump. Two similar outlets are also placed below No. 12 cylinder on each engine. Sieve plates having  $\frac{11}{16}$  inch diameter perforations cover drain pots in way of these outlets, and in addition the sump has a working platform 7 inches above the bottom and made of steel plate, having  $\frac{3}{8}$  inch diameter perforations. During the basin and sea trials, the oil from the port outer and port inner engines was being drained into the port inner tank, and the port outer tank which contained a certain quantity of clean oil was not in use. The starboard inner drain tank was similarly used for the starboard inner and outer engines. There is no connection between the drain tanks of the port engines and the drain tanks of the starboard engines except that from two 4 inch branches on each drain tank

a 5 inch air pipe is led to the top of the funnel, the pipes from the two outer tanks being joined to a common pipe at "D" deck and the two inner tank air pipes are similarly arranged.

Independent centrifugal separators are used for purifying the lubricating oil and fuel oil. The pipe systems of these separators are not connected in any way. The separators are located on the starboard side, the fuel oil separators being forward, and those for the lubricating oil situated at the after end.

*Lubricating oil supplies.* Log entries dated 8th September, 1947, show that the main engine crankcase oil was disposed as follows:—

Port outer double bottom drain tank 1,680 gallons (not in circulation at trial).

Port inner double bottom drain tank 4,760 gallons (in circulation at trial).

Starboard inner double bottom drain tank 4,760 gallons (in circulation at trial).

Starboard outer double bottom drain tank 1,680 gallons (not in circulation at trial).

Reserve tank at "A" deck 800 gallons (not in circulation at trial).

The whole of the above oil was unused prior to the basin trial on 6th August, 1947, and was supplied by W. B. Dick & Company, 8,000 gallons being supplied on 25th July, 1947, and the remainder at various times prior to the vessel arriving in Belfast for refit.

In addition, the following lubricating oils were on board:—

Used main engine crankcase lubricating oil in starboard outer storage tank .. .. .	1,600 gallons
Auxiliary engine crankcase oil in starboard inner storage tank CY3 grade .. .. .	1,660 "
Cylinder lubricating oil in cylinder oil storage tank .. .. .	280 "

There was also on board small quantities of stern tube oil, compressor oil, and telemotor oil.

*Fuel.* No diesel fuel was taken aboard in Belfast, and at the time of the trial there remained 734 tons in deep tanks Nos. 1 and 2, 3 and 4. In addition there was 8½ tons in the service tanks. The fuel was supplied by the Shell Company of Egypt in July and August, 1946. It was gas oil having a specific gravity of 0.83 at 90° Fahrenheit, closed flash point of 190° Fahrenheit, and 31 Redwoods viscosity at 140° Fahrenheit in seconds per 50 cubic centimetres.

*Engine Room Ventilation.* A pair of 45 inch fans situated forward of the engine room skylight provide positive ventilation to all parts of the main engine room at various heights, and in addition a discharge trunk is carried below the bottom platform in each forward corner. A pair of 40 inch fans ventilate the auxiliary engine room.

In formulating this report it is deemed necessary to deal in detail with an outstanding consideration which has arisen in the course of the Inquiry. A glance at the history of this vessel from the viewpoint of the main engines, will indicate that overheating of the trunk type pistons was always a probability, especially when new liners, or new liners and pistons, had been fitted. There is clear evidence that on at least three occasions minor crankcase fires occurred, which were directly attributable to overheated pistons. It is equally clear that the Engineer Officers of the "Reina del Pacifico" were fully alive to this danger at a relatively early date from the vessel coming into service. Details were given in the course of evidence of each occasion of overheating, the effect of the overheating, the measures taken to cool the overheated parts, and of occasions when renewals were found necessary. The inference to be drawn from this

information is that an affected piston could reach a temperature sufficiently high to ignite lubricating oil and cause fire in a crankcase.

Coming to the incident of the 11th of September, 1947, it is significant that a different set of conditions prevailed, inasmuch as, on this occasion, the engine had been running—after an extensive overhaul—for a period of approximately thirty hours. During this period full power had been developed for the last 6½ hours. Over this latter period nothing untoward occurred, except that the fuel pump of No. 8 cylinder starboard outer engine had not functioned properly. This defect persisted notwithstanding that all measures possible in the circumstances had been taken. The first indication that something was seriously wrong with any of the engines was a warning shout given by an employee of Messrs. Harland & Wolff, to the effect that No. 2 cylinder liner of the port outer engine was hot, whereupon the control lever of that engine was immediately brought to the "stop" position by Mr. Oxburgh, the Owners' Chief Superintendent Engineer. After a few minutes, and without any action being taken to cool the over-heated parts, the control lever was moved to the "starting" position by Mr. Owen, Assistant to Mr. Oxburgh. Shortly after this last movement of the control lever an explosion occurred. It should be noted, however, that prior to putting the control lever to the "stop" position, the fuel valve of No. 2 port outer cylinder was by-passed by Mr. Forbes, one of the ship's engineers.

In order to appreciate the circumstances leading up to the explosion, it is necessary to review what occurred from the ship's arrival at Belfast for re-fit at Messrs. Harland & Wolff's, in September, 1946, until the date of the explosion. From the evidence it would appear that the usual procedure in regard to the supervision during the overhaul of the machinery was followed. This being so, it was the duty of Messrs. Harland & Wolff to carry out in a proper and workmanlike manner, and to the satisfaction of the Owners, the various items of work enumerated on the repair list prepared by the Owners, and furnished to the Repairers. The Owners' representatives on their part, one of whom was always present, considered it their duty to inspect each important part of the machinery, which included pistons and cylinder liners, before such parts were refitted.

The question of responsibility for the manning and running of the machinery of the "Reina del Pacifico" during trials now arises. It is to be noted that the "Reina del Pacifico" was not a new ship. In the case of a new ship, the manning and running is entirely the responsibility of the Builders, until the ship is handed over to the Purchasers. When the machinery of a ship that has been in service for a number of years, as in the case of the "Reina del Pacifico," has undergone a big overhaul, it is customary for a reliability trial at sea to be carried out. It is not customary, however, for such a ship to be subjected to speed trials, unless some alterations have been made which might affect the ship's speed in relation to the revolutions of propeller or propellers. No such alterations were carried out on the "Reina del Pacifico" during the re-fit preceding the sea trials in question. When new machinery is installed the Builders are concerned with every part of it, but when being overhauled after service, the repairers are only concerned with the items mentioned on the repair list compiled by the Owners.

The question of the actual explosion will now be considered. During the Inquiry, two theories were advanced in evidence as to the origin of the explosion:

(1) That an explosion of moderate violence occurred in the engine room between starboard inner and starboard outer engines in way of No. 7 unit, at a point about 6 inches above the double bottom tank

top. This explosion is alleged to have caused the inflammable contents of the starboard outer engine crankcase to ignite and explode, resulting in the inflammable contents of the other three engines being ignited. The initial cause of this explosion was claimed to be due to fuel oil leaking on to the tank top from a main engine fuel oil supply pipe, through a hole of about 1 m/m diameter, and at a pressure of about 30 lbs. per square inch. It was further alleged that the igniting agent was a spark caused either by blowing through the cylinder indicator cocks on the starboard inner engine, or by two pipes abrading at a position 3 inches distant from the afore-mentioned leakage.

(2) That No. 2 piston on the port outer engine had reached a temperature whereby it formed a "hot spot" of sufficient area and temperature to ignite the inflammable contents in the crankcase of that engine, and to cause an explosion of relatively low pressure. It is further alleged that some of the crankcase doors of this engine were blown off, and the burning contents reached the engine room in the form of pressure and flame waves, which found their way into the crankcase of the other three engines, igniting the inflammable contents and causing further explosions. As the theory appended in (1) of above paragraph was not pursued, and was actually withdrawn in the course of the Inquiry, no comment is necessary.

As the theory put forward in (2) of previous paragraph is strongly supported by the evidence of the actual happenings, and by the technical evidence tendered, it must be concluded that the seat of the first explosion was in No. 2 crank-chamber of the port outer engine. The presence of a "hot spot" in the port outer engine must be accepted. This leads to the consideration of the possible cause of this particular piston overheating. In this respect it is necessary to have regard to testing, quality of manufacture, standard of repair, initial clearances, supply of lubricating oil, all of which, if correct, should obviate the possibility of overheating. Relative to the considerations mentioned in the preceding sentence, it is learned from the evidence that:—

(1) The initial diametrical working clearance between piston and cylinder liner is twenty-five thousandths of an inch (0.63 millimeters). Further, that when the pistons are running at a calculated conservative temperature, in the way of the gudgeon pin, of 160° Fahrenheit, the twenty-five thousandths clearance is reduced to something of the order of twelve thousandths of an inch. It must be obvious that such a working clearance on a diameter of 24.8 inches is undesirable. Again it should be noted that the primary reason for abandonment of the first sea trial was the serious overheating of two old pistons which had been fitted into new liners, viz. starboard outer No. 6 and port outer No. 11.

(2) The existence of a badly fitted gudgeon pin and/or bush which may cause overheating by mal-alignment, tending to destroy the initial working clearance.

(3) The inaccurate machining of connecting rod eye and foot and piston gudgeon pin boss, which makes for mal-alignment and reduction of initial working clearance.

(4) The existence of an additional piston ring and groove which was situated in such a position that when the piston reached the end of its upstroke, this ring overran the parallel portion of the cylinder liner bore and expanded into the bell mouth, thus making for mal-alignment of the piston and undue pressure on the gudgeon bearing.

(5) Inefficient lubrication of the piston owing to inaccurate timing of the cylinder lubricator, and the absence of a non-return valve fitted at the nearest point to the cylinder.

The reason for No. 2 port outer engine piston becoming overheated has not been fully determined to the satisfaction of the Court. The Court, however, is of opinion that whilst four of the reasons set out in preceding paragraphs (2, 3, 4, 5), would be sufficient to cause an increased operating temperature, the extent of these faults found in the case of this piston was not sufficiently serious to bring about the degree of overheating attained. With regard to No. (1), it is felt that there is a distinct possibility that the fine tolerance given to this piston would in itself cause serious overheating, if the temperature of the piston was raised unduly by one or more of the faults enumerated in (2), (3), (4), and (5) above.

The existence of a "hot spot" in No. 2 port outer cylinder having been accepted by the Court, the theory advanced for the presence of ignitable material in the crankchamber must now be considered. That such material did exist, and was ignited, resulting in ultra rapid combustion which brought about a mild explosion, must be accepted. A reference was made in the course of the evidence to the experiments conducted by H. Bara, Engineer-in-Chief of the French Navy, directed to establishing (a) that the crankcase of a diesel engine operating normally is able to propagate flame, (b) that the origin of the ignition of crankcase contents can be traced to serious overheating of some moving part situated inside the crankcase.

Turning to the evidence of the Chemical and Mechanical Engineering Experts the following deductions can be made:—

(1) That the piston of port outer No. 2 engine had reached an average temperature of at least 500°F., with surface temperatures at certain areas of the piston well above 500°F., and in the vicinity of 1,500°F., as a maximum.

(2) According to the evidence this piston overheated within a period not exceeding ten minutes.

(3) That no previous overheating of pistons occurred under such conditions as the case under review, as to time under full speed, and revolutions per minute attained.

The following observations are made in reference to the explosion. The first is closely allied to the findings of Bara and other Investigators, and is supported by the evidence given at the Inquiry. The analysis of the contents of the crankcases in engines similar to those fitted in the "Reina del Pacifico", has revealed an oxygen content something of the order of 20%. Under normal working conditions crankcases contain no combustible gas. The above analysis is taken when the atmosphere of the crankcase is composed of lubricating oil in an atomised state, the fine particles being surrounded by air, and so forming a mist. This mist is due to the turbulence and general agitation set up in the crankcase by the rapid gyrating and reciprocating of the parts of the engine. This condition is intensified by the severe surging effect of the trunk pistons. Such an oil mist can be ignited by a "hot spot" of sufficient intensity to reach the spontaneous ignition temperature of the lubricating oil. The spontaneous ignition temperature of the oil in use was approximately 720°F. The oil mist was ignited by (1) hot body of the piston (most probable). (2) The burning lubricating oil leaving the piston bearings and cylinder liner (probable). (3) Vertical streaks of very high temperature surface metal on the skirt of the piston and walls of the cylinder liner (most probable).

It would appear from the evidence that when the mist became ignited, the burning would be consistent with the percentage of oxygen present in the crankcase, and would come under the term "rapid." The building up of pressure would be relatively slow, and would not assume appreciable magnitude until the advent of fresh air, drawn through the mist by the

extractor fans into the burning mixture, which would cause ultra-rapid combustion, and build-up of pressure taking the form of a mild to moderate explosion. This is supported by the fact that no damage was sustained by the engines apart from crankcase doors and covers. Most of the damage to these was caused by their striking objects external to the engines.

There is a further possibility based on certain evidence given at the Inquiry. Expert knowledge suggests that whilst small particles of lubricating oil intimately mixed with the right proportion of air is highly inflammable, it cannot be detonated. As the evidence is that detonation in a mild form did occur in No. 2 port outer engine crankcase, it might well be that explosive gas existed, and that the lubricating oil particles had been evaporated to form, with the air, an explosive mixture. The evidence goes no further than that the hot piston ignited the gaseous contents of the crankcase. As no evidence was submitted to show how this gas was formed, the following theory is submitted by the Court.

The evidence leaves no doubt that No. 2 piston had reached an exceedingly high temperature, the estimate being between 500°F. and 1,500°F., the cause of which will be referred to later. As an interval of time elapsed between stopping the engine and the explosion occurring, the Court cannot completely accept the theory that the heat in the piston alone was sufficient to ignite the explosive gas, since it is apparent that when the explosion occurred the piston would be appreciably cooler than when the engine was stopped four to five minutes earlier. The information was given in evidence by Mr. Bull, of the Ministry of Transport, who examined No. 2 port outer engine piston soon after the accident, that a most noticeable feature was that the inside of the piston skirt was in a dry condition, i.e., free from lubricating oil. This would suggest that during the four to five minutes which elapsed between the engine being stopped and the explosion occurring, the heat in the piston was sufficiently high to cause the oil on the inside of the piston skirt to evaporate. During the four to five minutes the engine was stopped, this lubricating oil would be gasified, and the major portion of this dense gas would remain inside the piston skirt as long as the piston remained stationary. To explode this gas it would be necessary to supply the requisite proportion of air and an igniting agent.

Whilst this gas was being produced in the stationary piston, the crankcase extraction fans continued to operate, and in this way air would find its way into the crankcase to mix with that already present, so that the air necessary to form an explosive mixture with the dense gas produced inside No. 2 piston skirt would be present.

The heat in the piston was produced by excessive friction between its outer surface and the inner surface of the cylinder liner, so that the outer surface of the piston skirt would be at a higher temperature than the inside surface. If the temperature of the inside surface of the piston was sufficient to evaporate the oil on this surface, the oil on the outer surface would be even more readily evaporated.

Prior to the engine being stopped, the contact surfaces of the piston and cylinder liner had become badly scored. During the time the engine was stopped, the working clearances would be still further reduced by the liner cooling more rapidly than the piston, so that when the engine was re-started a tearing action would take place, and it is reasonable to assume that sparks were produced immediately or very soon after the engine began to revolve on starting air. In considering this suggestion, it must be remembered that during the four to five minutes that the engine was inoperative, water at sea temperature continued to circulate through the cylinder jackets, and lubricating oil at about 130°F., continued to circulate the pistons. The effect of this would be that the cylinder

liner would tend to close in on the overheated piston.

A further effect of setting the engine in motion would be for the dense gas inside the piston skirt to be thrown out into the crankcase. It would then mix with the requisite proportion of air with which it would be intimately mixed by the revolving crank and ignited by sparks produced in the manner suggested in the preceding paragraph.

During the seventeen years that this ship has been in commission, five pistons had become overheated to the extent that on a number of occasions fire was produced inside the crankcase. It was observed that these instances of overheated pistons have always occurred after an overhaul which included the fitting of new pistons or cylinder liners, or both. It is the view of the Court that the cause of these trunk-type pistons overheating is that the diametrical working clearances were made to an absolute minimum in order to avoid piston "slap" and consequent excessive noise.

The original diametrical working clearances on these 650 m/m diameter pistons was 0.63 m/m in way of the skirt, and this clearance has been adhered to throughout the life of the ship.

It is the view of the Court that during the "bedding-in" process of new pistons and/or cylinder liners, the temperature of these parts rises above the normal working temperature, and with such fine clearances, unless the lubrication is fully efficient, and the contact surfaces free from dirt, and the cylinder not loaded above its rated power, the expansion of the piston reduces still further the working clearance, and there is grave danger of the piston and cylinder liner becoming seriously overheated.

The time which elapsed between starting the engine on air and the explosion occurring could not be accurately ascertained, the time varying from immediately the starting lever was operated to two or three minutes after the operation of the starting lever. Had the explosion occurred simultaneously with the operation of the starting lever the foregoing theory as to the production of the igniting agent would not be disputed. An interval of two to three minutes between starting the engine on air and the explosion occurring, however, does not rule out the theory that the sparks were produced as described. The lack of lubricant on the contact surfaces and the absence of working clearance would be sufficient to continue the sparking for quite two or three minutes. If this interval of time between stopping and re-starting the engine is accepted, the reason why the explosion did not occur until two to three minutes after the engine had been started up on compressed air, could be due to the mixture of vapourized oil and air not being in such proportion as to be within the explosive range, until the revolving crank had brought about, not only the correct proportions of air to gas, but the intimate mixing of the two.

The explosion in No. 2 port outer engine crankcase resulted in the weakest door of that crankcase being blown outward and flame entering the engine room atmosphere. Another result of the explosion in No. 2 crankchamber was to ignite the oil mist present throughout the length of the engine crankcase, and the rapid increase in pressure resulting from this burning action blew out other crankcase doors in this engine and liberated to the engine room the innumerable small particles of oil which had not been consumed inside the crankcase.

There is evidence that the whole of the engine room atmosphere below the level of the top platform, which is situated at the top of the cylinder jackets, was ignited and the flame entered the crankcases of the other three engines which, as far as is known, did not contain explosive gas, but air highly impregnated with minute particles of lubricating oil, which would be inflammable and be readily ignited by the flame

entering the crankcases. The increase in pressure which would result from this rapid burning process, in each of these three engines was sufficient to blow out the crankcase doors of these engines.

As to how the flame from the port outer engine entered the crankcases of the three other engines, the consensus of opinion was that the pressure produced in the engine room atmosphere, forced inward the unsupported lower ends of certain crankcase doors of each engine, and that when the inflammable vapour inside the crankcase was ignited the pressure blew the doors outward. The view that the lower ends of these doors had been forced inward before the whole of each door had been blown outward is supported by marks which indicated that the lower ends of the doors had made contact with the revolving cranks. The only other way in which flame could enter the crankcases of these three engines would be through an annular opening of 1 m/m width between the cylinder liners and the crankcase diaphragm plates. Whilst this is unlikely, it is not impossible.

Reverting to the opinion that the bottoms of the large crankcase doors were forced inward by the pressure produced in the engine room, it was not possible to ascertain, with reasonable accuracy, the dynamic force required to distort the doors in this way.

As there is an element of doubt as to how the flame from the port outer engine reached the other three engines, we strongly recommend that the matter be pursued by explosion specialists who have not hitherto investigated the problem which has arisen on the "Reina del Pacifico."

The following modifications in design have been suggested by witnesses with a view to preventing recurrence of crankcase explosions in this ship:—

- (1) The introduction of baffles between each individual crank chamber.
- (2) Complete separation of oil sump ventilating pipes.
- (3) Complete separation of crankcase vapour extractor pipes.
- (4) Re-design of crankcase doors to permit quick inspection of the crankcases.
- (5) Re-design of explosion discs on ends of crankcases.
- (6) Provision of carbon dioxide gas system as a blanketing medium for the crankcase.
- (7) Remote recording of cylinder liner temperatures.
- (8) Increasing the diametrical working clearance of the pistons.

In regard to the proposed modifications put forward in the course of the Inquiry, we wish to place on record the following observations. We agree that such

alterations and additions would reduce the explosion hazard in the "Reina del Pacifico." In the case of the proposal to sub-divide the crankcases, however, we feel that there would be practical difficulties. We are not prepared to say that a moderately light baffle between each chamber would have the effect of avoiding progressively increasing pressure in parts of the crankcase remote from the point where an explosion takes place.

Although there is no evidence whatsoever to support the suggestion that the flame spread from the port outer engine to the other three engines by means of the crankcase vapour extraction pipes or the lubricating oil sump venting pipes, we are of the opinion that each of these pipes should be led to the atmosphere, i.e., that no two pipes should be joined.

If the diametrical working clearance of the pistons is increased as proposed at the Inquiry, and each piston is provided with four lead/bronze rings, two above and two below the gudgeon bearing, we are of the opinion that the main reason for pistons in this ship becoming hot will be removed. Nevertheless, it is our view that as there are so many cylinders and pistons (the number is 48), for the normal complement of engineers to attend, some means of registering an increase in temperature of the exposed part of the cylinder liners should be adopted. It would be sufficient to register an increase in temperature of the ahead thrust side of the cylinder liners, but the dials recording the temperatures should be grouped together and situated conveniently near to the engine control stations.

If the course of the flames and inflammable vapour released from the port outer engine was as stated at the Inquiry, it is probable that the pressure wave would not have reached the other three engines had the flames and vapour been able to take an upward direction soon after leaving the port outer engine. They were prevented from doing so, to a large extent, by the plated platform on either side of each engine, and at cylinder-head level. If these plates were replaced by open gratings any pressure wave released from an engine would be able to take an upward direction.

The alignment of the connecting rods of these trunk piston engines is of importance, if overheating of pistons is to be avoided. The alignment when the parts are at atmospheric temperatures appears to have had proper attention, but the Court is not convinced that due regard was given to the possible effect upon alignment of these parts when the unusually long crankshafts attain normal working temperature.

J. H. Campbell—JUDGE.

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