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INTEGRATING ENVIRONMENTAL IMPACT INTO FUTURE TANKER DESIGN PHILOSOPHY

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BACKGROUND

The grounding of the *Exxon Valdez* focused attention in the United States and much of the world on the problem of oil spills from tanker accidents. The passage of the Oil Pollution Act of 1990 in the United States, concern in other countries, and recent activities at the International Maritime Organization (IMO) of the United Nations are leading the way to finding new procedures to use in the tanker design process. However, the author feels that what is also needed is a new design philosophy. Elements of this philosophy would include concern for all categories of oil spills from tanker accidents, more emphasis on performance criteria, greater use of probabilistic applications of data bases, and an ongoing comprehensive research programme. The IMO Comparative Tanker Design Study is briefly mentioned in this paper as a prime example of an activity moving in the direction of such a new design philosophy.

Professor John Harrald of George Washington University has studied the evolution of regulatory safety concerns and has produced the diagram shown in Exhibit 1. Although naval architects have designed ships for many hundreds of years, the idea of explicitly studying the impact of ship design on oil spills from tanker accidents is relatively new. Professor Harrald feels that the *Torrey Canyon* accident in March 1967, spilling more than 100,000 tons of crude oil into English coastal waters, represents a turning point in maritime history. Since this time the focus of maritime safety regulations has shifted from concern about the safety of the ship (and its personnel and cargo) to concern for the external safety and environmental impacts caused by a release of the cargo.

Since the *Torrey Canyon* accident, many international and national initiatives have taken place which reflect this shift in concern. The IMO Conferences of 1973 and 1978 together produced fundamental changes in the way tankers are designed and operated. However, the high level of research activity in the 1970s did not become a major international ongoing activity through the 1980s. Recent events have again turned attention to the design of tankers to avoid oil spills from accidents. While this objective is a noble one, the ideal design approach is not obvious. An important aspect to be considered is the different types of accidents, or scenarios, that may result in oil spills.

DIVERSITY OF TANKER ACCIDENTS

There is no "typical" tank vessel accident scenario that leads to pollution. Nonetheless, a general understanding of the causes, nature and consequences of accidents should aid in selecting the measures most useful in preventing or reducing pollution.

The number and volume of major accidental spills from tankers have decreased significantly during the last decade. Tanker accident rates – collisions, groundings, fires and explosions, structural failures and other incidents causing loss of life and/or pollution – were particularly high from 1976 to 1979 before returning to a lower level throughout the 1980s. However, the volume of oil spilled continued to vary annually.

The rate of serious casualties to oil and chemical tankers (6,000 GRT and above, roughly equivalent to 10,000 DWT and above) reported by the IMO was 1.92 incidents per 100 operating tankers in 1988. An analysis by the National Academy of Sciences (NAS) Committee on Tank Vessel Design, comparing the number of serious casualties worldwide for the same tanker population and the estimated metric ton-miles of seaborne trade for crude oil and products, shows a relatively steady decline in this ratio between 1983 and 1988 (as presented in Exhibit 2).

The vast majority of casualties do not result in pollution. Only 6 per cent (518) of the accidents reported in an assessment of 9,276 accidents resulted in oil outflow (Lloyd's Register of Shipping, 1990). [In 18 per cent (1,701) of the cases information was insufficient to determine whether pollution had occurred.] At the request of the NAS committee, Lloyd's analyzed its database of casualties resulting in outflow greater than 30 tons from tankers 10,000 DWT and larger. The results, covering 370 pollution-related accidents, are broken down by cause in Exhibit 3. These data show that worldwide groundings/strandings and collisions/rammings (contact) cause roughly equal numbers of major pollution incidents (those resulting in spillage of more than 30 tons, or approximately 10,000 gallons) for tanker sizes considered by the NAS committee. This finding is also valid when considering spilled volume.

US Versus Worldwide

In US waters, for tankers over 10,000 DWT, grounding events clearly dominate in terms of both numbers of accidents, and, particularly, volume spilled as shown in Exhibit 4. This should be no surprise in view of the shallow access to Gulf of Mexico and East Coast ports. Examples of shallow-water groundings include the *Argo Merchant* in 1976 (approximately 25,000 tons outflow), the *Alvenus* in 1984 (7,389 tons outflow), the *Esso Puerto Rico* in 1988 (4,050 tons) and the *American Trader* in 1990 (975 tons). These groundings account for a large portion of accidental spills from tankers that have occurred in US waters since 1980.

Compared to worldwide spillage from major pollution incidents, major oil spills in US waters are relatively low in volume, whether measured in terms of thousands of metric tonnes as presented in Exhibit 5 or in terms of percentage of world volume as shown in Exhibit 6. The years 1982, 1984 and 1986, when particularly high or average US spillage coincided with unusually low world spillage, are exceptions to this. There is no evidence of a correlation between US and world losses.

The erratic nature of pollution is also illustrated in Exhibit 7. A few very large spills dominate the total outflow, comprising nearly 95 per cent of spillage, but they comprise less than 3 per cent of the events. In addition to the major groundings noted previously, the 13-year US record is influenced strongly by the *Burmah Agate* (1979), the *Puerto Rican* (1984), the *Georgia*, and the *Olympic Glory* (both in 1980). The record of outflow from smaller spills (under 30 tons or 10,000 gallons) in US waters shows significant improvement since the 1970s and has remained relatively constant, between 0.1 and 0.2 thousand tons, since 1983.

Since 1984 the total annual volume of small spills has been less than 5 per cent of the major spills. However, the reverse has been true regarding the number of incidents: On average, there have been over 50 times as many spills as major spills.

The few but calamitous large spills, such as from the *Exxon Valdez*, emerge clearly from the statistics, but the smaller spills that are not among the top 50 may also have significant environmental consequences. In 1989 and early 1990, four tanker spills over 200,000 gallons (equivalent to 650 tons of crude, or 600 tons of fuel oil) occurred near the continental US coast. These received much public attention and were noted by Congress prior to passage of the Oil Pollution Act of 1990. These spills were:

- The *World Prodigy*, which grounded and spilled 900 tons (also reported as high as 1,365 tons) of light fuel oil off southern Rhode Island in 1989. Fortunately, most of the oil evaporated quickly, but some local environmental damage was sustained.
- The *Presidente Rivera*, which grounded in the Delaware River near Marcus Hook, Pennsylvania, in 1989 and spilled nearly 900 tons of fuel oil. Local environmental damage was sustained.
- The *Rachel B*, which collided with a coastal towed barge and lost more than 800 tons of partially refined crude in the intersection of the Houston Ship Channel and Bayport Ship Channel.
- The *American Trader*, which grounded one mile off of Huntington Beach, California, in 1990 and spilled an estimated 1,200 tons (395,000 gallons) of light crude. While over a third of the light Alaskan crude oil was recovered, local pollution and beach damage was sustained.
- The *B.t. Nautilus*, which grounded in the Kill van Kull waterway, New York Harbor, in 1990, and spilled over 700 tons of fuel.
- Another accident demonstrated how a spill smaller than those listed (220 tons) may be damaging, capture the public attention and cause international repercussions when occurring in an ecologically sensitive area. In 1988 the barge *Nestucca* was struck while under tow on Puget Sound, and the hull was breached. The released oil, which floated inshore and affected beaches and shorelines in Washington, reached well along the coast of Vancouver Island, Canada, and caused significant short-term shoreline damage over much of the island and adjacent Puget Sound areas.

These accidents underscore the need to consider, when developing new design and operational practices, the types, sizes, and condition of vessels (and their areas of operation) engaged in the brisk import and coastal petroleum trade.

Vessel Size and Age

The IMO database for the world tanker fleet provides a large sample of incidents, both polluting and non-polluting, in most accident categories to offer some valid insight about accidents and tanker characteristics over a 15-year period ending in 1988.

The size of the tankers most common in US waters – 50,000 to 100,000 DWT – is within size range of the worst overall worldwide casualty rate of all size categories based on IMO data. The casualty rate for collisions and groundings for this size range is about equal to that for all tankers, but the rate for fires/explosions exceeds the average by 33 per cent (a rate of 0.76 per 100 ships per year compared to 0.57). Unfortunately, data related to many fire and explosion causes are either lacking or inconclusive.

There is some evidence of a link between vessel age and serious casualties: older vessels have more accidents, particularly fires/explosions and structural/machinery damage. However, the rate for collisions is relatively constant for all age groups. There is no clear evidence of a link between the rate for cargo-related explosions (range 0.18 - 0.25) and ship age between 5 and 25 years.

Safety of Life

Fires and explosions are the major accidental cause of injuries and death aboard tankers. Any consideration of tank vessel hull design configurations and operations must take into account the influence on risk to the crew of fire and explosion. Unfortunately, there is little accident data that might relate crew casualties to the cause of the accident or the environment, or that might allow detailed analysis of how ship structure, compartmentation and arrangements, ventilation and safety systems relate to fatalities and injuries. The NAS committee recognized, however, that steps to reduce pollution from tank vessels should not be taken without regard to the safety of the ship's crew.

Again, the 1989 analysis conducted by IMO provides the only comprehensive guidance available to the committee. Over the 15-year period 1974-1988 there was an annual average of six major incidents. There was a noticeable reduction in cargo fires and explosions during the years 1986 through 1988, which suggests that the international requirement for inert gas systems is having a positive effect. Cargo fires represent about a third of all tanker fires (others occur mainly in the pump room or machinery spaces) and pose the greatest hazard to the crew.

The IMO analysis in this area covers not only oil and chemical carriers, but also combination and gas carriers. Over the 15-year period, 1,209 lives were lost - an average of 81 persons per year. Of these deaths, 67 per cent (829) resulted from fires and explosions, and over half of these (480) were due to cargo fires and explosions. 167 lives were lost because of fires and explosions on ships under repair, including 83 in a single casualty in 1978.

The fatality record does not clearly reflect the effect of secondary causes such as a fire or foundering following a collision. Secondary causes account for the loss of many of the 149 persons linked to collisions over a 15-year period.

APPROACH TO DESIGN CRITERIA

There appears to be great advantages to using performance rather than design criteria as part of the tanker design philosophy. Design criteria prescribing certain technological solutions tend to "fix" technology at a point in time, thus inhibiting innovation and removing the incentive to advance ship technology and design. Performance standards tend to promote new development in terms of structural and operational innovations that will result in meeting or surpassing the standards.

The significance of performance standards can best be explained using the example of the automobile industry where, for instance, safety standards were adopted in the United States in the early 1970s. All passenger cars are currently required not to exceed a deceleration of 20 g (g is 9.81 m/sec2 at the Earth's surface) in a 30 mile-per-hour head-on collision with a rigid barrier. There are also other requirements concerning, for example, intrusion of the steering wheel into the passenger compartment. Each auto manufacturer took a slightly different approach to meeting these standards, and the highly competitive market resulted in many innovative and ingenious approaches to crash-worthiness. While the performance standards for cars are checked and enforced through mandatory compliance tests, no such full-scale tests are possible for tank vessels. Therefore, an alternative, purely analytical method should be developed to accept or reject a given tank vessel design.

Because routine full-scale testing of tankers is prohibitively expensive, it is more practical to establish relative performance standards with respect to a chosen design, rather than absolute criteria. Such a reference vessel could, for example, be a suitable double-hull ship (the new standard for new tankers traveling in US waters). In the automobile industry, establishment of worldwide performance criteria was preceded by a decade of research and development by regulatory agencies and the industry. Interested parties within the maritime community could launch a similar research programme, where one focus would be to establish equivalence criteria for choosing alternative designs based, for example, on the amount of cargo lost. The effectiveness of alternative designs could be examined in a wide range of collision and grounding scenarios. Additional small-scale and possibly full-scale static and dynamic tests would be necessary to calibrate various theoretical models and to obtain the scaling relationships.

Reflections On The Oil Pollution Act Of 1990

There are two major factors that arise when reviewing the Oil Pollution Act of 1990. First, the US Congress has chosen the "technical fix" solution. Rather than to focus on better training of crews or improved operational procedures in approaching ports (e.g., greater use of one-way traffic lanes), Congress has chosen a passive technical system for new tankers that is easy to conceptually understand and to confirm. Of course, to obtain the optimal benefits from the double hull, it must be properly designed, constructed, maintained, operated, inspected and repaired.

The second key factor in that the law basically takes a design standard rather than a performance standard approach. A particular design – the double hull – is mandated, although a reference to an equivalent design is mentioned, leaving the door open to other possible alternatives on which Congress would have to vote. While it is obvious that the purpose of the Act is to reduce oil spills, evaluation criteria are not defined.

This approach amounts to finding the answer without knowing the question. The answer is double hulls, but which of the following questions did Congress wish to address: What ship design will prevent all outflow of oil from an *Exxon Valdez* – type accident? What ship design will reduce oil spilled by 70 per cent (or 30 per cent) in the event of an *Exxon Valdez* – type accident? Is it more important to focus on the huge number of small spills or the tiny number of huge spills? These questions reflect fundamental policy issues that Congress never explicitly addressed.

One of the problems with a design standard is that it is difficult to evaluate another design as "equivalent" if the criteria are not explicit. Conceivably another tanker design could be equal or superior to the double hull by any possible measure of performance. In that case, the new design would be equivalent or superior to the design standard. However, in almost any evaluation between two design approaches, each will have its own strengths and weaknesses, requiring a trade-off among possible performance characteristics. In fact, the NAS committee was unable to find a tanker design that was environmentally superior to the double hull for all conceivable accidents, but suggested that the intermediate oil tight deck design deserved further consideration.

Work by the Marine Board and others leads to the conclusion that the double hull is superior for preventing oil spills from minor groundings that do not penetrate the inner hull (i.e., the huge number of small spills). On the other hand, the intermediate oil tight deck should be superior in groundings where the inner hull of the double-hulled vessel would be penetrated (i.e., the tiny number of huge spills).

IMO Comparative Study

The IMO Steering Committee on Comparative Tanker Design is undertaking a comparison of the double hull design with the intermediate oil tight deck (also called the mid-height deck) design. The IMO approach to this problem emphasizes three areas of research: (1) better understanding of data from previous accidents; (2) more sophisticated calculations of oil outflow and damage stability in defined groundings and collisions; and (3) model tank tests to simulate various grounding and collision scenarios. The analysis of previous accident data will provide a better understanding of the severity and frequency of certain types of accidents (and possibly other related information). The calculations allow researchers representing the various United Nations' delegations to discuss the most appropriate approaches to the problem. In addition, more effort is being focused on these types of calculations than has been done to date. Both a simplified method for oil outflow calculations and the use of a probabilistic analysis methodology are being utilized.

The model tests represent an advantage in that larger scale models will be used than in previous tests. The tests performed in static water conditions will allow validation of the results from the calculations. The results from the model tests with dynamic conditions, simulating currents or waves, will lead to advances in the understanding of what happens in these circumstances. The IMO Steering Committee is also looking at future general guidelines for tanker design.

NEW RESEARCH FOCUS

Naval architects traditionally have not designed tank vessels at the detail level to withstand groundings and collisions. While the technology base is adequate and there are internationally recognized standards for the design of vessels to assure their integrity during normal operating conditions, current design practice does not address in-process accident behavior, which aircraft and automotive industries refer to as "crash-worthiness." The state-of-the-art in understanding fundamental forces and structural reactions during tank vessel accidents is limited, particularly for groundings. Similarly, although computer models exist for estimating structural damage in particular scenarios, these models have not been validated with actual accident data or full-scale testing.

To better understand actual vessel performance and to move in the direction of establishing performance standards, more basic knowledge is required. "Performance standards" have meaning only if there is a mechanism to test various proposed designs against these standards; there must be a way to quantitatively predict damage to any design and the vessel's post-accident performance.

Present analytical methods rely on simplified assumptions and limited numbers of primitive control parameters, local to the site of impact. Consequently, damage projections are but gross approximations, lacking both the detailed accuracy required to quantify results beyond directional ranking, and the sensitivity to reflect any but the most major changes in assumptions and/or control factors.

Greater Understanding of Structural Behavior

Tank vessels vary significantly in structure, even within similar design types. Differences in basic structural arrangements, scantlings and detail, both individually and cumulatively, will result in different failure sequences and post-accident vessel conditions. Experience proves this, but present technology cannot project it beyond gross generalities. Basic theoretical research is needed into relevant material behavior leading up to micro-element failure and progressing through major structural energy dissipation into ship structures. Models of detail sequence behavior must be enlarged (1) to encompass the full variety of ship structures, (2) to reflect the global changes during the accident process, and (3) to account for the cargo-structure-water interface phenomena as the vessel's integrity is assaulted.

At present, dynamic progressions are defined through rudimentary static study of single-step movement from the intact state to local detail failure. This is an inadequate and misleading approach if there is to be any attempt to meet dynamic performance standards of integrated structures. The path of structural failure follows the movement of destructive force as it stresses contiguous local structure into plastic deformation, rupture and ultimately, failure. As the dissipating force moves into peripheral structure the process is repeated, moving like cracks in splitting sheet ice, seeking out the weakest path of resistance before dissipating in non-destructive stressing of steel. The projection path and extent of destruction remain quantitative unknowns.

To achieve an understanding of structural behavior that is adequate to development of vessel performance standards, specific needs must be met:

- Improved analytical techniques are required to understand the hull rupture initiation process, a key controlling factor in whether cargo will be spilled. Present analyses include making simplified assumptions and using limited numbers of parameters. In properly designed hulls, rupture may not be inevitable; to that end, further research also should be directed towards developing innovative hull materials and structural configurations.
- Improved capabilities are needed for predicting the vertical, lateral and horizontal extent of damage sustained to the ship bottom (of both single and double hulls). Current methods include making simplified assumptions. Improved methods would also help determine outflow from breached tanks, determine stability of damaged ships and plan salvage of stranded ships.

To make design tools available, a development programme would need to integrate theory, modeling, structural testing and verification with historical accident data. Other than the last aspect, all of these are within the ability of academia and industry. Unfortunately, verification is not possible with existing databases and is not part of industry practice.

More Detailed Casualty Databases

The preceding discussion points out another significant need. The NAS committee found existing casualty databases incomplete and/or misleading; of the dozens of accidents referenced in the study, not one is publicly documented to serve as an adequate resource for the most general accident description.

Records lack the detail documentation (vessel speed or description of grounding obstacle, for example) that would help relate a particular scenario to the exact damage done. Such information is either considered proprietary (frequently for legal reasons), or is recorded in an over-simplified form or not at all. In addition, there is seldom any database link between general accident statistics (such as the number or volume of spills) and the supporting details (vessel description, initial cause of accident, extent of damage in structural terms). An accident analysis typically must rely on manual search through incomplete records from numerous sources (such as the US Coast Guard, shipbuilders, operators, classification societies and marine casualty organizations). Therefore, better procedures are needed for inspecting newly damaged ships, including detailed determination of collapse/tearing of structure and full photographic coverage. This type of inspection, if mandatory, would provide an engineering and statistical data bank that could enhance understanding of the phenomena involved and lead to improved designs.

Research leading to establishing a mandated damage-assessment protocol should be undertaken; complete and accurate cause-and-effect data would enable development of an accurate vessel performance model. This research would require the cooperation of engineers, ship repair facilities, ship owners and operators, and legal experts.

Public Policy Aspects

Engineers and naval architects are typically more comfortable dealing with technical research objectively than issues relating to public policy. However, unless one tanker design is found that is superior to all others in all respects, trade-offs must be made between the strengths and weaknesses of alternative designs.

Consequently, it is incumbent upon the maritime community to work more closely with public policy makers. There is a dual role here. First, how does the public set priorities among alternative types of risks with different tanker designs? Second, the maritime community must be willing to educate public policy makers, and the public in general, as to the advantages of different designs and the trade-offs to be made. Note that in order for a tanker design to be recognized as equivalent to the double hull design under the Oil Pollution Act of 1990, the US Congress must pass new legislation setting such policy. As one might imagine, neither Congress nor the staffers that work with Congress are known for their knowledge of naval architecture.

Another policy issue deals with integrating tanker design into an overall assessment of tanker design, construction, operation, inspection and maintenance. Focusing on only one aspect will not ensure maritime safety as well as an integrated approach.

Research on the Influence of Tank Contents

Ship structural behavior following an accident is influenced by cargo and ballast status. Tank contents affect not only total vessel mass, but also the performance of the containment structures as they process damaging forces. The effect may be either to inhibit or to exacerbate structural failure and resulting oil outflow. The interaction of tank contents with the sequence of structural failure is neither understood nor taken seriously into account; the issue is no more than an aside in post-accident investigations. Research into the impact phenomena of tank contents (or lack thereof) will be required to quantify post-accident vessel status accurately.

The computation models to be developed for predicted potential oil outflow from a damaged ship should link kinetic energy, structural configuration and the extent of damage. More research is needed in determining the relationship between extent of damage, relative hydrostatic pressure, tank size and oil outflow. More accurate and complete analyses, based on past accidents in combination with a simplified description of probable events, may be appropriate.

In addition, more research is needed to understand the dynamic mixing of sea and cargo in a damaged cargo tank following an accident. Forces contributing to this process, which can lead to greater cargo outflow than explained by hydrostatic pressure, are poorly understood.

Models for Residual Strength

Calculation of the reserve strength of partially damaged hulls is an essential aspect of managing groundings, as the ship must be unloaded, salvaged and brought to a repair dock. Procedures for evaluating progressive collapse of a hull girder, subjected to a combination of still water and wave loads, need further development and application. Such models have been developed for offshore oil platforms. Some non-linear finite element programmes can be used, but they need further refinement if they are to be practically applied and more widely used.

Full-Scale Test to Destruction

A carefully planned and fully instrumented full-scale grounding test would contribute substantially to understanding of tank vessel structural response under traumatic stress. Each year a number of tankers reach the end of their useful life cycles. Possibly one or more of such tankers could be converted into experimental ships and subjected to a controlled grounding.

An analogous crash test of a fully instrumented Boeing 707 was sponsored by the Federal Aviation Agency with industrial involvement. The knowledge gained from the "test to destruction" of an instrumented surplus tanker would advance all of the structural research areas that have been identified. (The Netherlands government has announced that it is sponsoring the full-scale testing of barges in accidents.)

Summary of Research Needs

The technology base must be enhanced across the spectrum, from exploratory research to proof-of-concept development.

The result of the research projects described should be a reliable mechanism that can, irrespective of a vessel's details, accurately project structural and cargo behavior as a function of vessel design in any selected accident scenario. Whether the accident is a grounding or collision, the model must perform within the envelope of the given operating environment.

The needs include: (1) an integrated understanding of the dynamics of ship structural failure down to the micro level and related factors; (2) long-range research in failure theory (interactive behavior of over-stressed integrated structures in association with hydrodynamic loads); (3) protocols leading to mandatory engineering documentation of casualties; and (4) computational models resulting in outflow predictions.

In Japan, Norway, the US and other countries, future research programmes are being planned. Hopefully, the maritime community will commit itself to an ongoing, continuous effort of improving the tanker design process. Countries should cooperate in comprehensive, multi-year research and development programmes that would result in computational models for predicting vessel structural response during an accident and consequential cargo outflow. These are the engineering tools basic to development of vessel performance standards.

These programmes should (1) define the documentation, procedures and protocols that would remedy the absence of quantified engineering casualty data, (2) ensure adequate theoretical knowledge and application technology to design tank vessels to meet performance standards, and (3) achieve optimal pollution control by integrating use of design alternatives with operational and cleanup options.

The scope of such programmes would require the cooperation of government, the engineering and computer science communities, legal experts, shipbuilders, shipowners and classification societies. The author feels that the IMO is the body best positioned to coordinate such an important and international effort.

ACKNOWLEDGEMENTS

The author served as the Chairman of the National Academy of Sciences Committee on Tank Vessel Design during its 15-month life. Therefore, it is not surprising that the views expressed in this paper are consistent with the committee's final report, **Tanker Spills: Prevention By Design.** Exhibits 2 through 7 of this paper have been taken directly from the NAS report as well as a significant amount of the text (much of it verbatim). However, the author has added his own opinions to parts of this presentation. Consequently, other committee members or the NAS may not agree with some statements in this paper.

EVOLUTION OF REGULATORY SAFETY CONCERNS

CONCERN ABOUT SAFETY OF PASSENGERS
(LOSS OF LIFE FROM FIRE, EXPLOSION, SINKING)

↓

CONCERN ABOUT SAFETY OF CREW
(LOSS OF LIFE, INJURY)

↓

CONCERN ABOUT LOSS OF VESSEL AND CARGO
(ECONOMIC LOSS)

↓

CONCERN ABOUT PUBLIC IN AREAS AROUND WATERWAYS
(THREAT FROM TOXIC CARGOES)

EXHIBIT 1

Source: John Harrald and Kristen Harrald, "A Systems Approach to the Problems of Maritime Safety," Conference on Commitment to Success, sponsored by American society for Engineering Management and National Council of Systems Engineering, Chattanooga, TN, October 1991.

EXHIBIT 2. Worldwide rates of serious casualties to oil/chemical tankers 1974-1988 (6,000 GT and above). Source: International Maritime Organization Analysis of Serious Casualties to Sea-Going Tankers, 1974-1988. Tonnage-distance analysis was prepared by the NAS committee based on IMO casualty statistics and International Association of Independent Tanker Owners for miles data. Casualties/trillion ton-miles data covers period 1975-1988.

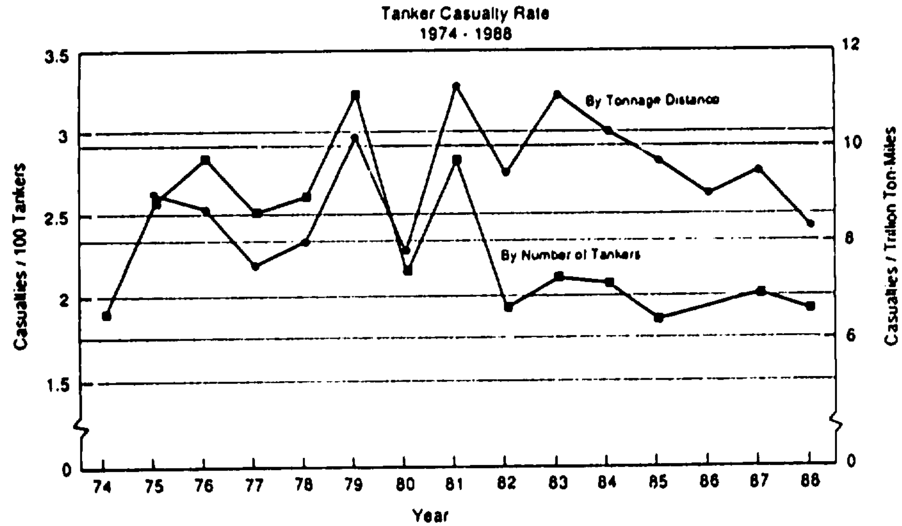
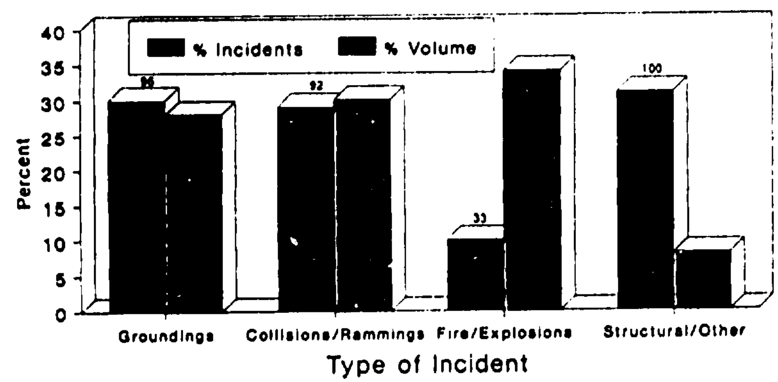


EXHIBIT 3

Major Oil Spills from Tankers and Causes
Number of Incidents and Volume-World

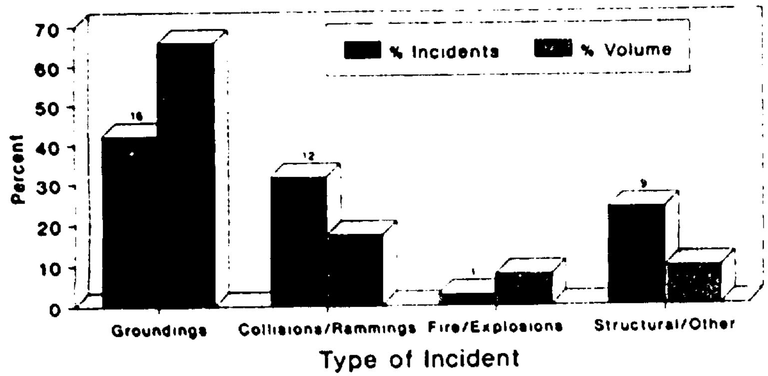
1976 - 1989



Source: Lloyd's Register

EXHIBIT 4

Major Oil Spills from Tankers and Causes
Number of Incidents and Volume-US Waters



Source: USCG/Temple, Barker & Sloane

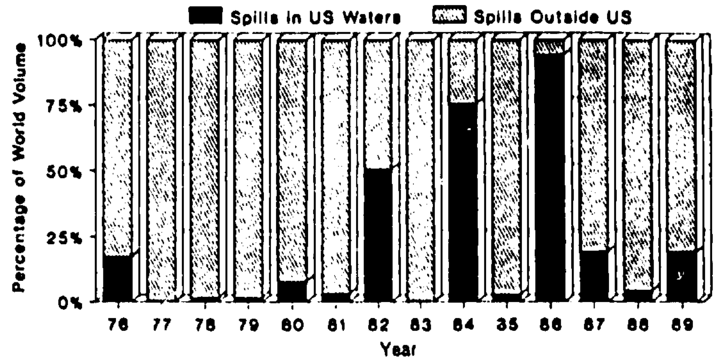


Exhibit 6. Comparison of major spills* in percentage of world volume -- U.S. versus worldwide.
*Over 30 tons of approximately 10,000 gallons (U.S.).

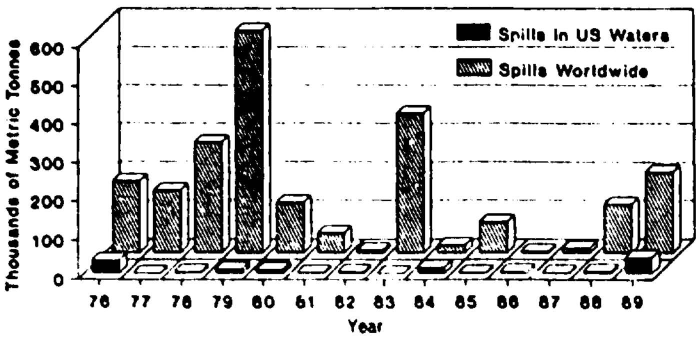


Exhibit 5. Comparison of major spills* in thousands of metric tonnes -- U.S. versus worldwide.
*Over 30 tons, or approximately 10,000 gallons (U.S.).

Tanker Oil Spills in U.S. Waters
Volume of Spills

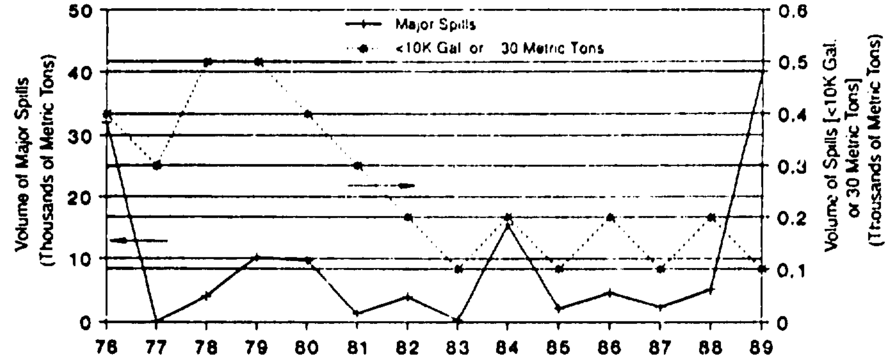


EXHIBIT 7

Source: U.S. Coast Guard/Temple, Barker & Sloane, Inc.

GENERAL INFORMATION

OVER THE HORIZON

The Techno Superliner research project reaches half-way point. In July 1989 seven leading Japanese shipbuilders and the Japanese government formed the Technological Research Association of the Techno-Superliner. The goal of the 10 billion yen (US$ 73.1 millon) budget is to develop an ocean-going transportation vessel with the ability to carry 1,000 tonnes small-lot, high-value cargo at a speed of 50 knots and over a range of 500 nautical miles. In the research project the following are identified as priority areas: Hull form and structural analysis; new materials; propulsion plant and control systems; and hydrodynamic performance.

Two hull forms are currently being studied, termed TSL-F and TSL-A. The TSL-F is in development under the auspices of Kawasaki, NKK, IHI, Sumitomo and Hitachi Zosen in conjunction with the Institute for Technical Research of Ships. The concept is a foil hybrid, which consists of a combination of main hull, fully submerged lower monohull, fully submerged foils, and struts. in operation the main hull is lifted out of the water by the submerged hull and the foils, thus reducing resistance. A 1:20 self-propelled scale model of the vessel has already been tested and the results show that waves of heights in the range 6 to 12 metres, the predicted (and design) wave height range for the proposed routes, had little effect on speed. Propulsion for the TSL-F is supplied by a water-jet system powered by gas turbine engines.

Research into the second hull concept, the TSL-A, is carried out by a team from Mitsui and Mitsubishi. The concept is similar to that of a surface effect ship (SES), which means that the vessel is primarily supported by an air-cushion with bow and stern seals and additional buoyancy from two hulls. The vessel is intended to have a cargo capacity of 150 TEU (twenty-foot container equivalents) all placed on the upper deck. Preliminary dimensions are: length 127 metres; beam 27.2 metres; depth 11 metres; draught off-cushion 5 metres and on-cushion 1.4 metres. The propulsion system is similar to the TSL-F – water-jets driven by gas turbines – and air cushion is created by four separate gas turbines. To meet the design criteria for the TSL-A, operation in wave heights between 4 and 6 metres, the vessel is fitted with four sets of motion control fins and a ride control system.

Papers describing the Techno Superliner project were presented at the Fast '91 conference (the first International Conference on Fast Sea Transportation) held at Trondheim, Norway, in June. The papers are available from: Tapir Publishers, Vollabakken 15, 7030 Trondheim, Norway. (**The Motor Ship**, September 1991, pp. 55-56)

Seaborne transportation of liquid hydrogen. One current focal area for federal German maritime research is at-sea transportation of liquid hydrogen. Hydrogen is viewed as a future energy source as it does not produce any harmful exhaust gas when converted to energy. The problem is that hydrogen has to be transported in a liquid state. Since hydrogen liquefies at extremely low temperatures – below 250°C (23.15K) - this causes severe problems related to materials and insulation technologies. Current research into the subject is performed by the Euro-Quebec Hydro Hydrogen Pilot Project, which is a continuance of an earlier pre-feasibility study to evaluate the possibility of supplying hydrogen generated by Canadian hydropower to Europe for conversion to electricity. The objective of the current phase of work is to demonstrate the feasibility of the complete project, including hydrogen manufacture in Canada, transport to and utilization in Europe, and economic assessment of the entire project. The research relating to the at-sea transportation is undertaken by Germanischer Lloyd in association with the Thyssen Nordseewerke yard and the August Bolten shipping line. (**MaK Toplaterne**, No. 63-90.)

CONFERENCES

The fifth Safety at Sea and Marine Electronics Exhibition and Conference (SASMEX '92) is to be arranged in London in the period 7-9 April 1992. The conference and exhibition, which cover a wide range of safety-related topics, are supported by the International Maritime Organisation (IMO) and other maritime organizations. Information can be received from: SASMEX 1992, Queensway House, 2 Queensway, Redhill, Surrey, RH1 1QS, United Kingdom.

The second International Congress on Energy, Environment and Technological Innovation is to be held in Rome, Italy, in the period 12-16 October 1992. Among the topics covered by the congress are technological innovation in the production, conversion and transport of energy, such as raw materials for energy and electrical, thermal and mechanical energy from various sources. The other main topics are technological innovation and environment, such as productive processes, land use and habitat. Information can be received from: Studio EGA, Viale Tiziano, 19 00196, Rome, Italy.

The second international ENS (Environment Northern Seas) Conference and Exhibition is to be held in Stavanger, Norway in the period 24-27 August 1993. The conference will focus on practical solutions to environmental problems across different sectors and geographic boundaries. The scope of the conference will be broadened to also include environmental challenges in the northern-most waters, that is, the Barents Sea, the Polar Basin and the West Atlantic. Information can be received from: ENS Secretariat, P.O. Box 410, N-4001 Stavanger, Norway.

DESIGN DEVELOPMENTS

US Oil Pollution Act (OPA) 1990 Legislation threatens tanker design development. OPA (see lead article), established a standard specifying that design alternatives for tankers should "provide protection... equal to or greater than that provided by double hulls." There are, however, no generally accepted criteria for evaluating such equivalency. It is prevalent thinking in the shipping industry that double-skinned design is not necessarily the best solution, and that accidents cannot be prevented by vessel design solutions alone. Vessel owners are concerned that international and national regulations will inhibit design development through fixing technological solutions and that they do not recognize all aspects of pollution limitations.

Two separate studies have been carried out on this subject. The first was a study undertaken by the US National Research Council (NRC) into the prevention of tanker spills by design (lead article), and the second was a study by an industry joint working group established by International Chamber of Shipping (ICS), Intertanko and Oil Companies International Marine Forum (OCIMF) to develop proposals relating to tanker design and pollution prevention measures. The report from that study concludes that the "need to make continuous effort towards improving ship safety and environmental protection is widely accepted. However, the statistical evidence, coupled with experience and the research that has been undertaken, does not indicate the need for a major revision of the Marpol provisions at this stage."

Intertanko is proposing that the US authorities accept a "horizontal bulkhead rescue tank design" which it claims offers a higher degree of marine environmental protection than double skinned design. The Intertanko proposition is developed from a Mitsubishi design, which is described below.

POLIS (Pollution Limitation System) developed by a Hamburg-based engineer, Mr. Paraskevopolus, is designed for installation in existing tanker vessels. The system evacuates oil from damaged tanks into special rescue tanks, which are connected to all cargo tanks. A system of pumps maintains a partial vacuum in the rescue tanks, and in case of tank damage a combination of vacuum and gravitational force evacuates the cargo from the damaged tank. Necessary rescue tank capacity amounts to only 4 per cent of total tank capacity, and the system can be fitted without dry-docking and without specialist skills.

POLMIS (Pollution Minimizing System), developed from POLIS by the same inventor, is intended for new vessels. Along with the vacuum-based rescue tank system from POLIS, POLMIS also features a new tank design in which the midships and largest tanks have a V-shape and are entirely isolated from the outer shell. (**The Motor Ship**, July 1991, pp. 32-35)

Mitsubishi Heavy Industries new mid-deck tanker cannot spill. MHI has long investigated various tanker structural configurations that would prevent or minimize oil outflow from damaged oil tanks. The end result was the mid-deck tanker, which has double sides to accommodate water ballast and to protect against collision. The mid-deck is located below the water-line so that the hydrostatic pressure inside the bottom tank is lower than for the water outside. In case the bottom tank ruptures, water will push its way into the tank, thus creating a seal between the oil and the ruptured skin. MHI has compared the performance of the mid-deck tanker to that of a double-skinned tanker in a number of scenarios, and found that they are grossly equivalent in terms of protection for smaller damages, but that the double-sided mid-deck tankers would perform better in the event of a larger damage. MHI hopes that the design can be accepted under the equivalency provisions in the OPA. (**Marine Log**, January 1991, pp. 40).

NEW VESSELS

"You'll never replace sail..." Sailing ships seem to be in the wind again, at least in the cruise industry. Two four-masted barquentines for luxury cruising in the Caribbean and Mediterranean are currently being built for White Star Clippers N.V. of Brussels, Belgium, by the Langerbrugge Shipyards of Ghent. The ships, named *Star Flyer* and *Star Clipper*, are designed by the Dutch naval architects RAL, R.McFarlane and R.Nugtern. High priority was given to ensure a good sailing performance, and the vessels are expected to reach speeds exceeding 15 knots (speed when using engine alone is 11 knots). The sails are not computer-controlled, distinguishing it from other modern sailing cruise vessels, and the passengers are encouraged to help with sail handling if they wish. Each ship can accommodate 194 passengers in predominantly double cabins. It remains to be seen whether this brings new wind in the sails for sailing vessels. (**Shipping World & Shipbuilder**, November 1991, pp. 374-378).

V-CAT test boat completed. This new high-speed catamaran from the Japanese NKK Corporation has met performance expectations. The vessel consists of a V-shaped hull and thin side-struts to improve sailing performance, and is ultimately to carry 200 passengers at a service speed of 40 knots. NKK built a 10 metre test boat which can carry seven passengers, thus making it possible for potential customers to imagine the standards of performance of the full sized vessel. Predicted performance of the eventual full size vessel was found to be: a maximum speed of 48 knots; little running trim even at high speeds; small wake; and a turning radius at full speed of about three boat lengths, with negligible inclination of the hull when turning. The rocking motion is slight even in waves as high as three metres. (**Small Ships**, November December 1991, pp. 23)

Raddison Diamond is the world's first twin-hull cruise ship. A 129.5 metre long cruise ship, the *Raddison Diamond*, is now under construction at the Rauma Yards of Finland, and will be delivered to Diamond Cruise this spring. The vessel represents a new approach to cruise ship design — according to Mr. Tuomas Routa of Diamond Cruise Limited's technical product development division, the vessel will have no rolling motion and will have improved heave and pitch behavior compared to that for traditional, mono-hull cruise ships. Four computer-controlled fin stabilizers will be mounted to ensure even better comfort for the passengers. The vessel has a crew of 177, will carry 354 passengers in 177 cabins, and is to operate in the Caribbean from the port of San Juan in Puerto Rico. (**The Motor Ship**, August 1991, page 24).

Five 5,535 deadweight tons (dwt) ferries for commercial vehicles are to be built by the Italian shipbuilder Fincantieri of the Finmare group. The ferries will carry up to 136 commercial vehicles of a standard length of 12.5 metres at a speed of 19.1 knots. Vehicle lanes are widened from the standard 2.7 metres to 3.1 metres for easy loading and unloading. Accommodation for 50 passengers will be in double-berth cabins. The ships will be built at the Palermo yard and are to be delivered in the period between late 1992 and 1994. (**The Motor Ship**, July 1991, page 7).

TECHNOLOGICAL IMPROVEMENTS

Tank support construction isolates tanks for high temperature cargoes. Engineering Centrum Groningen and CSD International, both of The Netherlands, have developed a tank support construction to prevent problems associated with the proximity of high temperature cargoes, such as asphalt, coal tar and creosote, to low temperature sea water. These cargoes are, due to low viscosity, carried at temperatures of 200°C and above, such that the support construction needs to absorb heat dissipated from the cargo tank and reduce it to an acceptable level at the hull in order to minimize thermal stresses. Along with other structural requirements, the new support construction also aims to solve problems known in earlier integrated tank designs, such as the tendency of the cargo to solidify on the hull plating, and energy loss from the cargo. The new tank support construction consists of multiple super-imposed layers of different materials. Steel plates 25 mm thick act as tank legs supporting a composite starting on the outside with a layer of EDPM rubber, then silicon rubber, and finally an injection-moulded sheet of Ultem 2300, a fibre-reinforced resin and rubber developed by CSD. (**The Motor Ship,** October 1991, page 58).

Tripled TBO with synthetic oil. The *MENER VAG*, a French 160 passenger ferry, is said to have cut its maintenance costs in half by changing to synthetic oil. The ferry is operated by Compagnie Morbihannaise et Nantaise de Navigation (CMNN), Nantes, for the Department of Morbihan in Brittany. The ferry shuttles passengers between the French port of Quiberon and the islands of Houat and Hoedic at journey distances of 20 kms and 30 kms. Equipped by two Poyaud 520-L diesel engines, the maintenance and repair (M&R) costs of the engines initially averaged US$ 14,000 per year. In 1986, after draining the mineral oil and refilling with the synthetic Mobilgard 120, the following results were achieved: M&R costs on the diesels dropped to an annual average of US$ 6,500. Where previously there had been one overhaul a year, with the new lubrication oil there has been only one overhaul in three years. In addition, the oil consumption decreased by 27 per cent. (**Marine Propulsion,** July/August 1991, page 32).

Propeller polish saves 12 per cent fuel. UMC International Plc tested propeller polishing on the Cunard liner *Queen Elizabeth 2.* After monitoring fuel consumption on six voyages, International documented fuel savings of some 12 per cent, 48.5 tonnes per day, at speeds between 27 and 29 knots. The approach includes polishing each of two five-blade propellers once with coarse grade abrasive, and again with finer grade abrasive. The second polish gives a surface finish of 1 micron (0.001 millimeters) centre line average, rendering a significant increase in propeller efficiency. (**Marine Propulsion,** January/February 1991, page 6).

Self-polishing coating gives better tin-free anti-fouling. The Courtaulds Coating group, based in the United Kingdom, has developed a new tri-butyl-tin (TBT)-free self-polishing copolymer (SPC) anti-fouling called Intersmooth tin-free SPC, which they claim gives the highest degree of fouling control currently available from a TBT-free anti-fouling. International expects that up to 85 per cent of all coated vessels will return to drydock in a satisfactory condition compared to the 70 per cent experienced when International's older TBT-free anti-fouling, called Interviron BQ, is used. Anti-fouling containing tin is causing increased environmental concerns since they have adversary effects on sea-life in harbour areas. International legislation is expected that will restrict the use of tin in anti-foulings for vessels. (**The Motor Ship,** July 1991, page 13).

Coating eliminates cancer risk. Jotun Protective Coatings (JPC), UK, has developed a new modified-epoxy ballast-tank coating which eliminates the danger of cancer experienced with tar-epoxy coatings. The coating, Balloxy HB Light, is claimed to offer good penetration- and water-resistance, and is also said to give extended corrosion protection. Two versions of the coating are available: a standard type which may be used in temperatures down to 10°C, and a winter version for temperatures down to -5°C. (**The Motor Ship,** May 1991, page 12)

NOTEBOOK

A commercial submarine *SAGA 1*, built by the French underwater experts Comex, has completed trials. The submarine is intended to be a feasible alternative to expensive diving support vessels for underwater operations associated with oil exploitation. It has a hyperbaric compartment equipped for 4 to 6 divers, and can operate without any external support during operation, starting the journey at a port and remaining on work site for several weeks. The submarine is 28 metres long, has a submerged displacement of 550 tonnes, and is able to operate at depths reaching 700 metres. Comex claims that the energy stored on board is equivalent to that stored in the batteries of a 2,000 tonne military submarine. *SAGA 1* represents the first commercial use of the Sterling closed-cycle engine (75 KW) which was developed by Kockums Marine of Sweden for underwater propulsion, and is seen by Comex as a test bed for the development of larger commercial submarines able to handle heavy equipment and possibly used for the development of oil fields in deep waters and under permanent ice. (**Marine Propulsion International,** May/June 1991, page 4).

A new "Total Comfort" concept for cruise ships is presented by MacGREGOR-NAVIRE's new Marine Cranes/Elevators Division in the cruise and ferry sector. It is based on existing well-proven technology incorporated into advanced solutions for on-board logistics, and is meant to upgrade the level of comfort for both passengers and crew. Jes Boldsen, the product director of the new division, describes parts of the "Total Comfort" concept through a hypothetical scenario: "When checking in their baggage, passengers are given a magnetic/electronic ID card which indicates baggage tag, cabin number and other data relevant for serving the individual. Baggage will be taken by automatic conveyor system and directed to automatic baggage accumulation and distribution systems, all controlled and monitored by computers receiving their input from the baggage tags." However, "Total Comfort" also includes extensive use of escalators and panoramic elevators, aiming to give the passengers a feeling of control and comfort at all times.

Boldsen highlights the importance of good planning and the participation by interior architects in the early stage of the design process. Based on detailed analyses of all traffic aboard the ship MacGREGOR-NAVIRE can plan "Total Comfort" concepts for both existing ships and new buildings. (**MacGREGOR-NAVIRE Marine News,** May 1991, pp. 8-9).