FIRE IN THE FORWARD GEAR ROOM

THE 'ILLUSTRIOUS' GEARBOX EXPLOSION

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Introduction

On 2 April at 1800 H.M.S. *Illustrious* sailed from Portsmouth on 'Operation Global 86', a round-the-world deployment, flying the flag of the Task Group Commander, Rear-Admiral Hogg, Flag Officer First Flotilla.

The pre-deployment AMP had been a busy one and major work had included repairs to the starboard outer power turbine and the change of its gas generator following an HP turbine blade failure; also the exchange of the input torque tubes on both inner drives, and increase of the cold pull-up on the outers. The ship had also docked to investigate and rectify a potential propeller shaft corrosion problem in way of the intermediate 'A' brackets. It had been an interesting period.

Having cleared Portsmouth the intention had been to work up to full power in order to set the top power of the new starboard outer and to check the settings of the other three engines. This was about to commence at 2000 when a report was received of a distinct 'thwacking' at shaft frequency in the vicinity of the starboard propeller. It was decided to put divers into the water to investigate. The ship was stopped and turning gear engaged on both shafts. The divers searched both shafts—not an easy task in the dark and with a slight swell running—and found nothing. It was deduced that whatever was around the starboard propeller had probably been shed when the ship went astern to stop in the water. She got under way again, first on the port shaft, then using both shafts; and indeed the noise had disappeared. After completing this unprogrammed evolution, the work up to full power commenced again at about 2300.

The Explosion

By about 0015 180 shaft r.p.m. had been reached and the bridge had just been asked to ring on 190, when a report was received from the Forward Engine Room of slight smokiness in the vicinity of the starboard outer power turbine. Whilst this was thought to be almost certainly the result of slightly oily surfaces after the power turbine rectification work, the Senior Engineer went to the Forward Engine Room to investigate. The increase in power was commenced and at 0031, just as 190 shaft r.p.m. had been reached, a loud explosion was heard and felt throughout the ship. In the Ship Control Centre (SCC), for the first few seconds there was confusion over what had happened and precisely where the problem lay. A great many Minerva alarms were indicating in HQ1, just as many machinery surveillance warnings on the

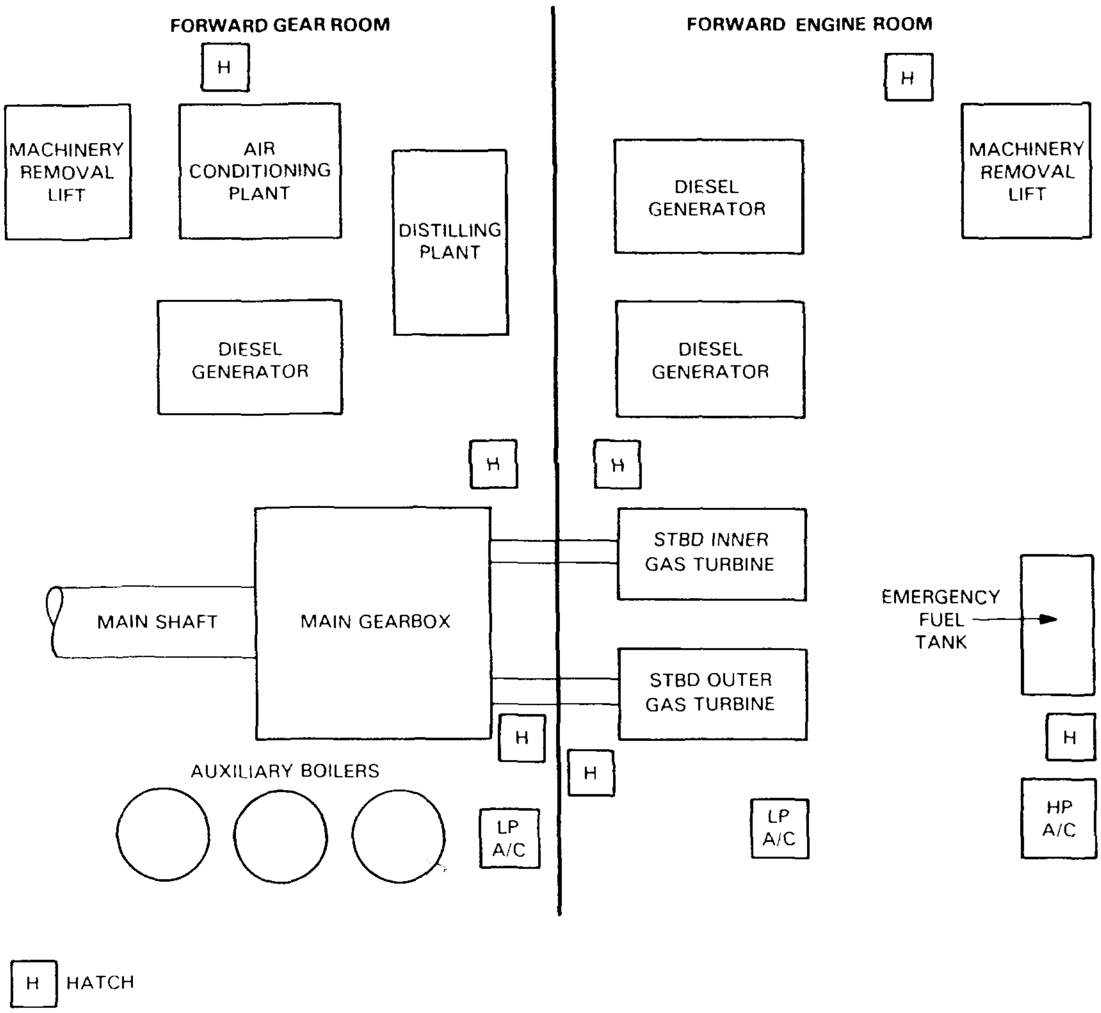

FIG. 1—MACHINERY LAYOUT

starboard shaft were illuminated in the SCC, and a diesel generator fire alarm was illuminated and sounding. However, any doubts about the whereabouts of the problem were quickly dispelled by the arrival in the SCC of the Senior Engineer, announcing that there was a major fire in the Forward Gear Room. He had been at the after end of the Forward Engine Room investigating the smoke from the starboard outer power turbine (FIG. 1) when the explosion occurred and as he returned to the SCC he saw thick black smoke issuing from the main Forward Gear Room access in 6K.

In order to follow the ensuing stages of the fire-fighting it is necessary to be clear about the various access routes to the Forward Gear Room. Normal entry is by the central hatch in 6K (FIG. 1), reached from the 6 deck centre line passage via a lobby or air lock containing the BTM operating cabinet. The port hatch (FIGS. 1 and 2), later to be the scene of the first attempt to enter the gear room, is also on 6 deck, at the foot of a ladder from 5K. The starboard hatch (FIGS. 1 and 3) is at the foot of the gear room uptake, a vertical space containing the hot exhausts of the diesel generator and also the auxiliary boiler uptakes. The gear room exhaust ventilation fans discharge into it. The uptake space is entered from 5 deck and is a difficult way of entering the gear room because of its congestion. Equivalent access to the After Gear Room and the Forward Engine Room is even more difficult, for, other than from the machinery space itself, their uptakes can only be entered at 02 deck level.

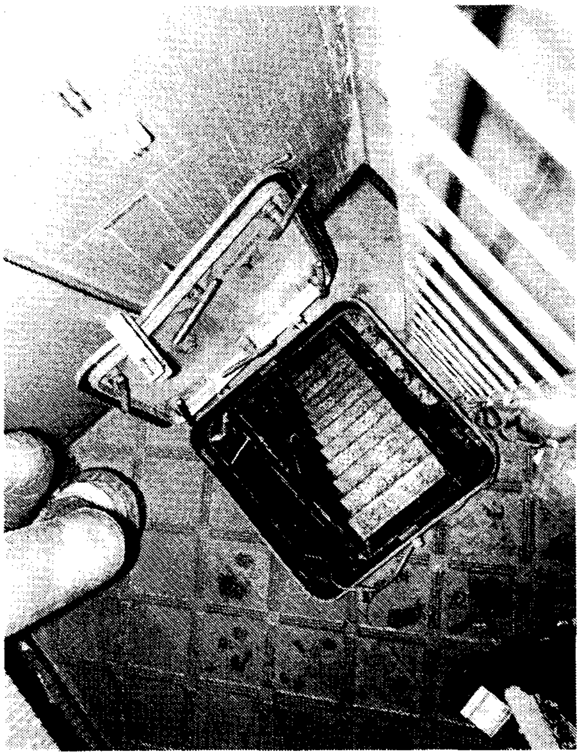

FIG. 2—PORT SIDE ACCESS HATCH BLOWN OPEN AND DISTORTED BY THE EXPLOSION. THE STARBOARD HATCH WAS SIMILARLY AFFECTED

Fire and Smoke

The fire alarm was raised on the main broadcast and the Standing Sea Fire Party (SSFP) piped for. Because of the time of night, many of the ship's company were turned in but despite this the speed of reaction was impressive. In the meantime however a CPOMEA, who until a few seconds before had been working in the gear room, realized the importance of shutting the manhole within the main hatch leading to it. Because the ship was in NBCD Condition Y, the main hatch itself was shut but the manhole with its Z-marking was open. Access to the airlock was critical since the BTM operating cabinet is sited within it and, although it is possible to fire the storage bottles from the adjacent bottle space, there is no other position from which to open the compartment drench valve. Closure of the manhole was achieved by an LMEM who had been working with the CPOMEA, aided by an MEM and directed by the SSFP Attack POMEM. This was critical to the subsequent fire-fighting efforts and it earned two of those concerned C-in-C's commendations.

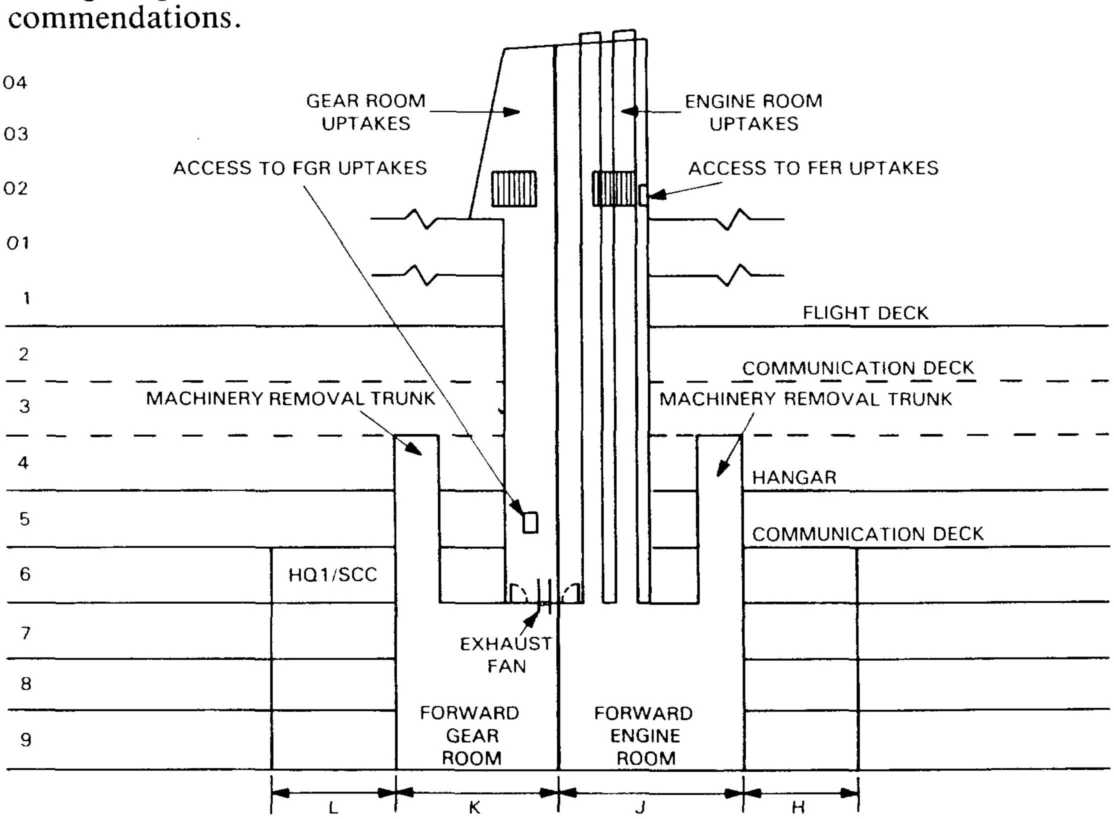

FIG. 3—ELEVATION, SHOWING MACHINERY SPACE UPTAKES

Meanwhile closure of ventilation openings for the Forward Gear Room had been initiated in HQ1 and was being done by the main steaming watch. Remote pneumatic closure of the exhaust vents was achieved rapidly from 6K but the manual closure of the inlet flaps in 4K boat bay took longer. Both machinery and general ventilation fans had been crash-stopped from the SCC and HQ1.

Smoke spread rapidly and reports reached HQ1 of smoke in 5 deck port and starboard, Ops Room and MCO, as well as 6K passageway and the Computer Room. Smoke clearance was started and soon most exhaust fans in the ship were running to clear smoke. This was effective and within a short space of time most areas were relatively free of smoke. Smoke curtains were also very effective and no smoke entered HQ1, despite reports of thick smoke in surrounding areas.

After the initial confusion, lasting for perhaps 15 seconds, had been resolved, the MEOOW had ordered Emergency Stop Starboard and had reported to the officer of the watch that he had a major defect in the Forward Gear Room. The ship had been stopped in the water using the port shaft and only when the starboard shaft had been stopped were the forced lubrication (FL) pumps stopped to prevent fuelling the fire with lub oil. This maintenance of the FL pressure probably contributed significantly to the lack of bearing and gearing damage. In fact, although not appreciated at the time, after the FL pumps were stopped the supply of lubricating oil was maintained (and the firefighting potentially hindered) by the continued running of the air-driven lub oil pump until its dedicated air supply ran out.

Fighting the Fire

The closing of the gear room vents ready for drenching was achieved in about 10 minutes and the first shot of BTM was then fired immediately. By this time emergency stations had been ordered and NBCD State 1 was being assumed. The Standing Sea Fire Party had commenced an attack on the fire by the port access. They were withdrawn in order to allow BTM drenching, but they had meantime discovered the port access hatch to be open. This hatch had been blown open by the explosion and was severely distorted (FIG. 2), although this was not realized at the time.

The BTM system allows two shots to the forward unit—either one to the engine room and one to the gear room or two shots to either one of those spaces. A similar system is fitted to the after unit. The first shot was fired, with some difficulty from the smoke-filled airlock, and the hatch temperature monitored. A magnetic dial thermometer, one of several kept in the SCC for use in the event of fire, was provided and attached to the hatch. It immediately rose to 350 C and showed no sign of reducing. The Senior Engineer reported this to HQ1 and the firing of the second shot of BTM was ordered. Thus within 15 minutes of the explosion, all the available BTM had been used. The secondary system, high level AFFF (foam) sprays, was then immediately brought into use on a basis of two minutes spraying in every five, utilizing the intervening period to top up the AFFF storage tank.

Meanwhile the MEOOW was carrying out the machinery space system isolations so that the fire was not being fed with fuel or air from outside. Electrical isolation had also been achieved and the diesel generator sited within the gear room had been taken off load and stopped remotely from the SCC.

Boundary cooling was being established and reports were being received from adjacent compartments. Despite an initial scare that smoke or BTM was present in the Forward Engine Room, this was quickly shown to be minimal and it was evident that J/K bulkhead was intact. In general the bulkheads around the compartment were reported as being only slightly warm at lower levels. On 7 deck, bulkheads were reported as warm (cable passage, workshops, etc.) and it was at the Gear Room deckhead that temperatures were highest. Whilst this is not surprising, it does lead to a difficulty in assessing whether the fire is still burning or whether the higher temperatures are the result of convectional heat. This waiting period plays havoc with one's nerves but any temptation to enter the compartment was resisted and total reliance was placed in the AFFF sprays, which could of course have continued as salt water sprays had foam stocks run out. These sprays undoubtedly do help to cool the compartment, although the average nozzle is sited 0·5 metres or so below the deckhead and so their effect on that boundary is significantly less than elsewhere.

It was however decided to enter the Forward Gear Room uptake space to check that there was no fire burning there. At the outset, an apparently impressive fireball had emerged from the top of this uptake at the base of the funnel, giving those on the bridge their first clue that all was not well below.

The uptake space was being boundary cooled and temperatures were generally low. A firefighting team therefore entered it from 5 deck starboard. As with the team that had earlier attempted to enter from the port side, they found the gear room hatch blown open and they therefore attempted to get down into the machinery space. There was no fire in the uptake space but there was a significant amount of smoke there and conditions were not easy. Hence this team needed to be relieved by the time they had reached the hatch. Their report from this position was that there was a glow from somewhere towards the centre of the gear room. The relief team was led down by the CMEM who had led the earlier team to attack the fire from the port access. In spite of considerable difficulties, CMEM Aldridge led his team down the vertical ladder into the Gear Room itself until the ladder disappeared—the lower third of its length had been blown away by the explosion—when he was forced to withdraw. On his return however he was able to say that with his limited view of the gear room he had not seen any sign of fire and that he had been aware of a six foot hole in the gearbox casing. This was the first positive indication that the ship had suffered a gearbox explosion. Until this point the most likely source of the problem was thought to be one of the three auxiliary boilers sited on the starboard side of the compartment. CMEM Aldridge reported his sightings personally to HQ1 and without hesitation volunteered to lead a second re-entry. It was decided, largely because of the initial report of a glow in the centre of the gear room, to return to the port access for this attempt and Aldridge led his team in by this route. This time they were able to reach the lower plates. They moved across the machinery space and they were able to report that there was now no fire in the gear room. The fire was thus declared extinguished at 0250.

The Damage

An immediate inspection of the compartment commencing at the port side revealed a scene of considerable devastation. The whole space was smoke blackened, significant amounts of cable had been burned, and both structural and pipework lagging were damaged. As the investigating team progressed across the gear room, however, the true horror of the gearbox itself overshadowed all else. It now had its side covers blown outwards from the base to the upper plate level and arched upwards above that (Figs. 4 and 5).

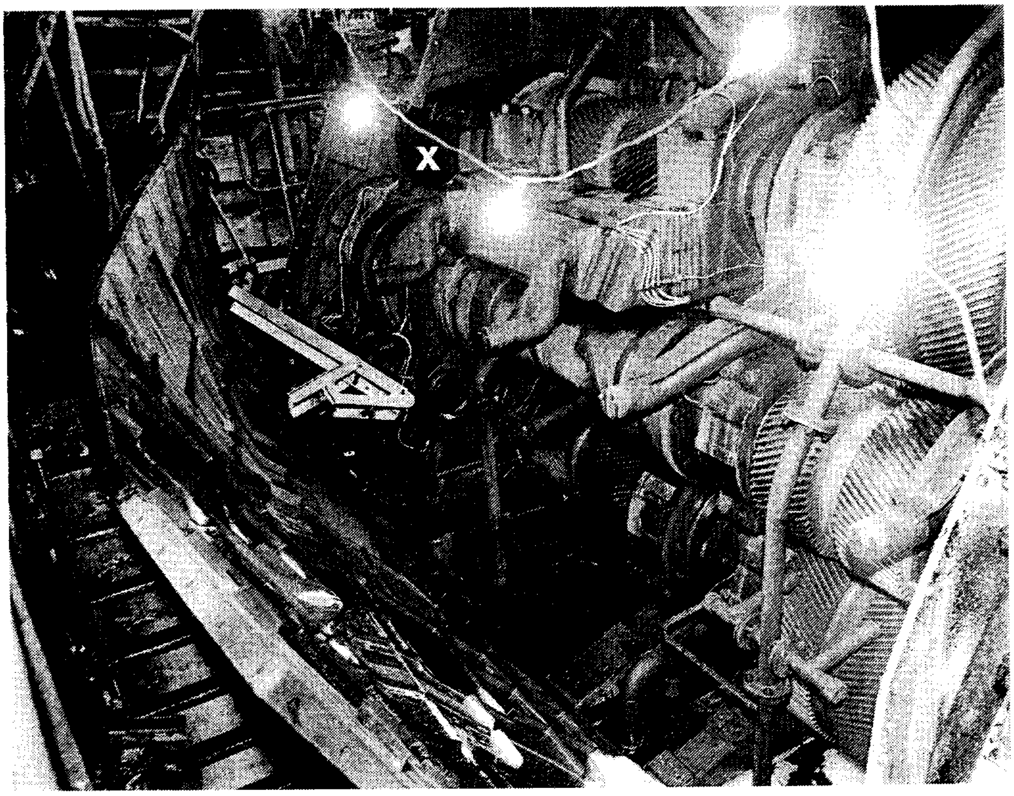

FIG. 4—THE DAMAGED GEARBOX SHOWING THE LOWER INBOARD COVERS BLOWN OUTWARDS. THE SSS CLUTCH IS BEHIND THE CYLINDRICAL BAFFLE MARKED X. THE EFFECT ON THE STARBOARD SIDE WAS ALMOST IDENTICAL

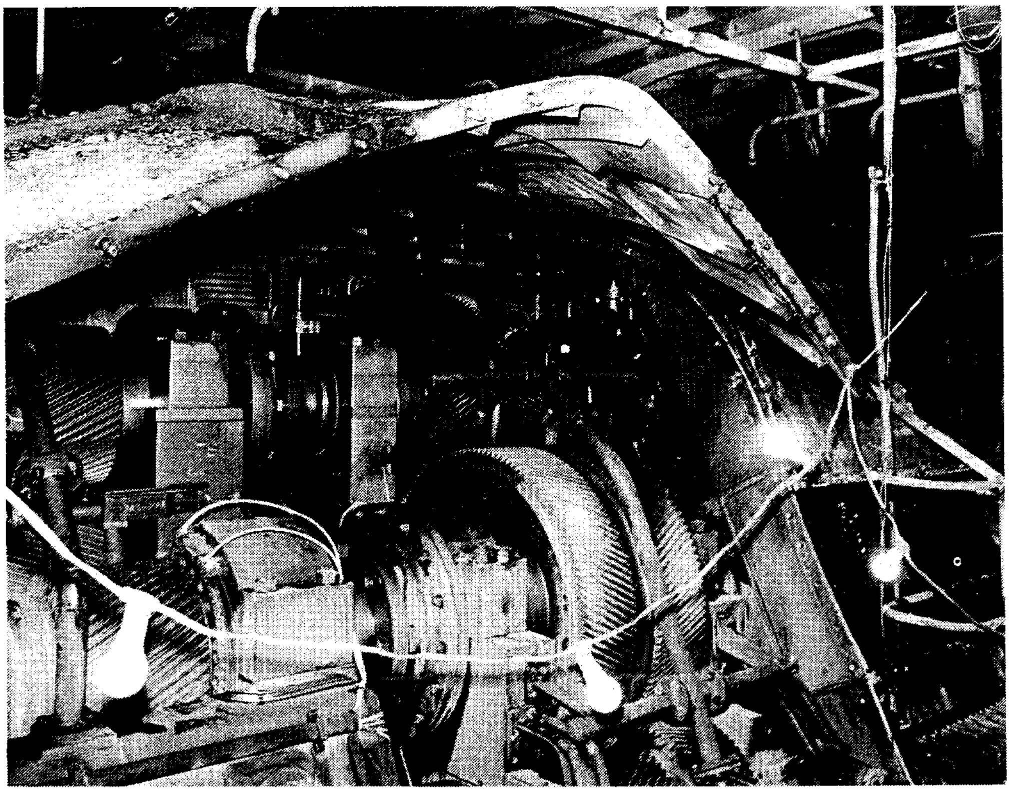

FIG. 5—THE TOP COVERS ARCHED UPWARDS. AGAIN THIS WAS MIRRORED ON THE OTHER SIDE OF THE GEARBOX

Immediately evident was the symmetry of the explosion. The effects upon the inboard and outboard sides of the box were almost identical. Clearly months of work were going to be involved in repairing this and there was no question but that the ship should return to Portsmouth. Turning gear was engaged on the starboard shaft, the ship got under way on the port shaft and, having disembarked her aircraft, arrived alongside North West Wall at 0900. Those in Portsmouth Naval Base, who the previous evening had breathed a sigh of relief that one of the CVSs was out of their hair for the next nine months, were on the jetty to meet us and to view the devastation. Support in several forms, including a TCV, was quickly provided. The TCV helped to pump out bilges and the gearbox sump and carried out an initial clean down of the worst areas of the compartment.

Initial examinations of the gearbox showed remarkably little sign of damage to its internals. The gears themselves appeared unscathed except for the obvious and very rapid reddening as a rust film formed. Ship's staff immediately washed down with fresh water and the TCV repeated the process when it arrived. (The looks of amazement from the TCV crew when invited to spray water over the internals of a gearbox was one of the lighter moments of the saga.). The gears were sprayed with PX24 as a water repellant and subsequently with PX4 as a preservative. Instrumentation cabling within the box was undamaged and, in striking contrast to almost every other cable in the space, not even smoke blackened. The gearbox itself was the 'eye of the storm' and everything had exploded outwards from it (FIG. 6).

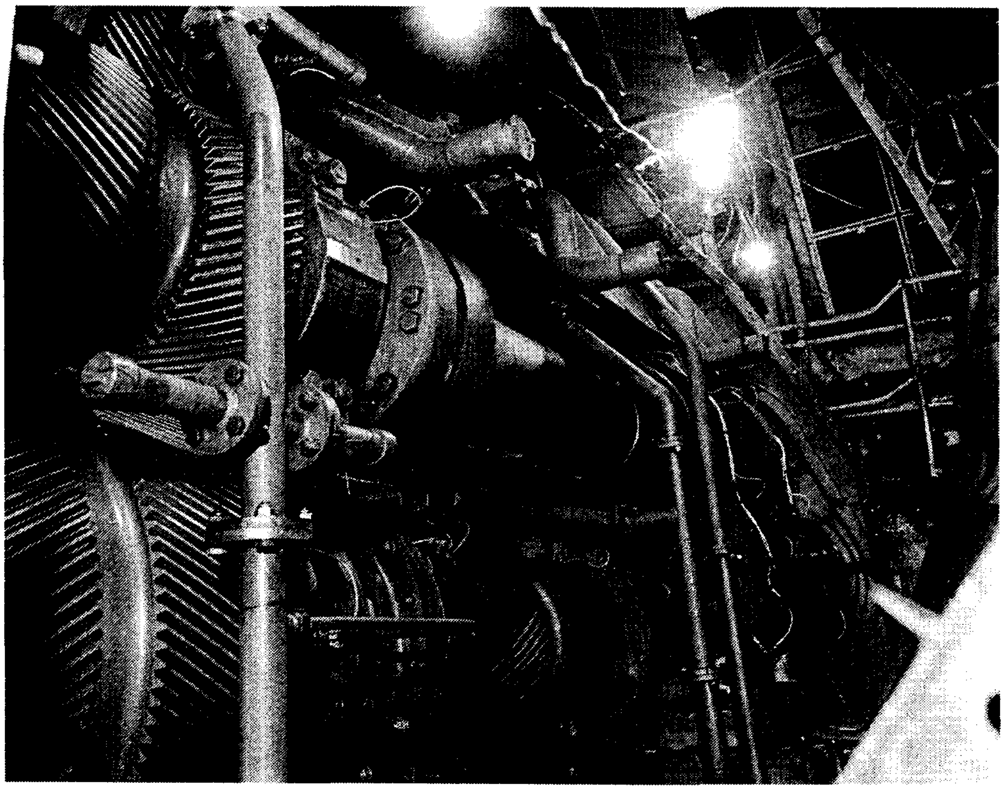

FIG. 6—OUTBOARD SIDE OF THE GEARBOX SHOWING THE VIRTUALLY UNDAMAGED GEARS. NOTE THAT INSTRUMENTATION WIRING WITHIN THE BOX IS NOT EVEN SMOKE-BLACKENED

Investigation into the Cause

At this point it is apposite to digress and look briefly at the history of gearbox explosions and the prerequisites for one to occur. One of the first people to arrive in *Illustrious* on that morning of 3 April was Dr Malcolm Holness from RAE Cobham (formerly the Admiralty Oil Laboratory). He was joint author of a paper on gearbox explosions[1] which summarized the work and findings of the Ministry of Defence Gearbox Explosions Working Party. This Working Party had been formed in 1970 to investigate gearbox explosions following two serious incidents, the first in H.M.C.S. *Kootenay*[2], where a major gearbox explosion killed seven men and injured three more, and the second in a Shore Test Facility in the U.K.

For a gearbox explosion to occur, the normally safe atmosphere inside must be converted into a flammable one. The normal atmosphere there, although not lacking a large quantity of fuel in the form of hot lubricating oil, is too lean for combustion to occur. This apparent contradiction is because the oil droplet size is too large for combustion and, even if an ignition source such as a spark were introduced, a flame front could not be established. In order for this to be possible an oil mist must be created, maintained and ignited. The production of such an oil mist, in the 20 or so explosions identified by the Working Party, was invariably caused by a frictional heat source associated with a large thermal bulk. Bearing failures were by far the most common cause and hence bearing design and instrumentation received much attention, instrumentation because it was believed that reliable temperature monitoring would always give sufficient warning of failure to prevent an explosion. The maintenance of the oil mist in the dangerous concentration is not easy, as the rotation of the gears, coupled with the drenching effect of the gearing sprays, tends to destroy it as rapidly as it is formed. However there is some evidence that if the mist can be created in a relatively enclosed space which is nevertheless connected to the main volume of the gearbox a 'two-stage' explosion may occur—an initial, minor, explosion releasing enough energy to ignite the larger volume and hence cause a major explosion. The two phases would be separated by only a very short time interval.

With this knowledge, and with additional assistance from Foxhill (Gearing Section and CVS Platform Section) and Commander-in-Chief Fleet Engineering Staff, a detailed examination of the gearbox began. It did not take long to find the sort of evidence we sought in the form of the starboard outer SSS clutch actuating shoe. The shoe is used to move the clutch axially from the 'locked out' to the 'ratchetting' position during a change from coupling to direct drive and from the 'engaged' to the 'ready to disengage' position during the opposite transition. The lubricated whitemetal faces come in contact with the appropriate collars on the SSS clutch ring. There should be a healthy 3/16 inch radial clearance between the shoe and the clutch switch operating ring. However it was evident from the blued ring and the similar discoloration on the shoe that a rub had occured on the circumference of this clutch. Additionally the whitemetal had melted over about half its depth and fragments were evident both in the area of the clutch and bonded to the ring (FIG. 7).

It is interesting to note that the SSS clutch is mounted within a semi-cylindrical baffle above the primary gear pair in an almost self-contained enclosure, which is nevertheless connected to the main volume of the gearbox. There are no sprays within this enclosure and the temperature of this 'bearing', not unreasonably, because of its intermittent and brief periods of contact, is not instrumented. There is continuous oil supply, however, to lubricate the contact faces and thus the conditions in the vicinity of the switch operating ring are probably as conducive to explosion as it is possible

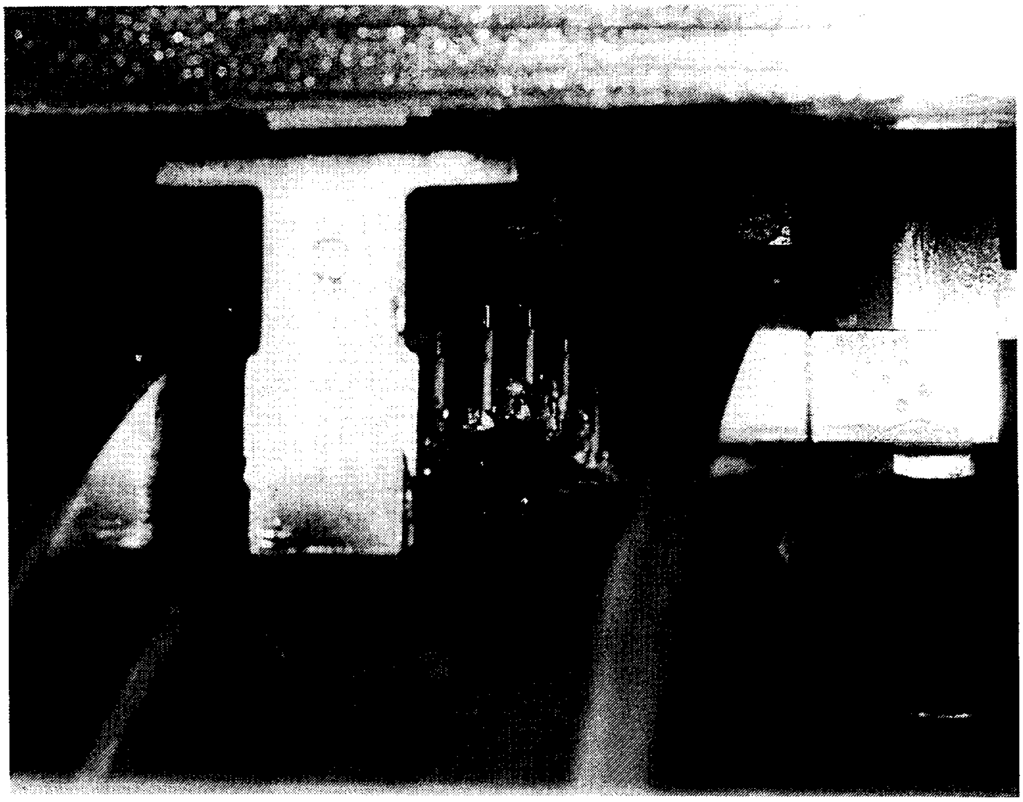

FIG. 7—THE STARBOARD OUTER SSS CLUTCH ACTUATING SHOE SHOWING DISCOLORATION OF THE STEEL AND MELTING OF WHITEMETAL OVER THE HEAT-AFFECTED AREA. THE CLUTCH SWITCH OPERATING RING IS ALSO BADLY DISCOLORED DUE TO HEAT

to conceive, provided a heat source is created. If there is anything in the 'two-stage' theory, then a near-ideal situation is presented.

These discoveries caused great concern because this starboard outer shoe had been changed by ship's staff during the pre-deployment AMP. A niggling intermittent defect had been evident for some time where clutch position indications had been unreliable. The shoe was examined as part of the investigations and was found to exhibit slightly uneven wear. Thus as a precaution and in case it was contributory to the problem, a new one was ordered and fitted.

The immediate worry was that the new shoe had in some way been fitted incorrectly. However the immediate Ship Investigation, led by the ship's Air Engineer Officer, soon revealed that not only had the shoe been fitted correctly but that it was difficult to see how to do so wrongly. The exchange is a straightforward bolting operation, the shoe being secured with eight socket head screws, centre popped to prevent slackening. Also, functional checks had been carried out, leading to the belief that all was well following this simple exchange. Thus a more detailed investigation was necessary and this the Board of Inquiry undertook, with ship's officers carrying out many of the detailed measurements on their behalf.

Analysis of the Clutch Dimensional Checks

The clearance between the actuating shoe and the switch operating ring (FIG. 8, dimension D) is the critical dimension and this could be checked in three independent ways:

(*a*) Using feeler gauges, with the actuator *in situ,* measuring the clearance between the end of the shoe and the switch operating ring.

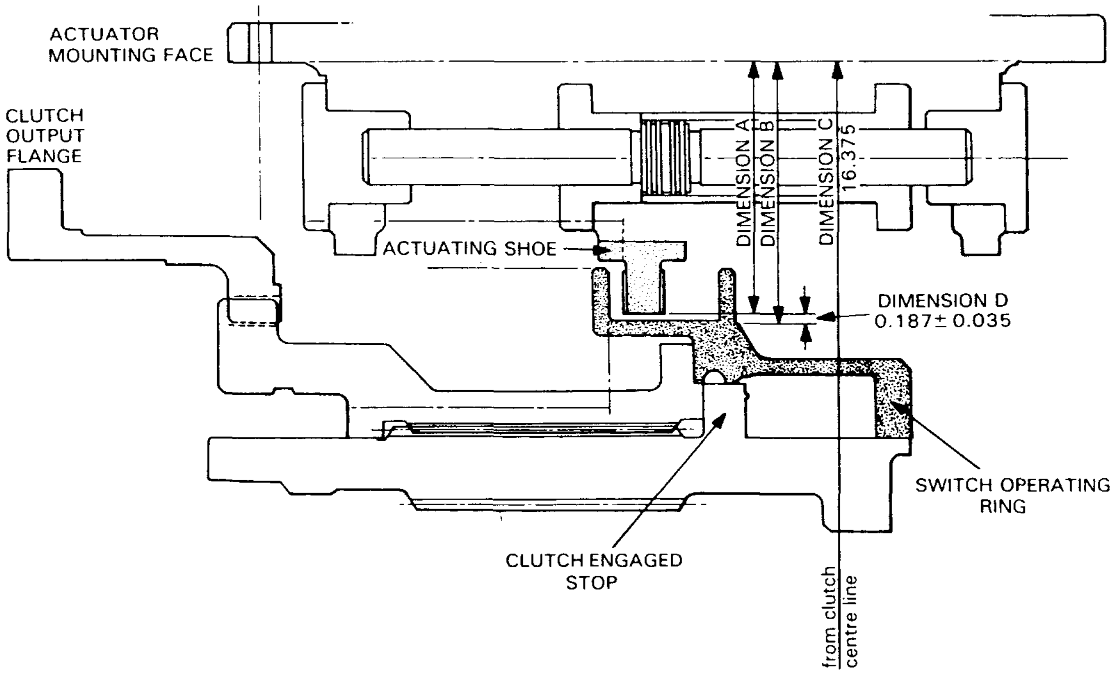

FIG. 8—SSS CLUTCH AND ACTUATOR, IN ENGAGED POSITION
dimensions in inches

(*b*) Measuring the distance from the clutch actuator mounting face to the circumferential surface of the shoe (FIG. 8, dimension A) and from the actuator mounting face on the gearcase to the closest point on the switch operating ring face (FIG. 8 dimension B). The clearance was then calculated as the difference between these two dimensions (B-A).

(*c*) Examination of the vertical surfaces of the switch operating ring showed an oil stain where the bearing face of the shoe had not contacted. By measuring the unstained area and the width of white-metal on the associated shoe the clearance was calculated.

These measurements were taken at the SSS clutch positions on both gearboxes (see TABLE I).

TABLE I—*Clearance between the actuating shoe and the switch operating ring*

	Feeler gauges inches	*Dimension difference* inches	*Staining* inches	*Design clearance* inches
Port outer	0.152	0.154	0.153	0.187
Port inner	0.029	0.030	0.028	0.187
Starboard outer	0.167	0.182	0.070	0.187
Starboard inner	0.100	0.088	?	0.187

For the starboard outer the clearance could not be calculated by the 'staining' method, because the shoe which made the stain marks was no longer available. The newly fitted shoe saw only two or three clutch engagements and had not contributed to the markings.

All the clearances were less than their design value and all were different.

Looking first at the port (undamaged) gearbox, the results of the three methods correlate well and gave confidence in the techniques being used.

On the starboard gearbox, dimensional checking could not give a clear picture of the situation before the explosion because of distortion of the gearbox covers upon which the clutch actuator is mounted. However, analysis of the stain marks which were made over a period of time (almost certainly over the period of service of the gearbox) can give an indication of the running clearance existing before the explosion.

The stain marks on the starboard inner clutch indicate a previously existing clearance of approximately 0.070 inches. This compares with measured and calculated clearances after the explosion of between 0.167 inches and 0.182 inches: in round figures an increase of 0.100 inches. This is a similar figure to the measured clearance under the starboard outer clutch shoe and yet it was clear that contact had occurred at this shoe from the blueing of the ring and deformation of the shoe itself; i.e. there had been zero clearance.

The gearbox explosion was remarkably symmetrical in all visible respects. The damage to the gearbox casings on both inboard and outboard sides is very similar and photographs of the two sides of the damaged gearbox require careful study to discern which is which. Thus all the evidence points to a deformation of the covers upon which the clutch actuator is mounted of the order of 0.100 inches.

Referring again to FIG. 8, the clearance is determined by the relative position of the surfaces of the ring and the shoe. This in turn depends upon the dimensions of the components and upon the positioning of the actuator mounting face with respect to the clutch centre line (FIG. 8, dimension C). The component dimensions were found to be within tolerance and it was the latter dimension of 16.375 inches, specified by the clutch manufacturer to the gearbox manufacturer, and toleranced to ±0.002 inches by the latter, which was found to be less than nominal in every case. The discrepancies were also consistent with the clearances which had been measured and calculated.

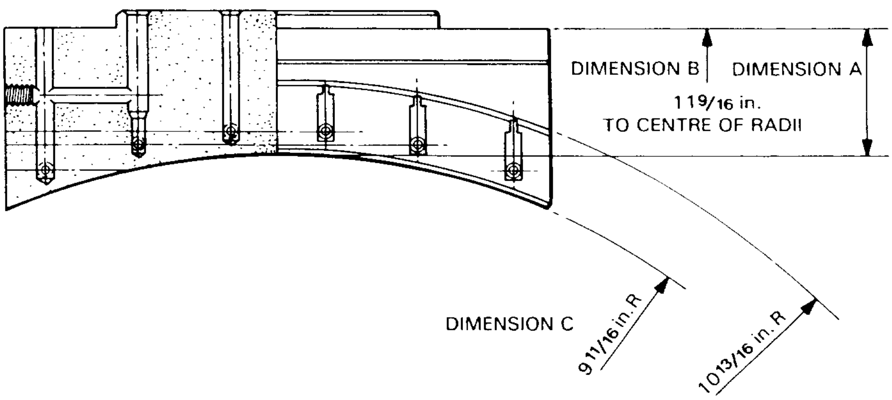

FIG. 9—SECTION THROUGH ACTUATING SHOE

Thus the evidence indicated that the critical clearance had always been marginal on the starboard outer and, further, that a frighteningly small clearance existed at the port inner clutch. The question then posed therefore was why had the incident occurred on 3rd April, shortly after *Illustrious* had sailed, and not earlier. FIG. 9 shows an extract from the shoe manufacturing drawing. The critical dimension is from the inner radius to the mounting face (FIG. 9 dimension A). This is the difference between two dimensions (B and C) both toleranced at ±0.010 inches and thus it may vary by ±0.020 inches from its nominal value. Examination of the available shoes showed that this range of dimensions could exist and thus it is conceivable that, at worst, the replacement shoe fitted to the starboard outer was 0.040 inches larger than its predecessor.

However, if this was the case, and the clearance had been eliminated by a slightly larger new shoe, why was it not detected when the shoe was changed?

After fitting it, the clutch was checked by moving it axially between the locked out and the ratchetting positions and after the ship sailed the clutch was engaged, and closely observed, twice before the explosion occurred. In both cases nothing untoward was indicated and a clearance had to exist for these checks to be possible.

The answer lies in the loading on the third reduction direct drive pinion and hence the position of the load line in its bearings at the full power condition. In the case of the outer drives the effect of gear loading is to raise the pinion and hence the SSS clutch in its bearings whereas in the case of the inner drives the pinion is forced down in its bearings. The effect is to reduce the static shoe-to-ring clearance by the amount of the clearance in the outer pinion bearings as the gears approach full power. This bearing clearance is of the order of 0.018 inches. Conversely, the inner clutches are forced into the bottom of the bearings and hence the 0.030 inches clearance at the port inner clutch is not reduced further at full power.

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There was now a complete explanation. The evidence provided by the measurements on the port inner clutch showed that a much smaller radial clearance than the design figure could exist between the clutch shoe and the clutch ring. Indeed in H.M.S. *Illustrious* all four clearances were less than the design figure. If the estimates of gearcase distortion above the starboard outer clutch were correct, it follows that a smaller clearance still was present at this clutch. Add to this the fact the outer clutches rise in their bearings under power and it follows that a near-critical situation had always existed. The exchange of shoe reduced the critical clearance by a few thousandths of an inch further although regrettably not sufficiently to foul in the static condition otherwise the problem would have been detected. It is deduced that a static clearance existed after the exchange but that it was less than the 0.018 inches bearing clearance.

As the gearbox approached full power the clutch rose within that bearing clearance and contact occurred. Frictional heat was generated and the temperature rose sufficiently to convert the normally safe atmosphere in the clutch housing 'enclosure' into a flammable mist. This eventually ignited and released sufficient energy to cause the main part of the gearcase to explode. That high surface temperatures were reached is confirmed by the metallurgical examination of the shoe and that these are sufficient to create the necessary conditions is well documented[1].

The change in conditions following the exchange of shoe was almost certainly due to the tolerancing of this component. A difference in the critical dimension of up to 0.040 inches is possible and, although the actual change is not known, measurement of the available shoes shows that the discrepancy between the old and the new shoes could well have been this large. Notwithstanding this evidence, a much smaller dimensional discrepancy would probably have sufficed to cause contact. However this tolerancing would be relatively insignificant if the setting dimension between the centre line of the clutch and the mounting face had been correct. This dimension, although apparently tightly toleranced on the drawing, shows a dramatic variation across the four clutches in H.M.S. *Illustrious* and the lack of accuracy and consistency of this dimension was the most significant factor in the explanation for this disaster.

With the benefit of hindsight it is a salutary thought that the most likely time for this explosion to have occurred was the first time that the gearbox approached full power—on Contractor's Sea Trials. The outcome, with a number of people in the gear room and perhaps a less worked-up fire-fighting organization might have been very different.

The Repair

This article would not be complete without mention of the repairs to *Illustrious*. The immediate requirement was to define the work package, and from that to estimate timescales, decide upon where the work was to be done, and to undertake the initial clean-up required before repair work could start in earnest.

The work definition for the gearbox was proposed by David Brown Gear Industries, its manufacturer, and endorsed by MOD. It consisted of lifting out every gear capable of removal (the main wheel is not), examination of all bearings, and checks of bearing lines both optically for straight line alignment and with mandrels for parallelism. Hardness and concentricity checks were required on all the removed gears and, concurrently with all this, a complete new set of gearbox covers had to be manufactured. A critical path network was drawn up which was invaluable and this was refined two or three times as the discussions on repair options proceeded. At the same time Portsmouth Naval Base was defining the work required to rectify the gear room fire damage. Two critical paths were identified, the gearbox work itself (and within that the parallel activities of ship work and cover manufacture) and the re-cabling of the whole machinery space. All other activities, it was estimated, were containable within these.

The early decision that the work would be done in Portsmouth served to dismiss fears that much wrangling would take place over the venue. This was greeted with delight by the ship and the Naval Base since both were convinced that her home base was the place to effect swift repairs. From the very start, the objective was for the ship to rejoin 'Global 86' and hence a very ambitious, minimum realistic timescale was set.

Even before the venue decision was taken, a dramatic start was made and within an impressively short space of time the gear room was swarming with

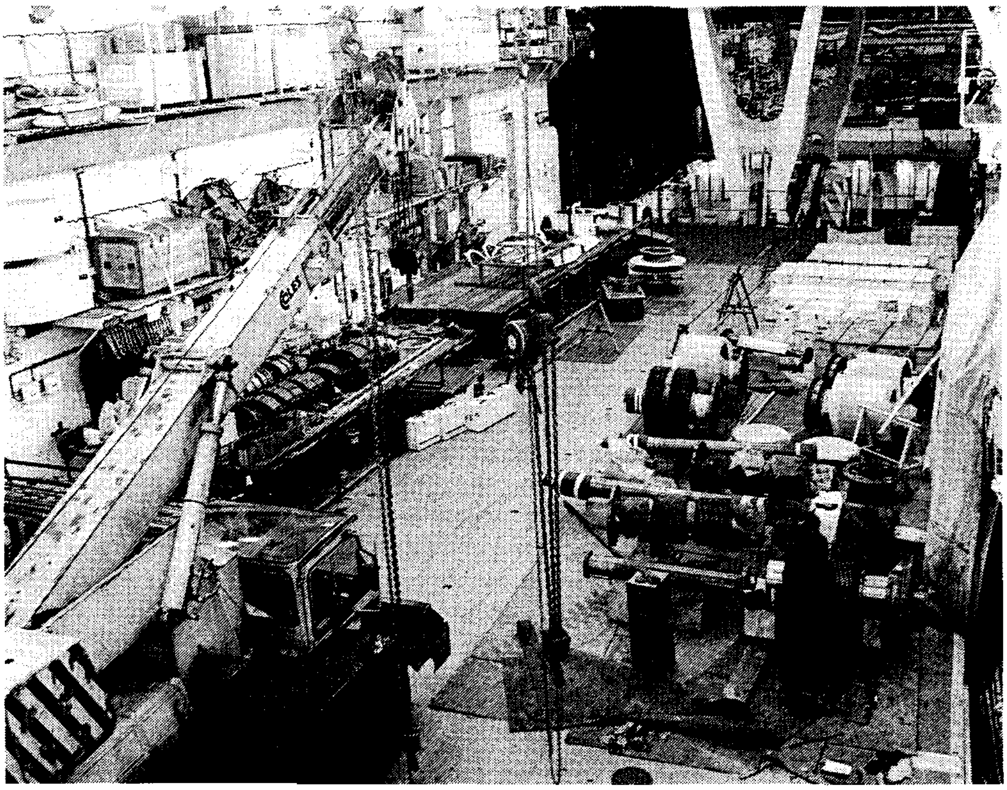

FIG. 10—THE FORWARD END OF THE AIRCRAFT HANGAR WITH MOST OF THE GEARS REMOVED FOR CLEANING, CONCENTRICITY CHECKS AND HARDNESS TESTING. THE LARGE WOODEN CRATES CONTAIN THE ANCILLARY SUPPORT EQUIPMENT

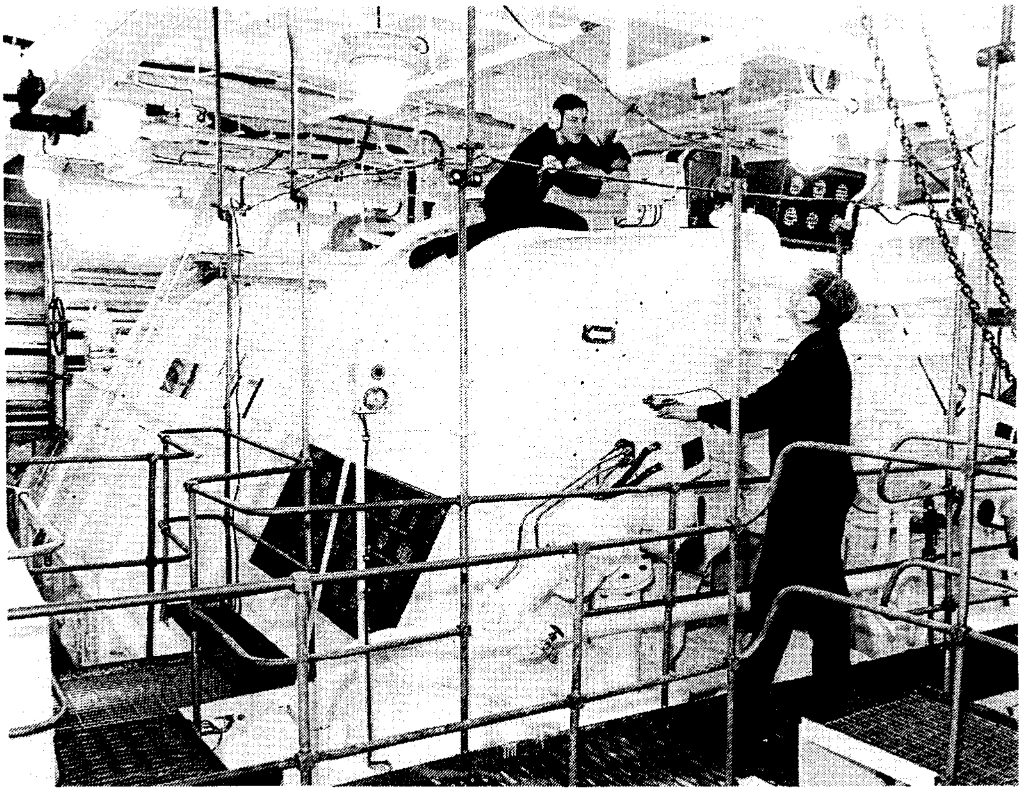

FIG. 11—THE FINISHED ARTICLE. THE REBUILT STARBOARD GEARBOX DURING PRE-SEA CHECKS

workmen. Stagers, laggers, shipwrights, electricians and, even at this early stage, painters were working alongside each other to prepare the scene for those who would tackle the critical path activities. The hangar became the scene of a village industry, with temporary workshops erected and such items as ventilation trunks being cleaned, relagged, painted and marked up for replacement without them even leaving the ship (FIG. 10).

All the planned work was achieved with round-the-clock working, seven days a week, by Portsmouth Naval Base for a total of thirteen weeks. At the outset, many had thought that six months was a more appropriate timescale. The successful completion was a tribute to the Naval Base, the support organization, numerous sub-contractors (particularly the on-site guidance provided by David Browns) and indeed to the design of the ship. Without the built-in removal routes, good documentation, and the facility to terminate cable runs in cable passages outside the machinery space, the repair would have taken much longer (FIG. 11).

The ship sailed on post-repair Sea Trials on 14 July, four days earlier than had been planned originally. These trials were entirely successful although they came close to being thwarted at the last minute by a disaster with the forward aircraft lift. All turned out well however and the lift was made safe to sail and finally repaired on completion of Sea Trials, before deployment. Once again a major effort was involved and the ship left Portsmouth with the feeling that the various tribulations had had the effect of further cementing the already excellent relationship between ship and Naval Base, perhaps exemplified by the enthusiastic response to a 'Ship Open to Visitors' evening held specifically for those who had repaired *Illustrious.*

After three and a half months of hard work *Illustrious* sailed again on 21 July to rejoin 'Global 86' at Singapore with a sense of major achievement felt both on board and ashore—something few of us would have thought possible on the morning of 3rd April (FIG. 12).

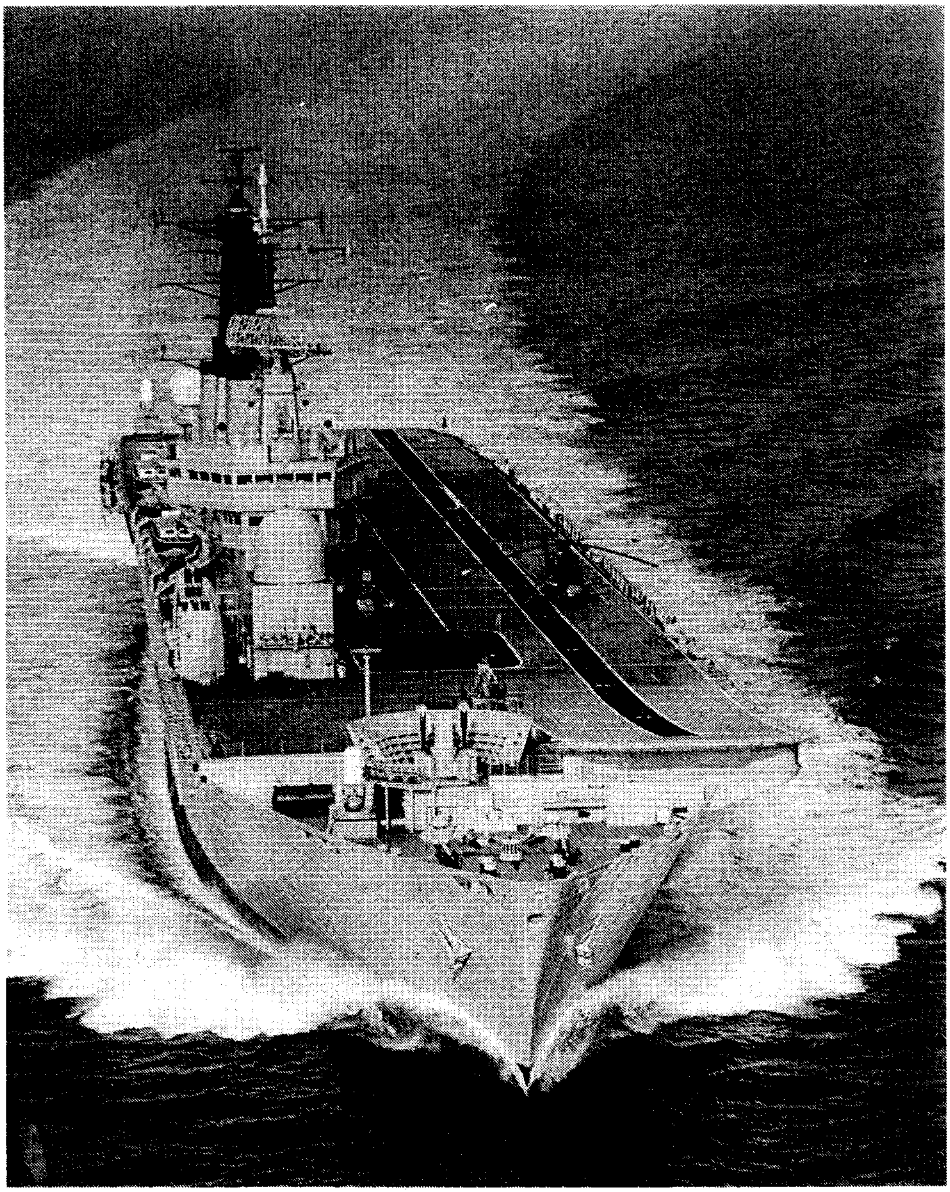

FIG. 12—THE PROOF OF THE PUDDING. 'ILLUSTRIOUS' AT FULL POWER DURING HER LARGE REPAIR TRIAL ON COMPLETION OF REPAIRS

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