Safety at sea and related research

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SUMMARY

This paper deals with mishaps to ships, their consequences and prevention. It is argued that present world accident rates are still higher than they need be, and that the causes are mainly human rather than material. Current research related to ship safety is reviewed in general terms.

ACCIDENTS AT SEA

Safety, like health, is conveniently defined in terms of its opposite; health is the absence of sickness, and safety is achieved if accidents do not happen. We can think of accidents as being of two sorts; injuries ot men, whether or not the ship is damaged; and damage to the ship, or the loss of the ship, whether or not people are hurt.

INJURIES

People are hurt and killed aboard ships, as in any other transport system or industry. The incidence, though regrettable, is not exceptionally serious by general industrial standards. Table 1 shows some figures for deaths in the British registered fleet over a recent period; when deaths due to suicide, sickness and so on are discounted, those due to injury are relatively few. No doubt similar figures could be produced by other shipping nations.

Table 1 - Deaths among crews of UK registered merchant ships

Cause of death	Average 1934-38	Average 1964-68	Average 1969-73	Year 1974
Casulaties to vessels	82	33	31	13
Other accidents	227	95	71	75
Disease, homicide or suicide	492	181	161	142
Totals	801	309	263	230

Breakdown for 1974

Cause of death	Total
Foundering of ship	7
Explosion or fire	6
Accidents on board	35
Accidents ashore	29
Homicide	7
Suicide	17
Missing at Sea	11
Disease	118
Total	230

The above total of 230 relates to an estimated total of 78,000 men at risk, representing a death rate of 2.9 per thousand seamen at risk. The rate has varied between 2.5 and 3.6 during the period 1964 to 74.

The total of 13 due to casualties to vessels represents a death rate of one man per 6000 at risk.

The above figures have been extracted from ref. 1.

An important exception to this favourable picture lies in the fishing fleets, where the figures for injury and death are much worse. Such injuries are typically associated with accidents on deck during the fishing process - handling nets, working with wires and so on - and suggest that some benefit could be expected from research into the ergonomics of fish-catching. However, fishing is not a transport process, and so the matter of fishing safety - as of safety aboard oil rigs and offshore servicing vessels - will not be considered further in this paper.

MISHAPS TO SHIPS

We shall consider a mishap (usually referred to by marine specialists as a "casualty") as an incident which leads to the damage or loss of a ship, whether or not people are hurt or killed. A convenient crude measure of casualty rates is provided by the over-all figure for ships lost each year, expressed as a percentage of the total number of ships at risk over the same period.

Alternatively this can be set out as gross tonnage lost in relation to tonnage at risk. The figures in Table 2 show

Table 2 - Annual World Merchant Ship Losses Expressed at a Percentage of Gross Tonnage at Risk

Year	Percentage lost	
1891	Sailing ships	3.7
1891	Steam ships	1.7
1913	Sailing ships	3.7
1913	Steam ships	1.0
1949	All ships	0.30
1959	All ships	0.23
1966	All ships	0.48
1975	All ships	0.29

Figs are from Ref. 1.
(1949 and 1975 from Ref. 2)

how this rate has fallen over the past century. The falling trend from the days of sailing ships and no radio is only to be expected. However, closer examination of the figures shows that the curve does not reach the zero level, or even approach it asymptotically; over recent years the loss rate has hovered uncertainly, and some interpreters even see signs of an increase. Table 3, abstracted with the author's permission from the so-far unpublished text of ref. 2, shows the indeterminate fluctuation over the last few years. Too much should not be read into these swings, the loss of a single large modern ship can distort the short-term figures; the "Olympic Bravery" for instance at 126,622 tons gross representing over one-third of the world losses for the first quarter of 1976. However, one firm conclusion can be drawn: the steady improvement evident up to the 1950's has been checked, and it may even have been reversed.

Is this any cause for concern? The loss of life due to ship casualties is very small, microscopic in fact in relation to the rate of deaths in road transport. The rate of loss of cargoes and vehicles, though not negligible, is reasonably small in relation to the total at risk. It can plausibly be argued that things are very well as they are, that the sea will always impose an unavoidable minimum of hazard to any vessel which ventures out of harbour, and that any research devoted to reducing loss rates further will not be cost-effective.

THE CAUSES FOR CONCERN

There are two good reasons for not accepting this let-it-go argument. The first is that the ocean is not expanding in width and depth to suit the large modern ships; as vessels grow in speed and size, above all in draught, they are increasingly confined to narrow channels and fairways which cramp their motions, degrade their steering and lessen the scope for collision-avoidance manoeuvres. The risks of grounding and collision, in fact, seem bound to grow with the number, speed and size of ships operating in the finite ocean. If losses are not to get worse, some positive action is called for to prevent such groundings and collisions from happening.

The second reason lies in the size and physical nature of many cargoes now being carried. A generation ago the sinking of a cargo ship meant a loss to the owners and the underwriters, and possibly distress to the crew and passengers, but the community at large was not affected. Now, however, we are carrying enormous quantities of obnoxious substances by sea, in particular oil, gas and chemicals, and an accident can have widespread effects far more unpleasant and actively harmful than could have resulted from any conceivable mishap with the cargo ships of past years. The effects and cost of oil pollution are familiar enough to need no elaboration (though it should be borne in mind the Torrey Canyon was a relatively small tanker by present standards). Apart from the sheer scale and cost, the new factor here is the involvement of innocent third parties; members of the public remote from the scene and unconnected with the shipping business can suffer. In this context it is not only chemical pollution we should worry about; one can point to the private householders ashore in south-east England who had their windows broken by the blast from a foreign tanker blowing up in 1971, in waters which were then regarded as international. More recently a Liberian tanker has exploded in Los Angeles harbour, breaking windows ashore up to 21 miles away. A notable number of private citizens live within 21 miles radius of the world's main oil terminals.

Since, then, the community at large can now suffer loss from the activities of the marine transport industries, the community is entitled to take an interest in the conduct of those industries, and if necessary to impose regulations to minimize such loss. In such activities Governments individually, and collectively as IMCO, act on behalf of their citizens.

The really serious accidents, however, are those which have not so far happened at all, outside science fiction stories. The one usually quoted is the collision between a liquid gas carrier and a cross-Channel ferry. There is nothing inherently impossible about such an occurrence, indeed it seems less unlikely than a head-on encounter between two air-liners at 10,000 metres altitude. The ships move in only two dimensions, and these can be crowded in places as the Dover Straits radar plot will show at any time (see fig 1).

ANALYSIS OF STATISTICS

The loss figures compiled by Lloyd's lend themselves to breaking down in various ways - by nationality, by cause of loss, by type and size of ship, by age of ship and so on - and a fascinating set of such figures will shortly appear in ref. 2. It is proposed here to comment briefly on only two features of these figures; the type of loss, and the effect of nationality.

The world figures broken down into broad categories of accident - Grounding, Collision, Burnt and so on - show considerable fluctuations, but there seems to be a slight decrease in groundings since 1960 balanced by an increase in Burnt (which include explosions) and founderings (ie sinking due to weather damage or capsizing). The Burnt category includes the various tankers affected by ballast tank explosions.

The nationality subdivision shows a quite remarkable scatter of loss rates, (see Table 3). The wide discrepancy

Table 3 - Shipping losses of some of the principal flags, expressed as a percentage of the total gross tonnage at risk, over the period 1967 to 1975

	%
Lebanon	4.72
Philippines	2.23
Cyprus	1.96
Korea	1.66
Somali Rep.	1.57
Singapore	1.32
Panama	1.11
Greece	0.90
Netherlands	0.56
Liberia	0.46
Spain	0.41
Italy	0.38
Canada	0.37
Denmark	0.26
U.S.A.	0.21
Norway	0.18
Japan	0.17
Sweden	0.16
Germany FR	0.14
United Kingdom	0.11
France	0.09

The figures are extracted from ref. 2.

in loss rates between the best and the worst shipowning nations has been pointed out time and again in the marine press (E.g., in ref. 8). The causes can lie to only a small extent in the ships themselves, as even in the worst fleets these are for the most part still classed by reputable classification societies and thus mechanically adequate for safe operation. The causes must be sought rather in the way in which the ships are operated, in the standards of officer qualification and of inspection. (A detailed study of ship loss causes among the flags of convenience would make a fascinating research project if one could only come by accurate information for each loss). The spread of loss rates between flags suggests that human factors may have an important bearing upon marine safety.

THE CAUSES OF SHIP CASUALTIES

It is easy enough to list casualties under types - grounding, collision and so on - but far harder to establish exactly why each grounding etc. did occur. Press reports are usually uninformative on the subject, for understandable reasons where officers' careers and reputations are at stake. However, in a small sample of cases one can delve further. If a shipping accident involving British registered ships involves significant loss of life, or attracts public concern for some other reason, then the UK Department of Trade sets up a Court of Inquiry to conduct a formal legal investigation, and the reports of a number of such inquiries are available. For the cases so investigated over a period of some 14 years, it will be found that in roughly 2 cases out of 3 the accident could be put down to human error of one sort or another, rather than to material failure.

This sample is not of course large or random, and the 2/3 ratio cannot be assumed to apply to all shipping at all times. However, other studies carried out quite independently on different samples still show the preponderance of this human factor. For instance, the US Coast Guard reported in 1963 that over the period 1957-59 in 199 collisions involving 398 vessels there was mechanical failure in 6 vessels and "personal failure" in 289 vessels. (Ref. 3). Other observers have estimated "human causes" as 9 out of 10.

Evidently, therefore, if we wish to reduce further the present loss rate we should look first to the human element rather than to the material engineering of our vehicles. This is not to say that ships cannot be improved mechanically, but mechanical performance and reliability are already well researched and further effort will lead to only marginal gains, whereas the human field is so far little explored and moderate effort may lead to major gains.

THE NATURE OF HUMAN FAILURE

Consider first the part of the human in groundings and collisions, which together account for something near a half of all losses of ships, and an even higher proportion of damaging casualties short of total loss. A grounding or a collision results from the ship being in the wrong place, ie. from a navigational error of some sort. In steering or navigating a ship the man is provided with information, through his own eyes or via sensors such as radar sets.

On the strength of this information, and drawing upon his training and experience and local knowledge he takes various decisions. He gives effect to these decisions by giving orders or operating various control knobs. What can happen to lead to a wrong navigational act?

Following the chain of events through, we can group errors into four categories. First there is the error of perception, where the man fails to see another ship in his path, or sees it but wrongly interprets its aspect. A commonly quoted instance arises when the masthead lights at the two ends of a long ship are wrongly thought to belong to two separate small ships; in trying to steer between them the navigator rams the tanker amidships. Similar but more subtle errors occur in interpreting the radar display or echo-sounder chart. The slippage in fact occurs at the interface between the world and the man's senses.

The second sort of error happens inside the man's head. He acquires the right information, but through ignorance or bad training or downright incompetence he takes the wrong decision.

The third kind happens when the man has the right facts and makes the right decision, but gives orders which are misunderstood or operates a control wrongly. The error again happens at the interface between the man and his surroundings.

The fourth kind of error happens when the man knows axactly what he ought to do and how to do it, but deliberately does something different. An example might be when he fails to reduce speed in bad visibility in order to save a tide, or when he enters a shallow harbour with less than the under-keel clearance prescribed by the local harbour master. Such actions are conveniently called errors of malfeasance.

At one time all these human manifestations were regarded as outside the world of the engineer; fit matters for discussion perhaps between the officer and his Owner and the underwriters and the Marine Administration, but not amenable to treatment by research. In recent years this view has been revised, and there is now research going on in a number of countries aimed at reducing the incidence of human failure. The remaining sections of this paper are mainly devoted to reviewing this work.

BRIDGE ERGONOMICS

Errors of the first and third categories outlined above happen at the interface between the man and the "world", meaning in this case mainly the equipment and instruments on the ship's bridge. The study of the relationship between man and his working environment is known as ergonomics, which is now a respectable branch of science with established techniques and principles. Ergonomic studies have long played a part in the design of aircraft cockpits, and even of automobiles. How do modern ships' bridges stand up to an ergonomic examination?

The answer is, pretty poorly. A classic study by Wilkinson in 1971 (Ref. 4) showed that merchant ships were ripe, ideed over-ripe, for the ergonomists' attention. A field study carried out by a UK firm under contract to the Department of Industry confirmed this view, and in a long series of visits to ships a collection of cases was built up illustrating in a multitude of ways "how not to do it" in designing or laying out instruments. One could list a multitude of petty instances - inaccessible switches, confusing labelling and dial markings on instruments, windows which could not be cleaned, indicator lamps causing dazzle at night, slippery decks and absence of hand-grips; mostly small points, but adding up sometimes to what looked like a deliberate effort to make the officers' job difficult and confusing.

Concurrently with this project, similar studies have been under way in Holland, Germany, Norway and Sweden. The emphases of the various national programmes are different; the British effort has depended mainly upon watching the seaman at work, the Continental programmes have placed more reliance upon questionnaires addressed to practising mariners. However, an important point to note is this: the marine ergonomics teams in these countries are in touch with one another, and with the US Coastguard too, and there is a fruitful interchange of ideas and information. In the UK the study has produced a draft "Code of Practice for the design of ships' bridges", the text of which is now under discussion with the marine industries. Parts of the document read largely like a platitudinous recitation of the obvious, but the need for it is apparent in the numerous bridges which fall short of some of the most elementary ergonomic requirements.

Apart from the physical design of the ship's bridge, there are physiological aspects of the man-ship match which deserve investigation; for instance, the deterioration in human performance caused by noise, vibration, heat, fatigue and seasickness. Some spin-off from military work in these fields could benefit civil studies.

EXTERNAL ERGONOMICS

This refers to the functioning of the interface between the man and the external world, as distinct from the shipborne environment of bridge instruments and controls. Here the main matching requirement lies in the need for the man to be able to judge the tactical situation correctly with his own unaided senses, and in particular to be able to assess another ship's movements simply by looking at her, and by listening to her whistle signals. In daylight and good visibility there is little difficulty, but at night or in fog visual problems can arise from the difficulty of interpreting the appearance of the ordinary navigation lights. By international agreement all large ships carry five navigational lights, laid out in a specified manner - two masthead lights, a stern light and the red and green side lights. These serve to indicate the presence of a ship, but not her size, speed, aspect angle (except in very approximate manner) or intentions. The lighting standard was based upon oil lamps and was adequate for the days of sail and slow steamers. Now however the availability of modern electric lighting techniques suggests that a great deal more information could be conveyed at modest cost, in particular by using the ability to modulate or flash the navigation lights so as to make them stand out from accommodation lights, shore lights or other sources with which they might be confused. Collision studies suggest that an indication of intent or helm action - eg. "I am putting my rudder to starboard" - could be valuable to other ships in the area; such an intent could conveniently be signalled by, eg. flashing or occulting the starboard side light. A study of marine optical perception in relation to various lighting schemes is being planned in UK.

Regarding audible perception, whistle signals still have a part to play in closequarters situations, in harbour or in fog. A difficulty sometimes arises in deciding which of several visible ships is the one emitting a perceived noise. In the days of steam this was conveniently indicated by the white plume issuing from the funnel responsible, but the air whistle of the diesel ship or tug offers no such clue. A proposal has been made that the operation of such a whistle should also trigger a bright all-round flashing light. This would show identity in clear weather, and also bearing and range (from the time delay) in poor visibility.

TRAINING

The second sort of human error discussed above is that which arises from incompetence, ignorance or inadequate training. In this context the training concerned is that involved in ship handling, navigational decision making and emergency procedures. At one time the necessary skills could be picked up on the job, largely by trial and error, and this may still be feasible in small ships. In large modern vessels however the trial and error process is ruled out by the cost and danger; it is simply not practical, for instance, to let a pilot learn how to con a VLCC into Rotterdam by experimenting with a loaded vessel.

The air transport industry has long faced a similar problem, and air pilots are now regularly trained on flight simulators, machines which reproduce faithfully the reactions of the vehicle and present a realistic "machine interface" to the man. It was a logical step to apply the simulation technique to the training of seamen, and a number of training simulators are now in operation in europe and USA. Those known to the author are listed with outline particulars in Table 4.

It is not claimed by any simulator operator that the simulator can take the place of sea experience. It is however claimed that, for a certain range of instructional topics, it is far more cost effective and safe. Moreover, the simulator enables some things to be done which could not be done at all at sea, even if the cost and time could be afforded; in particular the simulator enables exercise conditions to be repeated exactly, time and again. This is useful for testing purposes, for comparing students, for weeding out the basically imcompetent and those with no aptitude for seamanship, and even for examinations. Further, exercises can be carried through to the point of actual collision or grounding if necessary. Time is saved because the desired environment and weather conditions can be laid on immediately the machine is switched on - there is no time lost in steaming to the exercise area and waiting for the right conditions of daylight and weather.

Table 4 - Ship training simulators in commission

	Country	*Place*	*Operator*	*Optical display*
1.	France	Grenoble	Sogreah	Manned ship models in lake
2.	Holland	Delft	TNO	Shadowgraph
3.	Holland	Wageningen	NSMB	Shadowgraph
4.	Germany	Bremen	School of Navigation	Slide projector
5.	Sweden	Goteborg	SSPA	Multiple CRT screens
6.	UK	Warsash	School of Navigation	Point light projectors (nocturnal view)
7.	USA	King's Point	MARAD	Multiple projection TV (mainly research facility)
8.	Japan	Hiroshima	University	Projection TV
9.	Japan	Tokyo	University	Projection TV

As in ergonomics, there are different emphases in the various national approaches. First in the simulator field were the Dutch with their shadowgraph machines at Delft and Wageningen. These were specifically for training in ship handling in currents and shallow water; no other ships were involved and so collision avoidance could not be exercised. The lighting conditions represent subdued daylight. The French approach is to use manned models in a lake. The German simulator at Bremen uses a daylight scene made up from a multiplicity of slide projections, and again is primarily for ship handling. The British simulator at Warsash is entirely nocturnal, ships and buoys being shown only by points of light. This machine can be used for handling, but it is intended mainly for exercises involving up to four "other ships" controlled by the instructor. The American CAORF machine at King's Point is vastly more elaborate and expensive than any of these, using colour television projections of daylight or nocturnal scenes, including other ships; this machine however is intended for research purposes rather than training.

With this diversity of approaches the art of marine simulation should make rapid progress. While simulator construction is a matter of development rather than research, the research world has a crucial contribution to make in the formulation of the mathematical models which, fed into the computer, represent the behaviour of "own ship" in the response of the simulator to the man's orders. These models are far from simple, because they have to take into account not only hull and engine characteristics of the ship, but also the sea depth (which seriously affects steering behaviour), current, wind, tug forces and so on. An un-representative model is at once detected by an experienced ship handler, who knows what response to expect from a given change in helm angle or propeller revolutions.

Making a simulator and filling it with officers under training is not enough. Follow up studies are required to assess just how effectively the simulator is in fact doing its job, to detect any weaknesses in the procedure and to devise improvements. This involves the objective measurement of human capability in seamanship, a far from simple matter. Human measurement of this sort has been common enough in some fields ashore; marine scientists now have to learn the techniques and apply them to the mariner.

The simulators referred to so far are for ship handling and navigational decision making generally - they represent in effect the bridge. There is however scope for simulation techniques in several other aspects of ship operation, notably in main engine control, cargo working and so on. Engine control room simulators are already in use, particularly for complex installations involving, eg. combinations of gas turbines and diesels. One could contemplate the possibility of linking a bridge and an engine simulator together, for exercising jointly deck and engineer officers. This could, incidentally be done for a new ship before the construction of the actual ship; for exercising entry to a harbour before the construction of the harbour.

MALFEASANCE

This is what happens when the man possesses all the correct information, knows the right thing to and and quite deliberately does something different. It is not peculiar to any one mode of transport, and quite possibly some members of this Conference will have malfeasantly exceeded the road speed limits on the way to this session.

It can be argued that action of this sort is as old and as incurable as sin itself, and that any transport system will have to accept a certain amount of wrong-doing by its practitioners as long decisionmaking is left in human hands. In some transport modes we can replace the driver by a computer, and we can program the computer to be completely without sin, but the unmanned ship is a long way off yet and we are left with the mariner and his sinful ways. Can anything be done to incline the seaman towards virtue?

History suggests that exhortation unsupported by enforcement is likely to make no more impression upon the seaman than it does upon the ordinary motorist. Driving behaviour on the roads, however, does improve when the traffic police are visible and active, even though the actual number of prosecutions may be small. There is evidence that marine traffic responds in a similar way, and here it is appropriate to cite experience over the last few years with shipping in the Straits of Dover area.

The narrow seas between Dover and Calais carry one of the most dense concentrations of shipping in the world. Up till 1967 ships were left to pick their own routes through the Straits, but in that year a "Routing scheme" was introduced by IMCO under which preferred paths were set out on the charts, laid out in such a way that ships travelling into the North Sea would keep to the French side and those leaving the North Sea to the English side. "Inshore Zones" adjacent to the two coasts were reserved for local and coastal traffic. All seaman were exhorted to comply with the scheme, but there was no legal enforcement.

In 1972 a survey was carried out by the National Physical Laboratory on behalf of the UK Department of Trade to ascertain the extent of compliance with the routing scheme. Over a sample period it was found that no less than 12% of the traffic in the main lanes was travelling in the reverse direction, and that a considerable proportion of the traffic in the inshore zones was on international passages not calling at UK ports and so ought not to have been in these zones.

Following these surveys, the Channel Navigation Information Service was set up by the UK and French Governments in collaboration. This organization includes radar stations ashore on both sides of the Channel by means of which Coastguards observe all shipping movements, and a VHF radio service over which shipping is advised of local conditions, any special hazards and so on, and in particular ships in general are warned about "rogues", ie. individual ships seen to be moving the wrong way in the main lanes. Further, when conditions permit such rogues are identified by aircraft and their behaviour is reported to their owners.

The effect of this surveillance upon shipping behaviour has been marked. During a special survey of shipping carried out over a sample period of 3 days in August 1976, the proportion of ships travelling the wrong way in the main lanes had fallen to 6%, and of these some were minor fishing vessels. The proportion of ships on international passages improperly using the English inshore zone had fallen from around one-third to about 10%. More detailed information is in Refs. 5 and 9.

Since 1972 certain countries have made compliance with the IMCO routing scheme mandatory upon ships of their own flag. In July 1977, by international agreement, compliance will be made mandatory upon ships of all IMCO members-ie. of all the major shipowning nations. There are many routing schemes throughout the world; compliance generally cannot be predicted, but in the Dover Straits scheme it can be expected that compliance will be virtually complete because this scheme is effectively policed, it is seen to be policed, and there have already been procecutions against certain British seamen detected in transgression. (The UK Government was one of those which made the scheme mandatory upon UK ships in anticipation of the international agreement on routing). Such prosecutions do not need to be particularly numerous or drastic to convey the message: Coastguard can see you.

This brief account of one result of the Channel Navigation Information Service suggests that, in resisting the temptation to commit an act of malfeasance, the wavering seaman's conscience can be remarkably stiffened by the knowledge that an impartial outside agency can observe his movements, and if necessary identify him and call him to account. At the same time it shows up an area where the policing action could be made more effective by some suitable research; this is in the field of ship identification. Existing radar sensors are very effective in detecting and locating ships and plotting their movements, but to a radar set one echo is just like another; to achieve positive identification it is at present still necessary to send out an observer in a patrol ship or aircraft to apply the human eye - preferably backed up by a camera if prosecution is contemplated. Patrol activities of this sort are expensive and can be hazardous in bad weather, and a positive method of identification by remote means would be invaluable. Admittedly the technology already exists to do this by means of radar transponders, but these argue a target ship willing to purchase, fit, maintain and operate the device properly at all times; in the long term this may be achieved by international agreement, but in the short term some device to provide information without active participation by the target ship would be welcome; even partial information - such as size and type of ship - would be useful.

In the absence of patrol identification, a certain amount of detective activity is possible using the photographic records which are kept at all times of the Coastguard radar. For example, in the retrospective examination of a reported collision incident, it proved possible to identify one of the ships involved by analysis of her speed and course, as traced back through the radar photographs, in conjunction with the information on arrivals and departures in European ports chronicled daily in Lloyd's List. However, such studies can take days; for an identification procedure to be useful operationally it must produce results while things are still happening at sea. If cmmercial shipping data are to be consulted, this would call for on-line access to a constantly updated computer bank of commercial data.

THE RULES

In discussing human failures we have so far assumed that there is available somewhere a body of rules by observing which a seaman can keep out of danger, or at least avoid colliding with other ships. In relation to the latter hazard there are the internationally-agreed "Rules for preventing collisions", which do in fact tell the seaman just what he should do in the way of changing course and speed where he meets another ship. The rules however cannot cater for every possible eventuality; most importantly, they provide no clear-cut guidance to the seaman who is confronted with not one but two or more on-coming ships, a common enough situation. Unfortunately opinion among seamen themselves is far from clear-cut on what the rules should say in such cases, or even whether it is really practical for the rules to say anything at all. In theory an experiment could be mounted by devising alternative sets of rules and setting sample populations of ships to follow them to see if collisions increased or decreased. Although manifestly impossible in the real world, such an operation is still feasible by computer if we can devise a mathematical model of how a ship's master will behave in various situations when constrained by an appropriate set of rules. Ideally one should also introduce the random element inseparable from human participation, and this means introducing a real man working in real time. There is clearly scope in this area for operational research workers using simulation techniques. The mass of data recorded on films taken over five years radar observations of shipping in the Dover Straits are available to provide real- life tactical situations for input to such studies.

SHIP ENHANCEMENT

So far we have considered how best to enable the seaman to operate safely with the conventional merchant ship as at present conceived. Is it possible however that by making material changes or additions to the fabric of the ship we could enable the seaman to do his job better?

We have already discussed sensors and controls under the heading of ergonomics; there is always room for improvement here. As regards the ship itself, it is often argued that the risk of collision and grounding can be reduced by improving the stopping ability and manoeuvrability, on the reasoning that the more quickly a ship can decelerate and turn, the less likely she is to run into something.

The stopping requirement is one which appeals to the public imagination, and braking devices for slowing down big ships are invented and re-invented with tedious regularity. As can be predicted from basic mechanics, such devices will work, but if they are effective they are too large and heavy to be practical; if they are small enough to be feasible they give so poor a deceleration that they are not worth fitting. The water parachute has in fact been demonstrated on the full scale in Japan for slowing down a ship, but the operational hazards of this device seem likely to exceed those which its stopping power is supposed to avoid.

With manoeuvring devices we are on more promising ground. A variety of thrusters are becoming available which can be used to impel the ship in various directions, notably sideways, and special rudders are available which greatly improve ship handling, in particular at low and zero speed. Examples are the Pleuger, Becker and Schilling rudders and the Rotating Cylinder Rudder. Specialised propellers, notably the Voith-Schneider and Schottel propellers, can generate thrust in any desired direction. Oddly enough, however, none of these devices seems to have demonstrated any particular virtue in preventing major collisions. In ref. 6 Dr. Gardenier of the US Coast Guard office of Research and Development argues that improved manoeuvrability does not necessarily help in avoiding collisions, and that in certain cases it can in fact even increase the net collision risk. The main virtue of the devices discussed appears to be in harbour manoeuvring and docking, where they undoubtedly minimise minor incidents of the sort discussed below. The prospect for reduction of major collisions and groundings by the operation of manoeuvring devices, however, appears small.

If the manoeuvring device can be thought of as a means of strengthening the seaman's arm, then there are various black boxes becoming available which correspondingly strengthen his brain power. These include the various kinds of shipboard computer, and in particular the different makes of "collision avoidance radars" (CARs). These will analyse the radar echoes, label them, predict their likely future movements and advise the ship's officers of the predicted outcome of any contemplated manoeuvre. Nevertheless, too much should not be expected. In a retrospective study the US Coast Guard examined the records of collisions occurring to ships over 10,000 tons gross over a period of five years. Analysis showed that "something between 9.6 and 13.1% of the collisions could possibly be prevented by such a system" (ie, a CAR system; ref. 6 again).

Thus, while there are undoubtedly some benefits to be obtained from enhancing the ship so as to provide the master with more muscle power and more brain power, it seems generally true that the prospects of reducing major accidents by hardware additions alone appear disappointing. It still seems that major accidents by hardware additions alone appear disappointing. It still seems that major accidents are more likely to be reduced by attention to the man himself and to his interface with his equipment, than by an equal effort devoted to inventing new hardware. Indeed, in some circumstances sophisticated hardware could even be actively pernicious - eg. a manoeuvring device which makes it possible to execute violent turns not expected by other ships' officers. Sending such machinery to sea would be of no service to the sailor.

MINOR INCIDENTS

The whole of the paper to this point has been concerned with serious incidents - those likely to result in the loss of the ship or severe damage, and to pollution of the environment. It is the duty of Governments to protect their citizens from such incidents and the consequences of them, regardless of economic factors; hence the attention devoted by the UK and other Governments to the prevention of collisions and groundings.

However, from the shipowner's point of view total losses of ships are relatively unimportant; far greater total sums of money are involved each year in what the insurance industry call "partial losses", ie. incidents which involve damage falling short of total loss of the ship, and extending right down to the trivial level, such as dented side plates, bent guard rails and so on. Also included are damage and breakdowns in ships' machinery and equipment. Very few of these incidents involve human injury or death, and so Governments take less interest. Nevertheless the total cost of "partial losses" to the insurers, and hence to the shipowners via premium payments, is very large; one approximate estimate suggests that over a recent one-year period "partial losses" cost the UK shipowners about 16 times as much as total losses. There is thus a substantial economic incentive for cutting down on the partial loss rate.

Of the incidents other than machinery breakdowns, by far the most common are those occuring in port and variously described as contact, impact or striking - ie. the contact between the moving ship's hull and a stationary object such as a dock, pier, moored ship or buoy. Many such contacts occur during berthing, particularly when the wind is strong. Of a sample of contact incidents examined at NMI, two-thirds occurred in winds exceeding 30 knots. The ship damage is not always the whole story; impacts frequently necessitate expensive civil engineering repairs to fixed structures as well.

The sums of money involved in partial loss repairs suggest that research in this field could be economically effective. Much of the incentive for the development of the various manoeuvring devices referred to above has come from consideration of the movement of ships in harbour. The berthing phase in particular still demands attention. The effect of wind has been mentioned. Modern container ships, and tankers when unloaded, present enormous side areas to the wind and the aerodynamic forces can be very large. Indeed with tankers at oil terminals the risks extend well beyond the minor category. To the detached observer it would appear that berthing techniques, and in particular the method of using tugs, would merit close examination. The conventional tug with a single screw propeller has severe limitations in putting large ships through complex manoeuvres, indeed the tug itself can on occasion be in danger, as the occasional "girding" or capsizing of a tug by the pull in its own tow rope shows. Improved flexibility can be obtained by replacing the screw propeller by one of the vectorable thrusting devices referred to above, but these have limited power. Perhaps we should drop completely the concept of a tug - the very name of which implies a device for pulling on a rope - and replace it by the idea of a moveable thrusting machine, a device which can be floated out and secured to the ship for use during berthing under the pilots direct control. There is scope here for considerable ingenuity.

SUMMING UP

Safety at sea is a complex matter and this wide review has unavoidably been somewhat superficial. However some general conclusions can be drawn.

First, ships are subject to a large number of minor accidents. These cost the owners a considerable amount of money. They happen mostly in harbour, often in berthing, but involve very little injury or loss of life. There is some economic incentive for research and development work, particularly in connection with harbour movement and berthing.

Secondly, the number of major incidents such as ship sinkings is relatively small, though the incidence varies markedly from one national flag to another. The cost in human life and injury is not at present very large, but there is potential for very serious loss, not only by the seafarers directly involved but also by unconnected third parties. There is also potential for serious pollution of the environment.

Thirdly, there are indications that major incidents are mainly due to human failure of various sorts, from which it follows that research is needed into the causes of human failures and the development of means to make such failure less likely. In particular there is scope for improvement in the methods and equipment used for training mariners. There is also a great need for the worst-trained mariners to be brought up to the standard of the best; this calls for political action and international negotation rather than research.

Finally, it is repeated that the safety of sea transport, as of land and air transport, depends in a large degree on the human element. As the years go by, bigger and bigger disasters become possible through simple human error or misjudgement. Such errors may never become completely impossible, but research is making available techniques for rendering them less likely. The extent to which these techniques are actually applied in practice depends upon the will and the money.

FOOTNOTE

The view expressed in this paper are entirely those of the author. The paper does not necessarily represent official policy or the views of the National Maritime Institute or the U.K. Department of Industry.

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