Chapter IV. Approaches for Reducing Pollution and Improving Safety

A. Introduction

This chapter deals with methodologies which address the total tanker transportation system in terms of system safety and environmental protection. This “systems approach” is considered highly desirable if meaningful improvements are to be made. Specifically, this chapter will discuss the aspects of the four interactive elements which describe the oil transportation system by tanker namely:

- the ship and its operational, design, and maintenance characteristics;
- the man who operates that ship;
- the systems (whether onboard or ashore) which furnish information and control for the man to operate that ship; and,
- the environment (in terms of wind, waves, harbor, channel configurations, traffic densities, etc.).

B. Ship Improvement

1. Nature of the Problem

As noted previously, the feature of tanker operations which accounts for the greatest volume of oil discharged into the sea by ships on a continuous, worldwide scale is ballasting and deballasting. Tanker accidents, on the other hand, while accounting for a lesser volume of oil discharges than do the operational discharges, have the distinct disadvantage of being large concentrated discharges often in the more ecological sensitive, near-shore zones. The following sections will describe certain ship design and construction features which would improve safety and reduce one or both of the previously discussed oil pollution sources by varying degrees. The possible improvements of each are also described.

i?. The Utilization of Segregated Ballast Spaces for Accident Protection

Although numerous alternatives have been suggested to improve the oil pollution protection of tankers, the one that has received greatest attention is the fitting of double bottoms to prevent or reduce oil spills in the event of grounding accidents.

A. DOUBLE BOT'I'OMS/DOUBLE HULLS

Double bottom construction had its advent in the early days of iron cargo ships in the latter part of the nineteenth centruy. It was necessary to provide a smooth deck on which to place the cargo within the hold, because of the cellular construction at the ship's bottom. Since then, double bottoms have been incorporated in passenger ships, naval craft (including Coast Guard vessels), combination carriers, container ships, dry bulk carriers, roll-on, roll-off vessels, etc. Moreover, every chemical tanker and liquefied flammable gas carrier are required both by the respective IMCO (International Maritime Consultative Organization) Codes and U.S. National Regulations, as published by the U.S. Coast Guard, to be provided with double hulls. (The intent here is to protect the hazardous cargoes from side and bottom damage due to collisions and grounding respectively.)

Although neither double hulls nor doube-bottom oil tankers have to date been required by regulations, a total of 34 ships so fitted are in operation, uncler construction, or under contract. These 34 tankers comprise a total of 3,483,000 deadweight tons (see Table IV-l). of these, 28 tankers, totalling 2,210,000 deadweight tons, are or will sail under the United States flag. As further shown by this same table, a great many of these tankers may enter the Alaska tn the West Coast trade.

TAIUA IV–1.—Double bottom *tankers in operation or under construction or under contract, January 1975*

Year built	Number	Deadweight *tons* (each)	Builder	Owner/operator	Flag	Remarks
1969-73	•6	***212,0@3***	***Sasebo,*** Japan	Mobil Shipping	United Kingdom and Liberia.	Foreign trade.
197476	bs	39,700	NASSCO, San Diego, Calff.	Aeron Marine	United States.	Do.
1975-76	4	89,700	do	Third Group	do	Do.
1977	2	***89,700***	do	Chestnut ShippiW	do	Do.
1976	4	89, 7CQ	do	ShipmorAssocia- tion.	do	Alaska trade.
1977-7s	2	89,700	Todd, San Pedro, Calif.	do	do	***Do.***
1977--	2	89,7CKI	do	Energy Tankers	do	Do.
1979	1	89,700	do	U.S. Linw	do	Do.
197s-79	3	89,700	do	Hawaiian International.	do	Foretgn trade.
1975-77	6	35,000	FMC, Portland, Oreg.	Chevron	do	Domestic.
1974	1	118,0tM	Sun Ship, Chester, Pa.	Not available	ado	Alaakatrade.
Total	034	3,483,000				
U.s. th3g	'28	2,210, m				

s All in service. 1 is actually *270,000* dwt.
b 1 in gervi~ec
o Mobil Oil Corp. has 7 additional tankers in the *30,000* to *40,000* range which have partial double bottoms, These tankers have double bottoms fitted beneath only the centerline cargo tanks and thusarenotincluded in the list of double bottom tankers.

Source: Maritime Administration, Office of Ship Construction, January 1975.

Table IV–2 lists all of U.S. flag tankers under construction or contract for construction as of October, 1974, according to statistics provided by the Maritime Administration. Of the total of 60 tankers under construction or under contract, within the United States 28 are of the double-hull or double-bottom design. In other words, nearly one half of the total number of ships under construction or under contract within the United States as of October, 1974, incorporate either a double hull or a double bottom. (While it is recognized that, due to the current worldwide tanker market "glut", any compilation of this sort is subject to fluctuations, it is especially noteworthy to recognize the order recently placed by two oil companies with NASSCO for 150,000 and 180,000 dwt double bottom tankers.)

TABLE IV-2.—U.S. *flag tankersqq under construction/contract, October* ***1974***

Compsny snd number	Desd-weight (w %	Estimated total cost (millions)	Percent subsidy	Owner	8cheduled delivery
Avondale Shipyards, New Orleans, La.: 6.	**165, 000**	**$400.0**	**None**	**Standard Oil of Ohio.**	**1978**
Bath Iron Works Bath, Maine: 4.	**25, 000**	**64.0**	**None**	**Marine Ship-bearing Corp.**	**1975**
Bethlehem Steel Corp., Sparrows Point, Md.:					
3--.-----------	**265, 000**	**210.2**	**43**	Boston Tankers- --	1975-76
2--------------	**265, 000**	**162.9**	41	Gulf Oil---------	1976
FMC Corp., Portland, Oreg.:					
41-------------	**35, 000**	**64.4**	**None**	**Union Bank (Chevron).**	**1975**
21------------	**35,000**	**35.0**	**None**	**--- --do ----- ------**	**1977**
National Steel Co,, San Diego, Calif.:					
3 a-------------	89,700	**83.6**	**43**	Aeron Marine -----	1975
1--------------	38, 300	**18.2**	43	Margate Shipping-	1975
4 ~--------- ----	89,700	**112.8**	36	Third Group---- --	1975-76
4 ~------- ------	89, 700	**120.0**	None	Shipmore Associ-ates.	1976
3-------------	**38,300**	**65.1**	35	Moore-Mc-Cormack.	1975-6
2 ~------------	**89, 700**	**65.8**	33	Chestnut Ship-ping.	1977

~ABLE IV–2.—U.S. *flag tankers under construction/contract October* 1974---Continued

Company and number	Dead-Weight tons (each)	Estimated total cost (millions)	Percent subsidy	Owner	Scheduled delivery
Newport News Shipbuilding & Dry Dock Co., Newport News, Va.:					
2--------------	390,770	277.9	39	VLCCIanci II----	1978
l -------------	390, 770	136.6	39	Zapata -----------	1979
Seatrain Shipbuilding Corp., Brooklyn, N. Y.:					
I -------------	225, 000	57.3	43	Polk Tanker ------	1975
1--------------	225,000	70.6	41	Fillmore Tanker---	1976
1-------------	225, 000	94.2	39	Pierce Tanker ------	1977
Sun Shipbuilding & Dry Dock Co., Chester, Pa.: 1 l---	118, 300	49.0	None	Undisclosed -------	1975
Todd Shipyards Corp., *San* Pedro, Calif.:					
3--------------	25,000	48.0	None	Marine Ship Leasing.	1974
4-------------	35,000	79.4	43	Sea Service Tankers.	1975-76
2a- ------------	89,700	67.8	None	Energy Tankers Corp.	1977
2 z- ------------	89,700	67.8	None	Shipmore Associates.	1977-78
3 2---- ---------	89,700	116.4	34	Hawaiian International.	1978-79
1 2------ -------	89, 700	38.4	None	U.S. Lines --------	(a)

1 Tankers with both double bottoms and double sides, 7.
1 Tankers fitted with double bottoms, 21.
3 Not available.

NoTE.—TotfLl number under construction, 60; total deadweight tons under construction, 6,842,510 tons.

Source: Maritime Administration, Division of Ship Construction, December 1974/ January 1975.

Most of the discussion which has centered itself upon the double hull/double bottom issue might be placed in **one** of the following categories:

- **cost;**
- **effectiveness,** from both **an** operational and accidental point of view;
- safety, and
- salvage.

B. COST OF DOUBLE BOTTOMS AND HULLS

Estimates of the added **costs** for double hulls **over** the capital investment required for **a** conventional single-skin tanker have ranged **over** the last 5 years from approximately **seven** percent **to** 30 percent **(or** more, **in some cases.** The additional **costs** for double bottoms, **on the** other hand, have ranged from three percent **to** 22 percent, estimates indicate. (Most of these estimates **were** usually made **on** the basis of comparison with older tankers without segregated ballast capacity.)

However, **in contrast to these estimates, U.S. shipyards say that, nowadays, double bottom and double hull tankers are being built at differential cost increases of approximately 3 and 5 percent respectively over the capital investment required for equivalent new single-skin tankers.1**

Table IV–3 is a tabulation of the various estimates which were made between 19'71 and 19'73, the period immediately preceding the 1973 IMCO Convention. As can be seen from this table, the average of all estimates of the higher costs for double bottoms and double hulls shows differential increases of 12.3 and 17.4 percent respectively. In each case, when compared to actual construction/contractual costs, they are overestimated by a factor of three to four. (In fact, an active study is being pursued, by a Japanese shipbuilding firm for a number of countries, on the costs and feasibility of retrofitting double bottoms on existing tanke~ which transit the Malacca Straits.)

I As reported by the shipyards who are now constructing double bottom and double hull tankers.

TABLE IV–3.—Estimated cost increases (in percent) of double bottom and double hull tanker designs as compared to actual construction or contractual cost

	Double bottom des~.x increase (percent)	Double d~~~~ increse (percent)
ESTIMATES		
Tankers and the ecology, SNAME transactions, 1971.	9.6	---- --
U.S.A. segregated ballast study for IMCO, 1972-73:		
(a) 21,000 dwt designs	11. 9-12.7	16. 0-17.0
(b) 75,000 dwt designs	12.2	17.2
(c) 120,000 dwt design	------	22.9
(d) 250,000 dwt design	6.4-8.7	17.5
(e) 500,000 dwt design	------	---- --
Ship design aspects of oil pollution abatement, 1971	3.6	8. 0-13.1
Segregated ballast tankers, RINA, 1973	13. 5-17.8	12. 4-16.8
MARAD, economic viabili~y analysis from EDF, et alwvs. Peterson, etal., 1973:		
(a) 35,000 dwt tankers	18.6	22.4
(b) 89,700 dwt tankers	(1)	7.3
(c) 225,000 dwt tankers	11.1	22.1
(d) 265,000 dwt tankers	21.8	33.4
Average of all estimates	12.3	17.4
ACTUAL CONSTRUCTION/CONTRACTS		
212,000 dwtMobile Pegasus class built bylHI	4.0	------
NASSCO, 89,800dwtdesigns being builtby National Steel and Todd, San Pedro	2.5	-_----
FMC35,000dwt design	------	4.0
Sun Shipbuilding 120,000 dwt design	--- ---	5.0
NASSCO 150,000 dwTt design	3.5	------
NASSCO 180,000 dw't design	3.5	------

IProvided initially with double bottom.

C. EFFECTIVENESS OF POLLUTION PREVENTION

In regard to the effectiveness of any double hull or double bottom design there are a number of factors which n~ust be integrated; namely:

- Extent of penetration from historical data;
- The oil containment provided by the double bottom in the event of an inner bottom rupture; and
- The distribution of oil outflows as a function of the type of accident; i.e., colllsion, grounding, and rammings;
- The smooth wall/bottom feature in so far as it affects tank ballasting and cleaning, clingage and stripping.

Apart from the obvious advantages of providing segregated ballast spaces, double hull/double bottom construction below and along the cargo length can provide "defensive spaces" for the cargo in the event of a collision, grounding, ramming. (See table IV+L)

TABLE *IV-4-Effectiveness of double sides and double bottom aocording to various sources*

[In percfmt]

	I$umble	Double bottoms
United States segregated ballast study to IMCO, June 1972 and February 1973	1 15-55	60-65.0
United States segregated ballast study to IMCO, June 1972, and February 1973, alternate method of calculating double botton effectiveness-		52
Preliminary analysis of tanker collisions and grounding by Bovet, January 1973	(2)	92
Effectiveness of doublt bottoms in preventing oil outflow from tanker bottom damage incidents by card, 1975		90
Booz-Allen study for Bethlehem Steel Corp. re Marad Eva in EDF versus Petersen, et al, 1973		37.5
Tankers and the ecology, 1971		73

1 For double side Widths of 1,4S m (4,79 ft) to 6,55 m (21 43 ft).
9 A complete range iaindicated as functions of striking sh~pmsw and velooity; to gfve an exam Ie however, for strikin velocitieaof9knota and lass, tohavea9Cpercent effective double side, its depth wd d ~aveto be on the ortér of 7 m (23 ft).

Note:—The above data (except for item 4) was submitted to the 1973 IMCO Pollution Conference but tha' conference, after much deliberation, did not impose double ixttom requirements.

While the double side issue has not been subjected to the exhaustive studies that double bottoms have, a recent and thorough study on the effectiveness of double bottoms was conducted by LCDR J. C. Card, U. S.C.G., ("Effectiveness of Double 130ttoms in Preventing Oil Outflow from Tanker 130ttom Damage Inciclents", l!larine Technology, January, 1975.) This study analyzed 30 tanker grounding which occurred in U.S. waters during 1969 to 1973. In short, it concludes that a double bottom height of 2.0 meters would have been effective in 96 percent of the cases with an attendant 11,550 tons of oil pollution prevented; i.e., given a grounding, the probability of penetrating the inner bottom is on the order of 0.04.

In any case, it would appear from the various analyses conducted that double sides and double bottoms can distinctly provide protection, given a collision or grounding respectively. Moreover, in the more severe cases of collisions and ,groundings where the inner hull may be ruptured, the double hull or double bottoms will provide three valuable characteristics: survivability? containment and time. Survivability prevents a major incident from becoming a catastrophic event. (For instance, some time ago the 212,000 clwt, double bottom tanker, Mobil *Pegasus*, experienced a severe explosion in Number 1 center cargo tank during the course of tank cleaning/ballast operations [the ship was not inerted]. Her owners have stated that if it were not for the presence of the double bottom, the ship would have probably broken in two and sunk.) Containment of the cargo is also helped by the double hull or bottom. Finally, it will slow down the rate of oil discharge to the sea and thus buy additional time for response.

To learn more about the concepts of oil entrapment within and the effect on double hull oil outflow rates, a series of model tests were conducted on a tanker of approximately 225,000 dwt with and without a double bottom.[2] While many parameters were varied, such as wave height, ship speed, and tank pressure, in general the report concluded that, given inner bottom damage, the double bottom was very effective" in preventing pollution; above and beyond its effectiveness in preventing any inner bottom rupture. In general, the amount of oil outflow to the sea was significantly greater for the single bottom version as compared to the double version.

It also showed this same trend both in waves and with variance in tank pressure. This Disparity decreases somewhat with increased ship speed and with more water allowed in the double bottom prior to inner bottom rupture. Regardless of the quantitative values, the tests showed that much more oil was entrapped within the double bottom than previously believed (U.S. Reports to IhlCO on Segregated Ballast, Parts 1 and 2) and that oil outflow rates are distinctly lower for a double bottom hull than for its single hull counterpart.

The distribution of oil outflows by type of accident (i.e., collision. grounding, or ramming) has also been thoroughly studied. Based on the data available in 1969, and 1970, it had been stated that oil outflows clue to groundings exceeded those from collisions and rammings by a factor of three. With an additional three years of data, this same ratio

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[2] *Netherlands Ship Model Basin Report for Mobil Shipping & Transportation, Co.,* January 1972.

has decreased to something on the order to 7 to 6; or in other words, the outflows are approximately equal.

The additional three years of outflow data coupled with the cost data given h Table IV-3, which shows that the initial projected costs of complete double hulls were grossly overestimated, has supported a shift in the emphasis from double bottoms to double hulls. Thus, in the macroscopic view, it appears that double hulls deserve more consideration that previously given. It should be noted that a view opposing double bottoms is stated in a booklet "Double Bottoms—Yes or No" issued by the American Institute of. Merchant Shipping. The principal negative reasons are safety and salvage considerations which are discussed in the following sections.

In addition to providing tankage for the segregated ballast and defensive spaces from collisions, grounding, and rammings, there are some other eff~ts which are derived from the incorporation of a double hull or double bottom design; namely, the smooth tank bottom surface which does not have the usual cellular structure to either obstruct the flow of oil during discharge or provide additional surface area upon which the heavier oils will adhere; i.e., increases the efficiency of the (hscharge operation and reduces clin~age. Additionally, the double bottom will allow pump suctions to be placed below the tank bottom as opposed to the conventional suction bellmouths which are above the tank bottom. The effect here is that the main cargo pumps can draw suction for a longer period of time, thus minimizing discharge time and, secondly, when the stripping pumps are being usecl, they can draw suction for a longer periocl of time, thus allowing more cargo to be delivered,

Overall then, the double hull or double bottom design allows more cargo to be discharged (i.e., an increased payload per voyage), it increases the efficiency of the cargo discharge operation (i.e., reduce turnaround time), ancl it mitigates the sludge build-up problem due to both the ability to draw off the bottom more efficiently and the lesser amount of clingage. (The net effect of having less sludge build-up is that tank cleaning frequencies and the associated problems of the treatment and disposition of tank cleaning residues can be minimized.)

C. SAFETY OF DOUBLE BOTTOMS AND HULLS

Ever since double hulls and double bottoms have been proposed for oil tankers, there has been genuine concern expressed by people as to aspects of these designs which might be counter-productive in terms of safety. For the most part these concerns are: (1) the possibility of the accumulation of flammable vapors in the spaces between the outer hull and the cargo tanks; and (2) the concept of lost buoyancy or added weight which a double hull or double bottom tanker will experience when the outer shell is punctured.

13xplosion potential aboard oil tankers has existed from their very inception. Whenever one can introduce an ignition source to a vapor-air mixture within the flammable limits of a product in a confined space, an explosion will occur. Throughout the years, explosion protection has been achieved by precluding any ignition sources from hazardous areas aboard the tankers and in some instances (through an inerting system) by not ever allowing the tank medium to pass through the flammable range.

Insofar as the safety of enclosed spaces adjacent to cargo tanks is concerned, void spaces and pumprooms have always been present aboard oil tankers. Moreover, many classes of vessels, including cargo ships ancl combination carriers, have operated with bulk flammable liquids above a clouble bottom or adjacent to a transverse or longitudinal void space; neither have exhibited any explosion record in these spaces. (Also as mentioned earlier, regulatory agencies vequire double hulls on chemical carriers and liquefied flammable gas carriers.) Specifically, during 1973 and 1974, worldwide tankers had an explosion/fire casualty rate of 4.1, while ore/oil carriers and bulk/oil carriers had explosion/fire rates of 4.4 and 8.3 respectively. While at first glance these figures might suggest that the bulk/oil carriers have a high potential for explosions related to their double bottoms, in none of the 13 cases did the explosion occur in the double bottom. According to an article in Motor Ship, June, 19'74, the International Chamber of Shipping has indicated that they suspect the cause of the bulk/oil carrier explosions to be due to either static electricity discharge in a slack tank, or ignition by compression clue to sloshing. In any case, it is not the double bottom that is the causative factor for the cxplosic,ns. Moreover, the explosions involve a situation peculiar to the bulk/oil carriers.

Finally, with respect to the explosion potential issue, if there were an accumulation of flammable vapors in the double hull or double bottom, there are]nuch fewer ignition sources present to cause an explosion than in cargo tanks. Moreover, on every ballast voyage, the double hull or double bottom will be "gas-freed" by the infusion of the ballast water to these spaces.

D. SALVAGE CONSIDERATIONS OF DOUBLE BOTTOMS

The issue pertaining to the lost. buoyancy of a tanker with a double bottom stems from a basic principle of naval architecture. That is, when a conventional single skin tanker is "holed" in the bottom? oil escapes to the sea and the ship actually rises; on the other hand> a double bottom version when punctured in the bottom does not lose oil, but rather floods a portion of. the double bottom with seawater and thus sinks deeper into the water. The question raisecl is, can this lead to a more hazardous situation by having the tanker more firmly aground?

As previously indicated, many other ship types (combination carriers, chemical carriers, cargo ships, etc.) have double bottoms and have not indicated any a,dverse effects in a grounding due to the presence of the double bottom. In fact, sinking rates due to grounding are less for these types of ships. Secondly, from a salvage point of view> it is more advantageous to keep the ship as firmly aground as possible and then give her sufficient buoyancy an(l proper trim at the selected moment for refloating. In fact, this was precisely t]]e situation with the ilfetuZa grounding incident.. *Metu?a* was initially only aground in the forward portion of the ship and lost some 6,000 tons of oil. However, tides and currents swung *Metu7a* such that she became totally aground, including the flooding of the engineroom, and subsequently lost an additional 49,000 tons of cargo. The salvers were then faced with the prospect of either discharging oil to the sea to generate the necessary buoyancy or 1 ightering it to another tanker, which was not an easy feat. A tanker with a. clouble bottom, on the other hand, may have been more firmly aground initially and thus precluded the tanker% further movement. 1t would also have provided more options to the salvers in terms of directly dewatering the double bottoms without oil discharge as well as providing additional compartmentation. As a matter of fact, the office of the Supervisor of Salvage of the U.S. Navy has indicated that the additional compartmentation of a double bottom design along with the more stabilized platform of a more firmly grounded vessel is a distinct advantage. To quote,"1 view the probability of a major sal~'age or pollution incident growing out of the grounding of a large single-bottom tanker an order of magnitude greater than for a double bottom tanker.'?

3. *Controllability Aspects*

one of the most discussed facets of tanker operations is controllability. For purposes of discussion herein, ship controllability is defined as the ability of the operator to control the ship according to the ship's inherent hydrodynamic characteristics and as modified by both the local environment in which the ship is operat ing and any periph~ral equipment (either on board or onshore) which furnish information :md/or control to the operator. Probably the most widely quoted statistic pertaining to supertanker controllability is its full-throttle-reverse stopping distance at 16 knots. For this maneuver, the supertanker requires about three nautical miles whereas a much smaller tanker (1'7,000 dwt) requires something less than one nautical mile.'

[3] Crane, C. L., *Maneuvering Safety of Large Tankers: Stopping, Turning and Speed Selection,* Transaction, SNAME, 1973. Full scale trials of three tankers of 191,000 dwt each demonstrated crash stopping distances of 14,400, 15,500 and 1%600 feet.

One would presume, however, that ships in general. and large oil tankers in particular, will be operating at speeds well below the 1(; knots when **in congested traffic areas or within the confines of a harbor. In fact, one would expect maneuvering speeds on the order of six knots,** wherein the stopping distances are reduced to three-quarters of a naut ical mile for a 250,000 dwt tanker and one-quarter of a nautical mile for a small tanker.

While speed regimes, or the limit thereof, narrow the disparity among tanker sizes, the tremendous difference in mass and the decrease in horsepower to displacement ratio of the larger tankers are such that at a given approach speed, the larger tanker will always require]]~ore distance and area in which to stop. ~~asica]ly, stopping performance is governed by ship size, speecl of approach, loading condition? astern thrust, time lag in reversing the propeller, added hydrodynamic resistance, added ~lo~ll]~'{lr"od~'~~amic retarding force, and use of tugboats.

As previously indicated, stopping distance increases with both ship size and approach speed; i.e., mass and velocity, the two parameters of kinetic energy. Thus, to minimize stopping distance for a gi}"en ship one must consider one or more of the following:

- Approach speed reductions;
- Ability to deliver more astern thrust;
- Ability to deliver astern thrust more rapidly; i.e., more quickly reverse the propeller;
- Added hydrodynamic resistance such as might be provided by parachutes and brake flaps;
- .Added nonhydrodynarnic retarding forces such as a rocket motor; and
- The use of tugboats.

Given that ship sizes, due to the economies of scale will probably not become smaller and that, after a point, approach speeds can become so low as to generate loss of steerageway, reducing ship size and minimizing approach speeds have limited application. However, in cases where wind and current effects are minimal, some studies indicate **that very low (2-3 knots) approach speeds can be maintained by a fully loaded tanker without losing steerageway. Based on improving a ship's stopping distance from slow and moderate speeds, the effectiveness** of practical l~min propulsion alternatives (that will deliver l~~ore astern power and cleliver it more rapidly is ranked as follows: double astern power, controllable-pitch propeller, slow-speed diesel, and ducted propeller. For in~proving stopping ability from h@l approach spee~~s. the ranking of effectiveness of practical main propulsion alternatives is: cent rollable-pitch propeller, double astern power, and ductecl propeller.

(The slow-speed diesel v-ould not be particularly useful here because reversing could not be attempted tintil ship speed and propeller speed had decelerated to safe levels.) In all, it may be said that it is of prime importance to minimize delays in response to engine orders, and make full use of astern power. (However, although this is emphasized, a large tanker's stopping response is rather insensitive to the time delay factor beyond that achievable with current main propulsion systems.)

Special hydrodynamic braking devices producing additional resistance do not at this time appear practical. These include water parachutes, wata brake flaps, bow flaps, and splayed twin mddem. At slow speeds, such devices would have to be enormous to be effective, and at high speeds they would present difficulties of construction, strength, arrangement, and handling. However, ther may be some benefit to improving directional control while stopping and while going ahead at slow speeds.

Similarly, special devices, such as rockets producing nonhydrodynamic retarding force to aid in stopping, have generally little effect and are not practical.

In general it may be said that both added hydrodynamic resistance devices and added nonhydrodynamic retarding force devices appear to be unwieldly, impractical, or to have low cost effectiveness compared with other methods.[4]

Although dramatic improvements in stopping performance cannot be expected with increased power alone, this might be worthwhile if deemed needed and available at relatively small expense. Other alternatives which might be considered are combining a reversible slow-speed diesel with a controllable pitch propeller, or combining a ducted propeller with either steam turbine or diesel machinery. Tugboats are regularly used to provide stopping force at slow speeds within a harbor. Given the tugs fixed to the tanker in "power tie-up>' so that the forward speed of the tanker and tugs is always the same, the effect of the tugboats is essentially that of an added constant retarding force. Their effect will vary as a function of ship size, approach speed, ship horsepower, number and size of tugboats, and local conditions in terms of wind, current, channel configuration, etc.

As previously indicated, another aspect of tanker controllability is low speed maneuverability. That is, when a tanker% speed through the water reaches a certain minimal level (below 34 knots), and external forces such as wind and current become more dominant, there is insufficient directional control afforded by the rudder. This so-called loss of steerageway at low speeds leaves a tanker vulnerable to col-

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d Crane suggests that the most effective mechanisms for increased stopping ability are to increase astern power, provide controllable pitch propellers, power by slow speed diesel and/or tlt ducted propellers. He also demonstrates relatively small improvements gained by other added devices.

lisions with other ships and fixed structures as well as susceptible to grounding.

In order to afford a tanker more turning moment at the low speeds (which also normally coincides with shallower water in which it is more difficult to turn) such concepts as lateral thrusters, twin screw propulsion systems, twin rudders, and the employment of tugboats have been considered. In a case studied on a single screw, single rudder 60,000 dwt tanker at a rudder angle of 30 degrees, the turning moment at a ship's speecl of three knots is less than twenty percent of the turning moment for eight knots. VVith a 1,500 HP lateral thruster employed, however> the combined turning moment generated at three knots by the rudder and the thruster is two and one-half times greater. Similar improvements are available with installations on larger tankers, although these ship's greater inertia detracts from their maneuverability even more so at slow speeds. In addition, lateral thrusters presently are limited to about 3,000 horsepower and the ratio of lateral thrust available to lateral resistance decreases with increasing ship size.[5]

In berthing operations at these low speeds (below 4 knots) maneuvering aids are absolutely essential to provide lateral control to a tanker. Tugboats have been used traditionally to fill this need. However, the effectiveness of lateral thrusters is such that at zero speed a thruster will deliver lateral thrust approximately equal to that delivered by a tug of the same horsepower. The thruster's advantages are that lateral forces are easily controlled by the docking master or pilot, whereas tugboats may be out of position at the time they are needed. Tugboats are also handicapped by the necessity of relaying orders from the ship to them. Conventional thrusters, however, cannot deliver thrust to affect forward or astern motion of the ship which a tugboat can easily do. In most instances, lateral thrusters have been installed to supplement tugboat assistance rather than to entirely eliminate it. ~ lateral thruster requires a differential cost increase in capital investment of something on the order of two percent.

Twin screw propulsion of ships generally results in improved maneuverability. lt~ost merchant ships employ single screw propulsion clue to its higher hydrodynamic efficiency and lower cost. The prime disadvantage of twin screw systems is the necessarily more complex power plant used, which results in a greater initial capital investment of approximately eight percent. Slow speed berthing operations are perhaps the situations in which twin screw capability would be most used and in which the greatest maneuvering benefits would accrue.

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[6] A bow thruster can be quite effective at very slow speeds but ineffective at high speed (see Crnne).

Twin screws on a large tanker would have one main advantage for controllability: If a rudder was located behind each, one engine could be reversed to avoid forward acceleration as the other thrusts ahead to provide flow over its associated rudder. (Differential speeds and directions of rotation at higher ship speeds would not be a practical mode of operation. hforeover, unless twin rudders were simultaneously employed, no significant improvement in developing rudder forces would be realized since rudders derive much of their effectiveness from being placed in a propeller's race.)

With smaller diameter propellers, which are inherent to a twin screw design as opposed to the single screw variety, there will be a reduction in available astern thrust for a given horsepower. Improved control during a stop may nonetheless be possible, thus aiding in the avoiding of accidents in areas with limited maneuvering room. (As a side issue, twin screw propulsion systems will provide added reliability in terms of having redundant propellers, shafting, gearing, engines, etc.)

As previously indicated, rudders deri}"e much of their effectiveness by being placed directly behind a propeller. Thus, to maximize the rudder generated forces of a twin rudder installation, these should be employed in concert with twin screws. Twin rudders, whether utilized to their full capacity behind twin screws or used with only a single screw, will have their impact felt only at speeds above four knots. Just as with a single rudder, when ship speeds become so low as to not create sufficient rudder lift, the twin rudders become relatively inefl'ective.

In many low speed maneuvering conditions and in practically all berthing operations, tugboat assistance will be required to at least provide astern and forward motion. Additionally, depending on the ship>s ability to generate lateral thrust at low speed through the use of thrusters, twin screws, etc., tugboats will be necessary to assist in providing the necessary side forces.

Certainly controllability of supertankers is an area in which additional research into the subject may be very desirable for future ship and port designs.

4. Cargo Tank Atmo~phere ContvoZ (Iwrt gas system)

With flammable cargoes, such as crude oil and its refined products, the hydrocarbon vapor in the ullage space (the space between the liquid cargo surface and the tank top) is above the upper flammable limit and thus too rich for combustion to occur. However, at all other times of operation when the tank has not been gas-freed, a flammable mixture (11 to 21 percent of air by volume) usually exists somewhere with the tank. Thus, given the proper mixture of flammable vapor and air> any ignition source can cause an explosion. Generally, the flammable mixture will be within the tank during cargo handling operations and during tank cleaning operations; both are times when the ignition potential is highest through electrostatic discharge phenomena, by either the introduction of other elements to the tank atmosphere, such as tank washing apparatus, or by a direct ignition source coming into contact with the flammable mixture.

The object of an inerting system is to reduce the oxygen level well below the lower flammable limit by displacement of the oxygen with an inert gas. The inert gas may be derived from either an inert gas generator or, as is more popularly done, derived from boiler exhaust gases. In the second instance, the only special equipment required is that associated with cooling, washing, and delivering the inert gas to the tanks.

The composition of the flue gases using a water free measurement criterion is: carbon dioxide ($C0_2$) 12–14 percent; oxygen (0_2) 4 percent; sulfur dioxide (S02) o.%-().3 percent; and, nitrogen (N*) the remainder. The more efficient the combustion, through control of excew air> the higher will be the proportion of carbon dioxide in the g~e% and the lower the proportion of oxygen. After passing through the cooling and cleaning process, the gas composition is only slightly different; the sudfur dioxide, itself corrosive, is washed out, and the amount of water vapor is reduced. Nitrogen and carbon dioxide concentrations are practically unchanged.

Corrosion of steel and combustion or explosion of hydrocarbon vapors are only possible in the presence of sufficient oxygen. Ordinary air contains about 21 percent oxygen which is adequate to support both corrosion and combustion. An inert gas system displaces the original hydrocarbon-air mixture such that the oxygen level in the tank does not exceed five percent by volume. Thus combustion cannot occur due to the lack of sufficient oxygen quantities. Simultaneously, the inert gas system minimizes the corrosion rate of the most susceptible under-deck longitudimds by some 40 percent. Finally, untreated flue gases contain approximately 250 milligrams per cubic meter of solicl material (soot) which are normally discharged to the atmosphere. ~~sing a flue gas inerting system, the solid material discharged is reduced to less than four percent of the noninerted system or some eight milligrams per cubic meter.

To date, both IAICO and ICS have recommended against the use of high-capacity tank-cleaning machines without the usc of an inert gas system. 111.4 R.41), in consideration of the explosion hazard on the larger tankers, requires inert gas system installations on subsidized tankers of 100,000 dwt and greater. The L'.S. Coast Guard has indicated a similar preference in an Advanced Notice of Proposed Rulemaking.

It is important to note, however, that while IMCO, ICS, MARAD, and the Coast Guard have recognized the special explosion hazard which exists on the larger crude carriers during the course of tank cieaning operations, the explosion potential remains for all tankers, regardless of size, (and with many classes of petroleum products) without inert gas systems whenever the tank atmosphere is within the flammable range. It appears that only requiring inert gas systems on tankers above 100,000 dwt does not address the total problem. It should also be noted that inert gas systems could be retrofitted on most existing tankers for costs similar to those of fitting the same system on *a* new ship.

C. Mm"ntenance

Oil tankers sinking from structural failures and thereby losing their cargo of oil to the oceans contribute nearly *75,000* **long tons (25,000,000 gallons) of oil pollution each year. In fact, during the 1969–1972 reporting period, the ECXl [a] casualty statistics list 16 oil tankers with an** average age of 17 years which sank and contributed, in themselves, over 260,000 long tons of oil pollution.

All of these 16 oil tanker structural failures occurred at sea. Apart from ecological effects, their impact must not be disregarded for three reasons:

The large number of shipboard personnel being lost with the ship;

The large quantity of oil (25,000,000 gallons) being lost each year; and,

The loss of the ship, itself. .

Table IV-5 and Table IV-6 illustrate the number of structural failures which resulted in oil pollution and their associated oil outflows as a function of the age of the oil tanker. Additionally, these Tables show that tankers which are less than ten years of age (43 percent of the total fleet) account for less than *28* percent of the structural failures and *4* percent of the associated oil outflow.

a Engineering Computer **Optecnomics,** Inc. **(ECO),** Arnold, Maryland, 21012.

TABLE *IV-5.-Distribution of t?te number of structural failures as a function of tanker age for the period of 1969-?'~ 1*

Tanker age (years)	Number of structural failures	Perce&t&f structural faflures	Perce&tg{ ta;k:~	Percent of structural failures/ percent of tanker fleet
0 to 4	14	12	20	0.62
5 to 9	17	15	23	.64
10 to 14	25	22	25	.88
15 to 19	37	33	15	2.17
20 to 24	15	13	5	2.57
25 to 29	3	3	7	.42
Over 30	2	2	5	.35
Total	113	100	100	

I Based on oil tankers greater than 100 grt from the ECO accident statistics.

TABLE *IV-6.—Distribution of the oil outjlow from structural failures as a function of tanker age for the period of 1969-Z??* [1]

Tanker age (years)	Nurnb~j Str;$uc;:;	Asaoci-8tCd oil outflow in long tons	Percent toi[oil outflow	Percent of total tanker fleet	Percent of oil Outtlowl per~~; fleet
0 to 4	14	6,053	2.03	20	0.10
5 to 9	17	4,770	2.00	23	.07
10 to 14	25	30,222	10.11	25	40
15 to 19	37	167,928	56.20	15	3: 72
20 to 24	15	89,719	30.02	5	5.82
25 to 29	3	90	0.03	7	.005
Over 30	2	17	0.01	5	.002
Total	113	1298,799	100.00	100	

1 Baaed on oil tankers greater than 100 grt from the ECO accident statistics.
* 2 structural failures wfth a total outflow of 20,440 long tons are not included within this table since the age of the 2 tankers was indeterminate.

On the other hand, tankers which range between **10** and *20* years of age *(40* percent of the total fleet), account for nearly 55 percent of the structural failures and over *66* percent of the associated oil outflow.

This means that a l&year-old oil tanker has over three times the probability of having a structural failure as compared with a tanker of less than 10 years of age.

With respect to oil outflow, a 15-year-old tanker loses, on an average, nearly ten times the amount of oil per accident, when compared with an oil tanker of less than 10 years of age.

A significant portion of tanker polluting accidents has been traced to hull failures, which in most cases have resulted in total ship losses.[7] High stresses in rough water are common to all tankers and can result in fatigue cracks which propagate across the hull structure if these fatigue cracks are not detected during the early stages of their development.'

A "special" marine inspection procedure could discover these potential structural problems.[8] Specifically, when an oil tanker becomes **10** years old, the surveyors may want to consider combining the experience of their merchant marine inspectors with the expertise of their **trained naval architects and conduct a rigorous, detailed inspection of the subject 10 year old tanker. It is foreseen that the surveyors' "in-**spection team" (the marine inspectors and naval architects), would be equipped with appropriate nondestructive-testing instruments to enable them to properly determine the amount of corrosion within the critical amidships structural band. The maintenance and operation of machinery, including any electrical/electronic components, should also be thoroughly examined. Upon completion of this "special inspection", the inspectors would have a good handle on the structural adequacy of the subject tanker and could do the following:

- Continue to allow the tanker to operate in a manner similar to her first ten years of operation;
- Limit operations to protected waters;
- Recommend the necessary corrective action to enable her to continue full oceans service; or,
- Reduce the stress level within the hull structure by reducing the sagging bending moment through conversion of amidships cargo tanks to clean ballast tanks.

With respect to this last item, Mr. A. McKenzie, Director of the Tanker Advisory Center. suggested in a recent article that the present idle tanker capacity should be converted into an equivalent amount of

7 The SS ***Texaco-Oklahoma,*** which broke in half **durg** a **March** 1971 storm 120 miles east of Cape Hatteras, North Carolina with the loss of **31 lives and spilled** her **cargo** of 30,000 tons of black oil, 1s a typical example. See NTSB Marine Casualty Report, July, 1972.

8 Keith and **Porricelli**, "An Analysis of Oil Outflow due to Tanker Accidents," and McKenzie, "A Study **of** Tanker **Total** Losses 1964–1973," October, 1974.

9 The **USCG** and **classification** societies conduct periodic surveys **of** all ships licensed or "classed." Such surveys of hull steel are very **difficult** in large ships and tend to be more spot checks than careful inspections and tests. The proposal here is for very careful and more detailed inspections of both the hull and machinery of 011 tankers reaching 10 years of age.

segregated ballast capacity on existing tanke.rs.l" This action would not only reduce the present excess tanker capacity but may also curtail oil pollution by reducing the number of structural failures through a lower associated hull stress level, This practice would also reduce the operational oil pollution through the designated clean ballast tanks.

It has been estinmted that b-y converting an existing "dirty ballast") 70,000 dwt tanker to a "clean ballast'" oil tanker, as proposed by the International Conference for the Prevention of Pollution from Ships for *future oil* tankers of 70,000 dwt and greater, the cargo deadweight (payload) wotlld be reduced by approximately 30 percent and the associated shipyard modification cost would be approximately $100,000. .4dditionally, the maximum stress level within the hull structure could be reduced by as much as 20 percent, through the judicious choice of cargo tanks which would be redesignated as clean ballast tanks.

D. Personnel Training and Licensing

over *50* percent of the collision or grounding type of tanker casualties can be attributed to human error. Moreover, the tanker cas~lalty rate has not shown any decrease over the past years; in fact, both the number of collisions and the associated oil pollution from collisions have actually increased over the original 1969–19'70 casualty data, while the actual number of operating tankers throughout the world has remained nearly constant. The 6,000 oil tankers, over 100 gross tons, presently in operation throughout the world are involved in over 700 accidents with a resultant oil pollution in excess of 200,000 tons, *each year.*" With this record the need for improved personnel training and licensing is self-evident.

By contrast, frequency of accidents within the aviation field as recorded by the National Transportation Safety Board (NTSB) show significant progress in improving overall flight safety. In fact, the fatality rate 12 has decreased from 5.2 to less than 0.1, or a 50 fold increase in the level of safety. IVhile some caution must be exercised in the transference of technology from the aviation industry to the marine industry, many of the principles are similar. Therefore> a considerable advance in the level of safety within the marine industry could be achieved by adapting some of the "tried and proven" techniques of their counterparts in the field of aviation.

The comments presented within this section on training and licensing can be app]ied to Marine Pilots and Docking Masters as well as

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10 }f~~enzie, A. M., "Tanker Conversions Advocated", Journal of Commerce. March 25, 1975.

11 USCG, "An Analysis of Oil Outflows Due to Tanker Accidents 1971–72."

12 Fatality rate is defined as the number of passenger fatalities per 100 million passenger miles.

ships' officers. Many are excerpts, updated when necessary, from work originally advanced in May, 1972.[13]

1. Training

Airline.—At least so far, candidates have entered the commercial airline field as well-trained and qualified pilots. According to one airline representative, candidates average almost four years of college and some 1,500 hours of flying experience. The airlines build on this experience with extensive training and retraining during the course of a man% flight career. The basic attitude and philosophy of the airline seems to be that training is the key to safety and crewmen must be taught to fly, and handle emergency situations for that matter, according to prescribed procedures.

As far as the United States is concerned, regulations require that both commercial and airline-operated training schools and programs (including both ground and flight training) be approved by the 'FAA. Regulations also require that airline flight crews receive annual recurrent training, and that those programs be approved by the FAA. The purpose of such recurrent training is to:

- Review and practice emergency procedures;
- Review contemplated equipment or procedural modifications; and
- Review proper flight procedures.

The major U.S. airlines make extensive use of centralized training facilities complete with full-scale equipment mock-ups and other visual aids. They utilize simulators both with and without visual displays in all phases of flight training. on the basis of a one company sample their training personnel are very high caliber, competent, dedicated people themselves well trained in teaching techniques.

Marine.—In the marine area, officer training begins in the maritime academies which in the United States are authorized to grant college degrees. From there, training is generally on-the-job in nature, and relatively few shipowners have any formalized in-house training programs. Some marine operators have utilized ship model training and, more recently, real-time ship simulators to teach shiphandling. Others have shipboard safety inspection training of one sort or another. As mentioned earlier, the training of junior officers is in the hands of senior officers who may or may not be so inclined or qualified to provide this training. No refresher or recurrent training is required by regulation.

Comments.—In light of the importance placed upon training by the aviation industry in relation to the overall concept of flight safety, it

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[13] Ma&~, Nicastro, and Schumacher "Aviation Marine, A Study of Contrast", 17th Annual Tanker Conference, May—1972.

would appear **desirable for the marine industry to re-evaluate its own training practices. specific items include:**

The curriculum of maritime training academies should be reviewed to ensure that up-to-date instruction is being given in such things as shiphandling and maneuvering> navigation and collision avoidance, cargo handling, etc. This is particularly important in light of the larger and/or more complex vessels that are now becoming common, and the availability of vessel simulators and more sophisticated electronc gear. Liquid cargo handling is hardly covered in todayk courses. Furthermore, the training and instruction to be given a cadet during his pre-licensing shipboard service should be formalized and made more specific. At the present time, it is essentially left to the Master of the vessel to which he is assigned.

Some form of formal training should be required before an officer can advance in grade. For example, this could take the form of stimulator, navigation, and/or collision avoidance training.

Some form of periodic, recurrent training should also be required to validate licenses. This again could take the form of real-time simulation training in maneuvering and in collision avoidance procedures. Perhaps! some actual ship board training, at sea, could be used as a follow-up to real-time simulation.

2. Lict?m”ng

Airline.—Pilot licensing requirements in the aviation industry are well controlled and administered by national governments. The regulations are designed to ensure that all aircraft are piloted by well-qualifiecl, medically fit personnel. In the case of commercial airlines, the regulations further ensure that the pilot is qualified on the particular aircraft he plans to fly, and that he maintains both medical fitness and flying proficiency. The key points are highlighted below:

In the U’nited States, the pilot of any and every t ype of aircraft must hold a current license issued by the Federal Aviation Administration (F.4.4) and validated for the type (single or multi-engine), CIWW (under or over 12,500 **pounds gross weight) ? and category of operation (private, commercial, air transport, etc.). Furthermore, any pilot who wishes to operate his aircraft when visibility may be restricted must also hold an instrument rating on his license.**

Specific requirements for the various kinds of licenses ~mry. However, in general, an applicant must pass a written examination, rornplete flight, training, and then undergo a flight test in an

airplane of the appropriate type to demonstrate his skill and proficiency to an FAA flight examiner. Every licensed pilot must also hold a valid medical certificate.

An airline captain by regulation must hold an airline transport rating for the specific type of aircraft he plans to fly. Candidates for this rating must have accumulated a specified minimum amount of flight time, must pass a very rigid medical exam, and must pass a flight proficiency test on the particular aircraft involved. Parts of the latter ma-y now be performed in simulators. The latter two items must be repeated every six months to hold the rating.

The pilot licensing standards of the regulatory authorities of other national governments closely parallel those of the FAA. This is particularly so when the country has an international airline and is a member of the International Civil Aviation organization (ICAO), a branch of the United Nations. Many countries, lacking their own airline pilot training facilities, have their pilots trained by airlines or flight training schools in the United States or the United Kingdom. For this reason, plus the fact that perhaps 95 percent of the world's commercial airliners are manufactured in these two countries, it is not surprising that English is the international standard language of the industry.

Although not specifically covered by regulation, it is important for comparison with marine operations to understand the procedures whereby an individual advances through the flight crew ranks of the airlines to the position of Clapt ain. F] ight c re ~~" candidates must l]a~"e a commercial pilot license and some minimunl amount of flying time. This ~'aries witl~ the airline, but is in the range of 400 to 500 hours. At least up until now, the majority of candidates have had military flying experience with flight time well above these minimums. Candidates are thoroughly screened ~'ia interviews, aptitude tests, psychological tests, and medical exams. i~fteI' sllch testing the airhne will accept only those candidates they feel have the mental and physical ability and aptitude to achieve L'aptain% status. Those accepted go to three to four months' ground and flight school, finally qualifying as flight engineers for a certain type aircraft (i.e., 707, DC-8, 727. 74'7. etc.). The man will then advance to J?irst Officer, and finally captain on a seniority basis, with both gp.ound and flight training required between advancement steps, as well as some minimum amount of flying time in grade. In addition, any officer must receive rather extensive ~roun~ and fli@t training before he can fly as a crewman on a different type of aircraft. As described above, a man must obtain an airline transport rating before he can function as Captain.

llfcmhe.-Marine deck officers are also licensecl by national governments. The first license is obtained upon graduation from ~overnment-

sponsored n)erchant marine aca[lemies, and service as a cadet (nonlicensed officer). very few, if any, officers now come up through the seaman ranks or enter merchant marine service following a naval career.

Advancement is made up throu@~ the officer ranks on the basis of *some* minimum sea tin]e in grade, followed by taking a government administered written examination for the next grade. Since an ocean license qualifies the holder to serve on any vessel from a sailing ship to the Queen Elizabeth 11, without regard to either vessel size or type, the exan]ination in professional subjects such as seamanship, cargo hand]ing, ship construction and nomenclature, and related subjects, is more theoretical in nature than of practical value in today's en}'irol~ment. No demonst ration of proficiency is required. The training of junior officers is in the hands of senior officers.

In contrast to aviation, the operators of small craft (under 100 tons) need not have any license. Hence, operators of pleasure boats, as well as some of the smaller commercial boats, require no licenses.

Marine licenses issued in the United States must be renewed every five years. In order to qualify for license renewal, a man must have had either service as an officer during the preceding three years, not necessarily in the rank of the license, or in a job ashore related to the operation of ocean ships. A test for colorblindness is given along with an open book examination on the "Rules of the Road' '—the latter mainly to ensure that the applicant is aware of any changes that have taken place during the preceding five years. Licenses in other countries are issued for life.

The contrast with aviation in the area of licensing is striking. Marine licenses in themsell"es CIO not assure competency. Licenses of airline flight crewmen come much closer to doing so in light of the extensive formal training and proficiency testing required, coupled with the tough hiring practices of the airlines. Many individual marine operators do have their own more restrictive employment practices to ensure that their people are competent. However, since in many cases both officers and crew are considered casual labor by ship operators, it would appear desirable to stiffen international maritime licensing requirements to include:

- Performance testing of some sort under both normal and stress conditions prior to issuing a license;
- Periodic proficiency checks to maintain a license; and,
- Some restriction as to size and type of ship the indivifiual. is licensed to operate (i.e., small vs. supertankers. anf~ frpighter vs. tanker). This implies, of course. that both written and performance examinations would vary as require(l to demonstrate proficiency and competence in handling the size and class]'essel involved.

co?n.men~s.-l~hile the marine industry lags desperately behind its aviation counterpart with respect to a transportational safety level, upgrading of the U.S. Coast Guard licensin g practices is being considered to include requirements for more direct supertanker experience for persons requesting licenses h operate these 1arge vessels. These proposed requirements are now under study and will be published within the near future.

Many experts contend that licenses for any large tanker operation. whether it be oil or any other hazardous commodity, should consider both the ships' size and cargo. They also contend that these operations should include regular training courses, upgrading programs, proficiency tests and safety instruction with respect to both the ship and the cargo.

The National Academy of Sciences is conducting a study of human errors in ship accidents through a series of interviews with shipboard personnel, and MARAD is preparing a pollution control manual and a study course for instructing shipboard personnel in pollution control methods.

All of these efforts should be closely coordinated with the intent of broadening and improving licensing and training practices for all U.S. merchant mariners and for others who operate in our waters.

3. Captain/Pilot Operations

Another area in need of attention is the present ambiguous relationship which exists between ships' masters and ships? pilots with respect to the pilot having control of the ship but the master having the responsibility for the safety of the ship. This relationship was highlighted on January 31,1975, when the Edgar M. Queewy struck the oil tanker *Com*nt?w8* near Marcus Hook, Pennsylvania, with the loss of *25 lives, 2000* tons of **oil pollution, and a tanker. The Queeny's Captain took control from the Queeny's Pilot while the ship was maneuvering near the BP dock where the** *Corz"ntho8* **was** discharging her cargo. The Captain then ordered the engines full astern, the @weny then struck the *Com"ntho8,* an explosion ensued and the State of Delaware suffered its worst marine accident in history.

Whether this accident would have been prevented or whether this accident would have resulted in even worse consequences had the Captain not taken control from the Pilot will probably never be known but it is a clear indication that improvements are required.

In light of the newer, larger, more complex ships now becoming commonplace throughout the world, another innovation is the "piloting team" concept. The "piloting team" usually consists of three qualified pilots, a Chief Pilot and two assistant pilots. One assistant pilot is normally responsible to the Chief Pilot for any tugboats, while the other is stationed on the bridge to assure that the ('hief Pilot's commands art' properly executed. The ships' Master assists the Chief Pilot continuously during any maneuver and translates his commands, if necessary, to the ships' bridge personnel. This team concept has worked extrenwlj? well on the Very Large Crude **carriers (VLCCS)** operating at the Hess Refinery in St. Croix. A natural extension of this "piloting team" concept would give the Chief Pilot both the control and responsibility of the ship, thus freeing the Master and his license fronl any repercussions should the Chief Pilot err. Moreover, it would prevent the ship's Master from assuming control> during the execution of a maneu~-er which was originated by the Chief **Pilot,** with potentially disastrous results.

E. Information and Control Systems

1. *Gerwrat*

Given a ship and men to operate the ship, there exists an entire realm of subsystems which furnish information to the operator upon which he makes decisions and/or which furnish control to him in execution of his commands. In general, these subsystems fall into six broad categories; namely:

- navigational aid systems;
- communications systems;
- information systems;
- control systems;
- vessel traffic systems; and
- collision avoidance systems.

A?. *~avigationa$ Aid 8y8te?n#*

The **navigational aid system is composed of those subsystems which permit a tanker to establish its navigational position. They include, but are not limited to:**

- impro,ed aids to nal.igation (buoys, ranges, structure% et~~)
- dual radar systems;
- satellite navigation systems; and
- LORAN–C or OMEGA.

The overall effect of being able to more routinely and more accurately establish navigational position is obvious-it will mitigate those grounding which occur because of unknown or erroneous navigational position. While aids to navigation, such as lights, daymarks, etc., have been employed by mariners for thousands of years, their inception was to guide a mariner to a desired point or along a desired path or to warn him of a hazard. The question now arises as to the optimum design, planning, and operation of such subsystems from the total marine transportation safety viewpoint. In other words, are logical-technical methods being applied in the decisionrnaking process to answer such questions as:

Where should navigatio~~al aids be placed ?

Where should the channel be dredged?

What type and amount of information should be afforded the operator from such subsystems ?

In short, this is an area where for minimal costs, technologies and sciences exist which can increase system safety based on aid to navigation design, placement, type, etc.

Another subsystem in the navigational system is the installation and use of dual radars for position fixing. The two-radar concept stems not only from the redundancy/reliability concern but also from the fact that, by using both a 3 cm radar with its high resolution for shorter range work and a 10 cm radar with its longer range capabilty, an oper-ator can be aff'orded the best available radar navigation system. Moreover, as will be discussed later, the 3 cm radar provides the necessary accuracy in resolution for employment with an anti-collision device.

In terms of long range navigational systems in the United States, the two most feasible systems would be LORAN-C or OMEGA and satellite navigators. Satellite navigation systems have the limitations of availability of satellite communications and their accuracy being a function of ship speed input. Both LORAN-C and OMEGA have the tidvantages of being cheaper? more accurate, and continuous availability. Between LQRAN--C and OMEGA, there will ultimately be better LORAN-C coverage in the United States than OMEGA, I.ORAN-C is more accurate, and has such options as continual digital readout and direct x-y position recording.

.9. (?wnmunicativn iYy8tem8

With the passage and implementation of the Bridge-to-Bridge Radiotelephone Act of 1971, essentially all merchant vessels operating within the navigable waters of the United States are required to have bridge-to-bridge communications.

The intent is to promote safety by establishing a common ling among vessels through which information and intentions may be relayed. In principle, it is the cornerstone upon which any vessel traffic system is built.

It has been stated, however, that the ultimate effectiveness of this system will only be as good as the communications discipline, the utilization of the system, and some upper limitation on the number of channels which an operator must simultaneously monitor. In the case of the last matter, it appears that two or three channels are the maximum that can be effectively monitored bu an o~erator. In some areas this limit has already been reached; i.e., harbor frequency, bridge-to-bridge frequency, and company frequency.

4. Information Systems

As discussed with the controllability aspects of the ship, the operator's decisionmaking process is interactively related to the information he senses. Historically, "seaman's eye", "feel of the ship", and other such experience factors accounted for much of the information input to the operator. Today, however, with the rather rapid increase in tanker size and the resultant, nearly imperceptible dynamics of ship motion and response, the operator can no longer entirely depend upon sensations heretofore used. For example, at the larger end of the tanker scale, it has been said that by the time a ship's turn can be sensed by a human, it is then very difficult to respond to that reaction. Thus in some instances. rate-of-turn indicators have been provided to measure this motion and provide the information to the operator well before he could sense it.

Also with the larger tankers, because of their tremendous mass (both actual and virtual), touching a dock even at very low speeds can exert tremendous forces both on the dock and the ship's structure. Thus, it is critical to be able to accurately measure very small differentials in ships' speed, differentials so small that they are imperceptible t% the operator. As a result, a number of devices have been developed to very accurately measure ship speeds at very low velocities as it approaches a dock.

Another aspect of largeness in tankers is that when a pilot or docking master is maneuvering the ship from a bridge wing, he is now removed up to one hundred feet from the center of the navigating bridge. This means that he cannot directly observe the helm position, engine orders, engine responses, etc., unless an appropriate means Of relaying these vital data are afforded, such as repeaters. (At the smaller end of the tanker scale, these may not be as vital since the physical dimensions would not remove the operator from the bridge center as dramatically.)

The intent of the foregoing three specific examples is not to necessarily underwrite the items discussed, but rather to cite an overall issue, namely the need to more fully understand in general what information an operator should be provided with. Furthermore, it is also necessary to comprehend how ship size and local environments may affect the general case.

Finally, it is important to note that, desipte the cited examples, information systems need not be restricted to onboarcl the ship. Information is also provided to the operator from external sources in the form of navigation data from aids, ship movement/intention data through communication systems, and other data through shore based radars.

5. *Control Systems*

Similar to information systems, ship control systems vary with ship size and local environments. However, in the context used herein, control systems are always aboard the ship since they are defined to be systems which directly cause control surfaces to respond and also including control surface dynamics. (This is opposed to traffic control where indirectly, from the controller through the pilot, the rudder is moved. Traffic control systems will be discussed later.

Basically, control systems fall into two broad categories: engine/propeller control and rudder control. Between the two, all directional and magnitude operator inputs to control surfaces (propellers, rudders, thrusters, etc.) are made.

The concepts of variations on propellers (twin-screw, controllable-pitch, ducted, etc.) and rudders (twin, flayed, and other devices to generate lateral thrust) were previously discussed as were the concepts of generating additional forces (more astern horsepower). This section will thus only speak to the systems which direct those control surfaces.

There again, as with information systems, the examples will neither be all inclusive nor specifically underwritten. Rather they will serve to illustrate a point.

It has been previously stated in the text that a prime consideration in stopping distance is the time which it takes to develop astern thrust. Once an operator has made the decision for astern thrust, his command must then be transmitted to the enginw and propeller shafting. Until very recently, this transmittal was done through a servo-mechanism known as the "engine order telegraph" whereby the engineroom matched "pointers" with the bridge's and then engineering personnel closed and opened throttles to the turbines accordingly. Nowadays, the bridge can be provided with direct control of both engine speed and direction, thus eliminating any error in transmittal as well as being able to do it more quickly.

Another control system is the one that exists between docking master and assisting tugboats. Conventionally, commands and executions are relayed through whistle signals and radio. However, with the larger tankers where the tugs cannot always be seen directly or where, as previously mentioned, channel monitoring may become overloaded and thus ineffective, or where, because ship speed is so critical, the time delay in tug response becomes paramount, all suggest at the very least the need to explore alternate methods for improving this control link. Now, it may be that the existing system is the most effective and practical arrangement. On the other hand, it may not be. In

any case, its necessity exists and its criticality increases with tanker size, thus suggesting the need for further analysis.

The two examples presented are meant to illustrate the potential impact of control systems on overall ship controllability and ultimate system safety.

6'. *Ve88eZ Traj%c h'y8tenw (VTL5')*

VTS can run the spectrum from a basic communication link to traffic separation to surveillance and advisory services to vessel traffic control. As can be seen, VTS can and do include communication systems, information systems, and indirect control systems; thus they are treated as a separate system within this portion of the text.

A VTS is an integrated system encompassing the technologies, equipment, and people employed to coordinate ship movements in or approaching a port or waterway. Regardless of the VTS level, its objective is to reduce the probability of ship collisions and grounding.

Historical casualty data and future projections for waterborne commerce have indicated a need for improved marine traffic safety in U.S. ports and waterways. VTS can make significant contributions to this effort.

Ports and waterways do not come in standard sizes or shapes. Each has its own physical characteristics, special hazards and degree of congestion. Some extend for only a few miles. Others cover several hundred miles. VTS must be tailored to the specific area serviced.

In general terms, there are three degrees of traffic management or control envisioned for the coordination of vessel traffic; namely:

- physical arrangements, such as a traffic separation scheme without manned traffic centers;
- disseminating advice in the form of navigational, weather, and vessel movement information; and
- positive control of vessel movements. (In this sense, the \'essel traffic center will direct ship movements as necessary for overall ship coordination.)

The Coast Guard in 1973 completed a detailed analysis of ports and waterways in the United States. Its ultimate result was a rank ordering of VTS needs for major U.S. ports. Systems for San Francisco and Puget Sound are now operational, the Houston system is under development, and New Orleans, Valdez (the southern terminus of the Trans-Alaska Pipeline), and New York are scheduled next. (The GAO in a report on VTS to the Congress dated January 21, 1975, concluded that the Department of Transportation should redirect its current program such that VTS implementation be more extensive initially and that the move from basic systems to more sophisticated systems be graduated; i.e., have much coverage with lesser levels of VTS.)

7. *Collision Avoidance System (CAS)*

Personnel error has been frequently cited as the dominant probable cause of collisions. The National Transportation Safety Board in "Special Study of Collisions Within the Navigable Waters of the United States-Consideration of Alternative prevention Measures", l?ebruary, 19'72, recommended that all vessels be equipped with a CAS. ~ number of on-board data processor/plotting, collision avoidance aids are currently available.

These systems all utilize a digital computer to automatically process radar data and display encounter situations in a form enabling the ship to be maneuvered to avoid potential grounding and collisions. There is some variation among the systems in regard to number of contacts tracked and automatic capabilities, but all provide at least one alarm for dangerous situations. The potential of CAS for reducing casualties through relief of deck officers' workload and improvement in decisionmaking process is generally considered excellent. (A ~ARAD study indicated that 40-50 percent of a deck officer's total workload is involved in collision avoidance.) The CAS has the added advantage that the onboard computer itself can be used for other functions, including the calculation of optimal cargo stowage and ballasting to reduce hull stresses.

MARAD currently requires a CAs on all U.S. subsidized ships; it is estimated that the average installed cost of each unit is approximately $90,000~ including ship-speed log. The U.S. Coast Guard has also proposed regulations requiring a CAs on new tankers.

F. Local Port Conditions

As has been referred to from time to time above, the variation in port configuration, traffic density, local current and wind conditions, bottom clearances, etc., will have a direct influence on marine transportation systems safety. In fact, the Ports and Waterways safety Act itself requires that the need and substance of any measures prescribed be in concert with not only the scope and degree of the hazard presented, but moreover, traffic patterns, port and waterway physical and environmental conditions, the ecological impact, and the economic effects. In essence, any measures which might be prescribed must be underwritten by their need, their effect or impact upon implementat ion, and their practicality in terms of cost and effect.

Due to the many factors of the local environment which affect system safety, it is clear that to attain a given level of safety will require different solutions at different sites at correspondingly different economic costs to the consumer. These different solutions will be derived as a result of the particular set of interactive elements which are in fact present from one site to the next. ,For example, consider the cases of an offshore port versus a conventional inshore port; or of a port with little traffic versus the port of New York; or finally, the case of a port with narrow channels, high traffic density, and high currents versus a port with no channel restrictions, little traffic, and minimal currents.

While equal levels of safety may be attained throughout the spectrum of ports and potential sites, it is a fact that to attain equal levels of safety will not only require different solutions but also different economic costs-costs which may be so prohibitive as to eliminate a site from consideration.

G. Oil Spill Cleanup Approaches

The previous sections have described alternative approaches to prevent oil spills originating from tankers. Even with optimum prevention systems employed, however, some spills inevitably will occur, and it is necessary to consider how such spills may be cleaned up before significant damage is done. The occurrence of such spills will constitute emergency situations which will require quick response and effective deployment of clean-up equipment. The following will describe some aspects of oil clean-up capability.

The U.S. Coast Guard has developed a quick response capability for emergency spill situations, particularly those arising from tanker accidents, to prevent further propagation of spilled oil in addition to cleaning up oil already spilled. This "U.S. National Strike Force" has available an Air Deployed Automatic Pumping and Transfer System (ADAPTS) which can be used to ofTload oil from a damaged tanker before it can spill from the tanker. This equipment, which was developed by the Coast Guard after a study of the Torrey Canyon disaster, was used in the salvage of the iKetuZu, which proved the value of such an approach. The U.S. Coast Guard strike force contingent and equipment sent to the Metuhz played an important part in restricting the oil pollution following this major casualty.

The Coast Guard also has under development a range of equipment for containment and clean-up of oil spilled on the seas. Such developments are valuable and necessary to meet the possible needs associated with tanker accidents.

Proposals for improvements in this clean-up capability are numerous and varied. These improvements can be categorized as follows:

1. Tanker Pump-out and Containment Equipment (ADAPTS with portable containers).
i?. Oil 13arriers for Rough l~ater (to "fence" in a spill on the surface).
3. Oil Absorbent Material (to "sop" up a spill).
4. Oil Clean-up Equipment for Rough Water (to skim oil off the water surface).

5. Dispersant.s which do no additional damage to the environment.

This report will not describe or analyze these systems. Such analyses are the subject of considerable attention in research programs of several federal agencies including the U.S. Coast Guard and the Environmental protection Agency. The oil industry has also developed capabilities for cleaning up oil spills. ~ major need at present is for effective methods and equipment to contain and recover oil spills in relatively rough offshore seas. These on-going programs could readily be directed toward possible new problems presented by the introduction of more or larger tankers into ~'.S. ports or coastal waters.[14]

The grounding of the VLC(l ,WetuZa in the Strait of Mngellan, in .&ugust, 1974, with the loss of over 500,000 tons of crude fuel oil in the surrounding waters, is an example of unnecessary delays leading to successively greater damage and more spillage over a long period of time-six weeks from the date of the accident. The total pollution damage from this spill is yet to be assessed and very little cleanup has been accomplished. However, the events and steps taken during this salvage operation constitute a guide for preparing contingency plans for similar problems that may occur in the future.

It may be desirable to require tanker operators to file emergency contingency plans prior to operation of supertankers in U.S. waters. (Contingency plans for accidents would describe source of salvage tugs and equipment? method of and source of pumpout equipment, available cirydock and repair facilities, method of cleanup in case of spills, source of containers for pumped-out oil, salvage techniques, and any other factors that could help minimize the impact of an accident. The U.S. Coast Guard engages in contingency planning efforts now and may also consider the unique planning problems of deepwater ports with regulations now under development.

Summzmy

The following list is intended to briefly point out items which have been discussed and proposed throughout this chapter as feasible approaches for reducing tanker pollution and improving safety. They include major aspects of the total tanker transportation system:

Ship Improvements:

- Double bottoms and double hulls.
- Segregated ballast tanks in double bottoms or double sides.
- Higher astern power levels and better control systems.
- Auxiliary thrusters and improved use of tugs.
- Twin screws and rudders for certain applications.

M 'Ioil Spills and Spills of Hazardous Substances, " U.S. Environmental Protection Agency, March 1975.

- Further research in slow speed maneuverability.
- Inert gas systems.
- Improved maintenance and survey practices.

Personnel Improvements:

- Improved training programs including review and recurrent training.
- Use of ship simulators for training and testing.
- Training for advances in grade.
- Periodic performance testing for licenses.
- Licenses tied to ship size and type.
- Special training for pollution control and safety.
- Clarify pilot/captain relationship and authority.

Improvements in External Controls:

- Improved navigational aid systems.
- Improved communications and information for captain? pilot, crew. tugboats.
- I'essel traffic systems for specific ports.
- ('ollision avoidance systems.