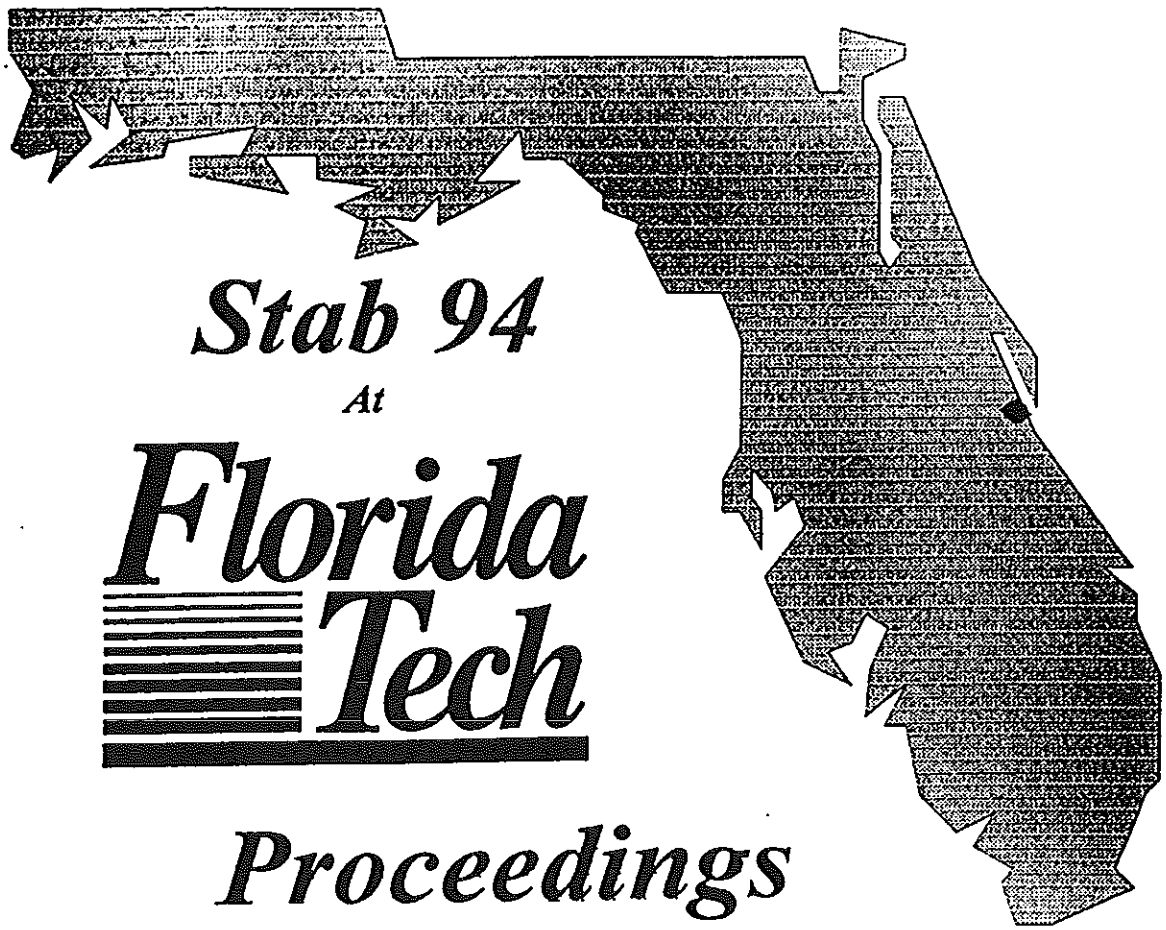
FIFTH INTERNATIONAL CONFERENCE ON STABILITY
OF
SHIPS AND OCEAN VEHICLES

NOVEMBER 7-11, 1994



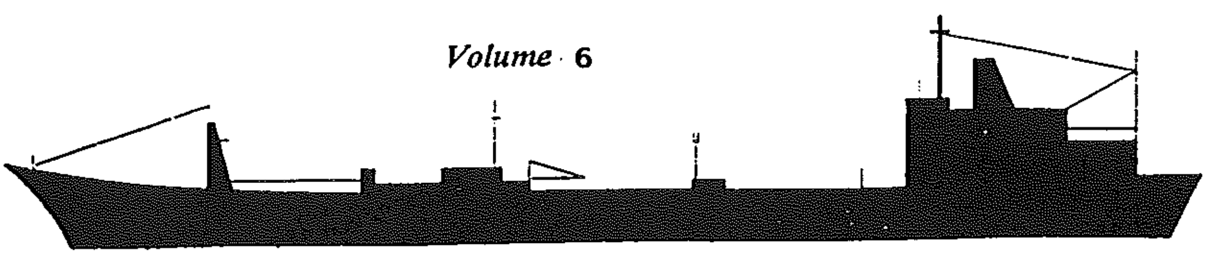
Stab 94

At

Florida Tech

Proceedings

Volume 6



150 W. UNIVERSITY BLVD.
MELBOURNE, FL 32901-6988

FLORIDA INSTITUTE OF TECHNOLOGY

LYNN E. WEAVER, Ph.D. - PRESIDENT

COLLEGE OF ENGINEERING
ROBERT L. SULLIVAN, Ph.D. - DEAN

DIVISION OF MARINE AND ENVIRONMENTAL SYSTEMS
GEORGE A. MAUL, Ph.D. - DIRECTOR

OCEAN ENGINEERING PROGRAM
ANDREW ZBOROWSKI, Ph.D. - CHAIRMAN

WILLIAM R. DALLY, Ph.D.

GRAEME RAE, Ph.D.

GEOFFREY W. J. SWAIN, Ph.D.

LEE HARRIS - ASSOCIATE PROFESSOR

W. A. CLEARY, JR. - ADJUNCT PROFESSOR

PURPOSE OF STAB 94

STAB 94 had been offered to promote a full exchange of ideas and methodologies regarding STABILITY OF SHIPS AND OCEAN VEHICLES and to provide an opportunity to professional naval architects, capsize prevention researcher, regulatory agencies, inspection and certifying authorities, ship owners, consultants and ship operators to present, discuss and listen to improvements in capsize prevention for all types and sizes of ships.

SPONSORS
The Society of Naval Architects and Marine Engineers
The Royal Institution of Naval Architects

TABLE OF CONTENTS

I. Supplementary papers

A. **Recommended Stability Criteria For Passenger-Carrying Submersibles**
Authors: CDR Randall R. Gilbert, Mr. Mark Ganulin

B. **On Probabilistic Qualities of Severe Nonlinear Rolling**
Authors: Dr. V. Belenky, Dr. A. Boukhanovsky

II. Errata

A. **Intact ship survivability in extreme waves: new criteria from a research and navy perspective.**
Authors: Dr J.O. de Kat, R. Brouwer, K.A. McTaggart, W.L. Thomas

B. **Operational Factors in Stability Safety of Ships in Heavy Seas**
Authors: Dr. Grochowalski, Archibald, Connolly, and Lee
(missing page from the paper)

III. Stability workshop summaries

A. **Probability in Stability**
Moderator: Professor L. Kobylinski

B. **Stability of High Speed Ships**
Moderator: Prof. M. R. Renilson

C. **Capsize Treshold**
Moderator: Dr. D. Vassalos

D. **RoRo Safety**
Moderator: Mr. W.A. Cleary

E. **Safety Case**
Moderator: Prof. Chengi Kuo

F. **Information to the Master**
Moderator: Prof. N.N. Rakhmanin

G. **Maneuvering and Survival in Storm Seas**
Moderator: Dr. J.O. de Kat
Co-mod: W.L. Thomas

H. **Human Factors in Stability**
Moderator: Dr. Stephen J. Allen
Co-mod: Professor Chengi Kuo

IV. Formal discussions

V. Replies to discussions

FIFTH INTERNATIONAL CONFERENCE ON STABILITY OF SHIPS AND OCEAN VEHICLES, 7-11 NOVEMBER 1994

Title of Paper: **Recommended Stability Criteria For Passenger-Carrying Submersibles**

Authors: CDR Randall R. Gilbert, USCG
Mr. Mark Ganulin, USCG

Abstract: U.S. passenger-carrying submersibles have enjoyed very safe operations ever since the first one was certificated in 1987. That success can be shared in part by several factors such as overall design, vessel maintenance, controlled operating limits, and well trained operators. One aspect of a submersible that is influenced by all of the factors mentioned above is stability. The stability of a submersible is different in many ways from a surface craft, primarily because the craft submerges below the air-water interface and loses all righting moments due to the effects of the waterplane. It is imperative in a stability analysis that all scenarios be taken into account while the vessel is surfaced, as it submerges and while it is at its operational depth. A logical and comprehensive stability criteria is necessary to provide a uniformly adequate safety margin for all submersibles.

The International Maritime Organization is developing a Code of Safe Operation for Submersibles which will include guidance on stability. In this paper we propose a criteria that was developed for modern passenger-carrying submersibles that are operating in a successful tourist trade today. We cover the development of the criteria, provide samples of its use, and then generalize the scope of the criteria so that it can be used on an international basis.

Commander Randy Gilbert, USCG, is Chief of the Hull Division, USCG Marine Safety Center, Washington, D.C.

Mr. Mark Ganulin is a staff Naval Architect, Hull Division, USCG Marine Safety Center, Washington, D.C.

Introduction

The business of carrying passengers below the surface of the water has blossomed into a multi-million dollar industry in several areas of the world. They have successfully carried passengers on a regular basis in U.S. Territorial Waters since 1987. Nearly all submersibles carry relatively few passengers, to shallow depths, where the coral and marine life are abundant and their brilliant colors are luminesced by clear tropical waters.

Many have drawn a similarity of this burgeoning industry with that of aviation. However, unlike the beginnings of early flight, the passenger-carrying submersible industry has enjoyed nearly accident free operations, with no known deaths that can be attributed to passenger-carrying operations thus far.

Some believe this commendable safety record is due to the technological advances of commercial & research submersibles that have been made in the last several decades. Others claim it is the careful treatment for which passenger submersible operations have received by all parties involved (i.e. designers, builders, owners, operators, regulators, etc.) The authors believe it is a combination of both and we would like nothing better than to see an unblemished safety record continue for all of history. We, therefore, wish to contribute our part to continued safety via this paper, by providing some insight into the sometimes obscure and elusive world of stability of vehicles that operate under the sea. We will then promote our ideas as a recommendation for a stability criteria that may, in the future, be recognized and used internationally.

History

The design and operation of modern submersibles has primarily been limited to this last half century, and only in this last decade has there been increased governmental control through safety regulations. The majority of the early underwater activity had been for military purposes but, following World War II, commercial efforts in research and exploration spawned hundreds of submersible designs and many were built and successfully operated. In the late 1960's, the U.S. Coast Guard (USCG) became involved in the Underwater Safety Project (USP) in order to develop a regulatory safety plan <ref 1, pg 324>. Much was learned and many safety policies were written.

On the heels of the JOHNSON SEA LINK casualty, in which two divers lost their lives <ref 2>, the USCG initiated legislation to obtain authority to regulate manned submersible activity <ref 3>. This bill did not become law for several reasons, primarily because of a strong anti-regulatory lobby. However, the USCG participated in the efforts of the American Bureau of Shipping (ABS) to develop a certification program which was published as guidance in 1968 and as rules in 1979, and most recently in 1990 <ref 1, pg 324; & refs 4-6>. Due to a large reduction in research efforts and a refocus of industrial efforts to remotely operated vehicles (ROVs) the USCG ended their efforts to regulate manned submersibles used for industrial purposes.

The first submersible to earnestly carry passengers was the AUGUSTE PICCARD. From 1964-65, the submersible AUGUSTE PICCARD carried thousands of tourists successfully during the Swiss National Exposition <ref 1>. However, it was unable to continue and relatively little commercial tourist trade existed until the mid 1980's. In 1986, the USCG was approached by Sub-Aquatics Corporation, to certificate a submersible similar to one they had operated successfully in the Cayman Islands since 1985. Since the ATLANTIS III submersible was to carry passengers in U.S. Territorial waters, the U.S. Inspection Laws for commercial vessels carrying more than 6 passengers would apply.

As a quick aside, the U.S. Passenger Vessel Safety Act of 1993, has broadened the scope of U.S. Coast Guard responsibilities to cover any underwater vehicle carrying 1 or more passengers for hire. We see this as a trend worldwide and will, therefore, treat all passenger carrying submersibles, big and small, alike in this paper.

Numerous safety concerns, well beyond the scope and intent of the U.S. Regulations for Small Passenger Vessels (Title 46 Code of Federal Regulations, Subchapter T), had to be ironed out by the designers of the ATLANTIS III and the USCG, in order to ensure that an adequate level of protection from harm was provided to the public <ref. 1, pg 325>. Fortunately, the small passenger vessel regulations allow for a variation from specific requirements when a strict application is not reasonable or practical, and an equivalent level of safety can be demonstrated. After many months of inspecting and testing, the USCG certificated its first passenger carrying submersibles in 1987, when the ATLANTIS III received its Certificate Of Inspection (COI) for operations off of St. Thomas, U.S. Virgin Islands.

During the plan approval process of the ATLANTIS III, the absence of a suitable, well-defined stability criteria to be used for passenger submersible operations, was most notable and received a large amount of attention. Much of the process of weaving together a comprehensive stability criteria consisted of researching the hazards of underwater operations and learning what criteria had been used for military submarines and for commercial and research submersibles.

Although passenger-carrying submersibles have enjoyed a nearly perfect safety record, there were several casualties to commercial dive submersibles that related to the stability of passenger carrying submersibles. The USCG used this information to develop suitable requirements for stability criteria. For example, the incidents of the SP-350 in 1959, the DEEPSTAR 4000 in 1966, and the PISCES III IN 1971, demonstrated the need for emergency drop weights and positive buoyancy <ref. 7, pgs 686-688>.

In 1987, the USCG published "Guidelines for the Stability of Small Passenger Submersibles," which is now incorporated in their Navigation and Vessel Inspection Circular No. 5-93 (NVIC-5/93) "Guidance For Certification Of Passenger Carrying Submersibles" as Enclosure (2). <ref. 8>

Submersible vs. Submarine

While conducting research, one must take into account the differences between vessels which are commonly called submarines verses ones called submersibles. The major difference, as regards stability, is that a submersible tends to "float" in the water like a balloon, while a submarine must travel relatively faster so it can be maneuvered as if "flying" through the water. When separating the subject of Hydromechanical Principles, for submersible we can concentrate primarily on hydrostatics and leave hydrodynamics to the design of the propulsion and control systems.

Some other differences which generally separate the two are: 1) the submarine is much more streamlined and therefore, the arrangements of ballast and trim tanks are different; 2) submarines are usually an order of magnitude larger so to accommodate large & heavy propulsion systems. Military submarines, in particular, have very large support systems and can remain below the surface almost indefinitely by themselves. Submersibles, on the other hand, have need for significant support services separate from themselves. None routinely operate in the open ocean without surface support and some shore support <ref 7, pg 13>.

Tourist vs Industrial Subs

For this paper we further break down the category of submersible into two types, Passenger and Industrial, in order that we might focus only on those involved in the relatively new tourist trade. The passenger carrying submersibles have evolved into markedly different vessels from the submersibles involved in exploration, research and industrial uses. In general, passenger submersibles operate at shallower depths and make several dives per day in a designated operating area. The pressure hull and ballast tanks are usually larger because of the larger & variable size of the payload (i.e. passengers carried during each trip). The pressure hull must also be large enough to have a redundancy in certain safety and life support systems and to accommodate many large viewing ports.

There are other differences which the reader should be aware of in order to better understand the passenger submersible. We summarize the more important ones.

Shallow vs Deep Operations

The U.S. Coast Guard requires emergency surface craft support for passenger submersible operations with diver assistance, which has thus far, precluded deep diving operations in U.S. waters. <ref. 8, encl (1) pg 29> Although the passenger submersible itself can be, and has been, designed to go much deeper than 45 meters (150 feet), the requirement for open dive support has become a de facto limiting design factor.

Stability while fully submerged

While submerged, Buoyancy Equilibrium and Statical Stability, can both be considered as a simple two-force system. One force being the total Weight (W) of the submersible, the second force being the Displaced volume of water weight (D) of the submersible system <ref. 10, pg. 210>. For discussion, the components W and D, are separate forces interacting with each other to form a safe controllable system. The second of the two forces is commonly referred to as Buoyancy (B); however, buoyancy is actually the difference between the two forces and is at equilibrium when W equals D.

When on the surface, D will rapidly adjust to always equal W, because we have what is called positive or reserve buoyancy. However, when fully submerged, D and W must be adjusted via the use of ballast tanks or physical weights in order to control buoyancy so that buoyancy is either neutral or slightly positive. It is a requirement for USCG certificated passenger submersibles to operate with a slightly positive buoyancy <ref 8, encl 2, page 7>. Vertical thrusters are employed to push the submersible deeper into the water. Thus, if there is a power failure in the propulsion system, the submersible will return safely to the surface.

When the submersible is fully submerged, the upward force that collectively acts at the center of all volumes displacing water, tends to move the submersible towards the surface. It is exactly equal to the total weight of the water displaced by all of the buoyant volumes. This displacement force is relatively constant for a submersible fully submerged under the surface of the water. When this upward force is greater than the collective downward gravitational force of the mass of the submersible W, the submersible is said to have positive buoyancy B and it will rise towards the surface (absent any thruster forces keeping it down). If, however, the weight W of the submersible is greater than D of the submersible, it has negative buoyancy and will descend deeper into the water. Since balance must be maintained in order to control the movement of the submersible, ballast tanks are employed to adjust W.

Most submersibles have two different types of ballast tanks, hard and soft. Hard ballast tanks are closed, "hard piped", water tanks which can withstand the external pressures of the water at the submersible's rated depth. Hard ballast tanks are primarily used to add or subtract weight in small, measurable increments in order to adjust for the variable payload of passengers. The soft ballast tanks are free flooding and are usually used to provide a variable for displacement. They must be sufficient for keeping the submersible safely on the surface during passenger transfer and transit.

While under the surface, stability of a submersible is directly related to the centers of buoyancy B (equals D) and the center of gravity G (equals W) <ref 10 pg 218>. Referring to figure 1, you can note the submersible is termed stable when B is in a vertical line directly above G (B-G is positive). When the submersible is stable it will tend to return to equilibrium in a spring or oscillatory fashion when disturbed by outside forces.

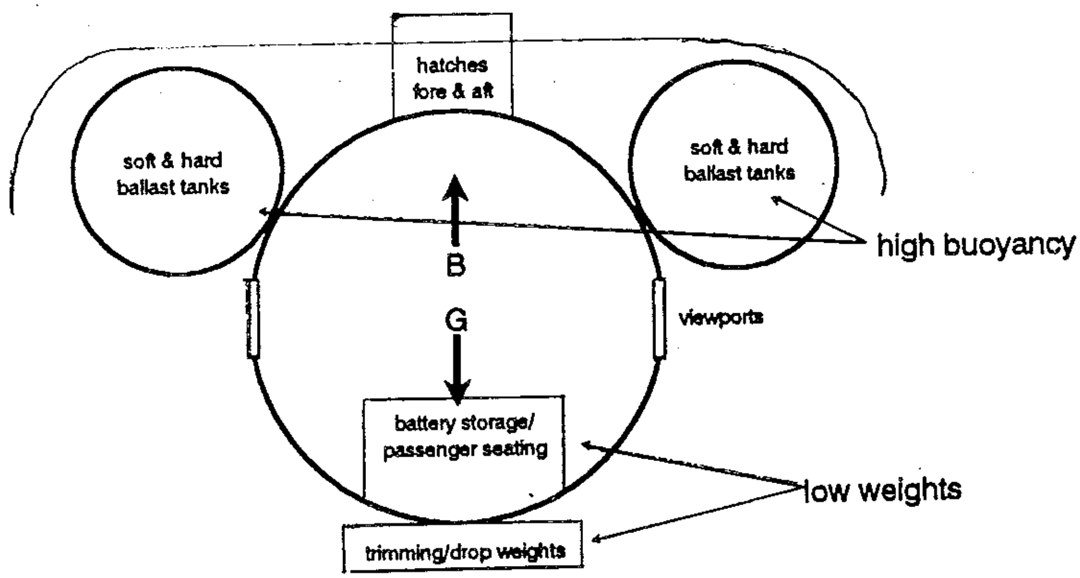


Figure 1

It is important to note that the lever arm created when the center of gravity shifts, is the same in all horizontal directions (i.e. both the longitudinal or transverse). However, if the hard ballast tanks are partially filled, the virtual rise in the center of gravity, caused by free surface effects, will be larger for ballast tanks that are oriented in a fore and aft direction. It takes less effort to trim a submersible than to heel it, thus the longitudinal stability of a submerged submersible is always more critical.

A righting moment is created when G is moved and no longer directly below B. The horizontal distance between the two vertical forces B and G, is the lever arm. The righting lever distance (Z), coupled with the weight of the submersible, (not the positive buoyant force which is zero when the sub is neutrally buoyant) causes a moment tending to right the submersible back to equilibrium. Refer to figure 2 to see the effect of a forward seated passenger who has just walked aft.

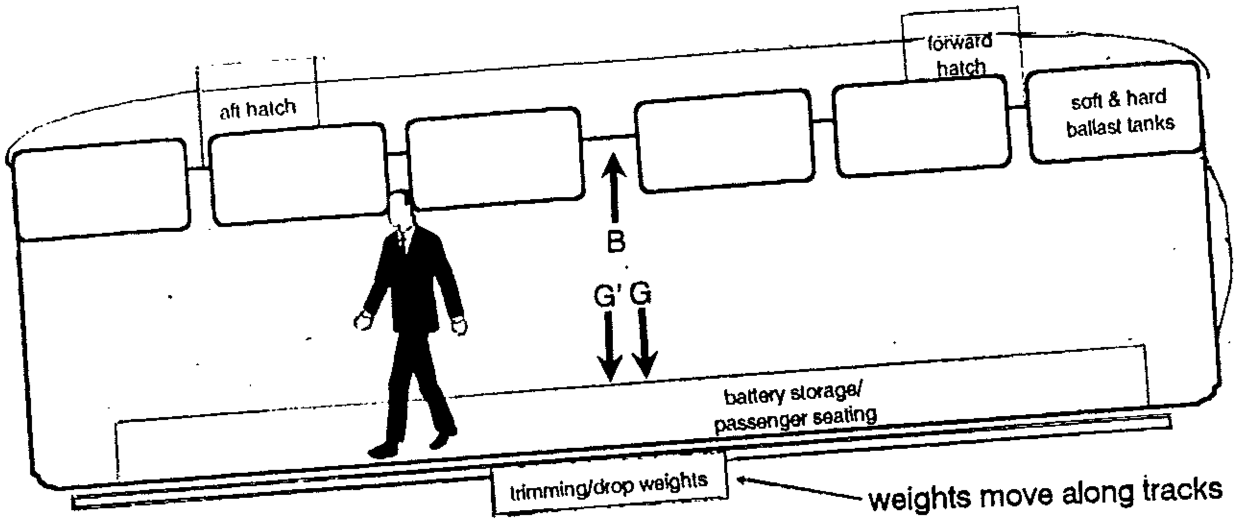


Figure 2

For passenger carrying submersibles, unrestricted passenger movement causes the largest and most hazardous inclinations. It is, therefore, reasonable, to set the submersible operational limits by maximum passenger heeling moments. For submersibles provided with fixed seating which is capable of keeping people from being displaced up to fairly large angles, the limits can be quite reasonable. A USCG certificated submersible must always maintain a minimum level of positive stability (GB), in order to counteract the movement of 10% of the passengers moving, not allowing the submersible to trim greater than 25 degrees <ref. 8, encl. 2, pg 15>. It is important to reiterate that seats must be provided for each passenger and they are required to remain seated throughout the entire trip.

A weight shifting system must be employed to reverse the effect of an unequal weight distribution which causes an unbalanced trimming attitude longitudinally. The submersible pilot is thus able to bring the submersible back to level. There are a variety of trimming methods employed. One common method uses a large weight which is shifted longitudinally along rails or tracks. Other systems use hard ballast tanks and shift water longitudinally. Hazardous moments could occur if the trimming weights were inadvertently shifted in the wrong direction, so the pilot must be specially trained and alert at all times.

During the design of the submersible there are certain other hazards which must be considered. One obvious hazard is the accidental flooding of one or more of the ballast tanks. Thus, sufficient reserve buoyancy is added to the soft ballast tanks to return the vessel safely to the surface. A USCG certificated submersible must have, in addition to the reserve soft ballast tanks, an emergency physical weight jettison system (drop weights) sufficient to ensure that the submersible will return to the surface with enough freeboard to open its hatches when the largest pair of ballast tanks is flooded or inoperable <ref 8, encl 1, pg 26>.

Dropping of the emergency drop weight can also become a hazard to stability. Since this weight is usually located near the bottom of the submersible, it can have a very detrimental effect on the center of gravity. The effect of actually letting-go the drop weight should be either calculated or tested while the submersible is under the surface <ref. 9, pg 24>.

<u>Simplified Criteria Developed for the ATLANTIS III</u>

During the initial stages of developing the stability criteria, for which USCG certificated passenger submersibles would be judged, a computer model for calculating hydrostatic properties was generated. Because of the necessity for detail and the complexity of shapes, particularly in the exo structure, the task was difficult and complicated. However, it was learned through this experience that, if a submersible was designed within certain parameters and arrangement of ballast tanks, B was always above G and the complex model was unnecessary. The problem of verifying that the submersible has sufficient stability was therefore reduced to operational tests and spreadsheet calculations, verified by a submerged inclining experiment.

By employing a spreadsheet, the designer can calculate with some degree of certainty, the submersibles weight and displacement and corresponding centers. By using this spreadsheet, the designer can demonstrate that G-B actual is greater than G-B minimum in all cases of normal and emergency operations below the surface. Refer to figure 3 to see a sample of a typical spreadsheet format.

Since there are always minute differences in the estimated weights and displacements entered into the spreadsheet, an underwater inclining experiment is conducted to obtain the actual G-B. Using the actual G-B, a small adjustment is then made to the calculated centers. The new adjusted centers are then used for all loading conditions to ensure G-B minimum is maintained during all operations.

WEIGHTS

Description	Weight	Position			Moment		
	W (kg)	X (m)	Y (m)	Z (m)	W * X (kg-m)	W * Y (kg-m)	W * Z (kg-m)
MAIN HULL							
Main Hull - Less Cutouts	26848.00	49.72	10.00	10.00	1334882.56	268480.00	268480.00
Fwd Sphere - Less Cutouts	1688.00	27.50	10.00	10.00	46420.00	16880.00	16880.00
Aft Sphere - Less Cutouts	1609.00	73.00	10.00	10.00	117457.00	16090.00	16090.00

DISPLACEMENTS

Description	Displacm't	Position			Moment		
	D (kg)	X (m)	Y (m)	Z (m)	D * X (kg-m)	D * Y (kg-m)	D * Z (kg-m)
MAIN HULL							
Main Hull - Less Cutouts	109727.00	47.92	10.00	10.00	5455626.44	1097270.00	1097270.00
Fwd Sphere - Less Cutouts	5721.00	27.25	10.00	10.00	155897.25	57210.00	57210.00
Aft Sphere - Less Cutouts	6070.00	73.00	10.00	10.00	443110.00	60700.00	60700.00

Figure 3

Stability on the Surface

A submersible is said to be on the surface when a sufficiently large portion of the buoyant volumes (hull and/or ballast tanks) is above the surface, creating a consistent waterplane area and reserve buoyancy. The water plane creates a corresponding moment of inertia (I), which can be calculated in both the longitudinal and transverse directions. The moment of inertia creates a metacenter (M), about which the center of buoyancy rotates for small angles of heel and trim. Refer to figure 4, to see how stability on the surface is governed by the distance of M from G (GM). M must be higher than G (positive GM) in order for the submersible to be stable.

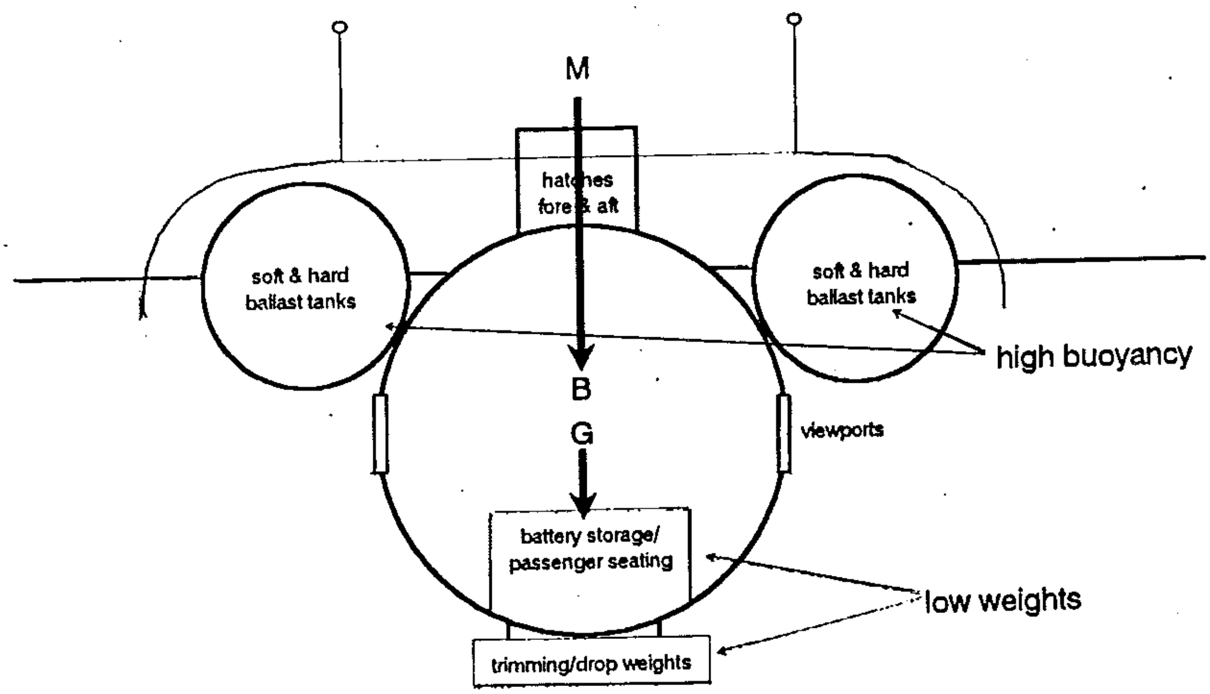


Figure 4

Unlike stability under the surface, transverse GM is quite different from the longitudinal direction. For most submersibles, the intersection of the waterplane along the hull and the ballast tanks is much greater in the longitudinal direction, so GM longitudinal is much larger than GM transverse. Thus, surface stability is usually only critical in the transverse direction. However, if passenger movement along the decks is unrestricted in the longitudinal direction, stability must be checked in both directions.

It is very important to consider the effects of moving passengers on and off the submersible. The hard ballast tanks should be adjusted to provide maximum stability during the operation. Particular attention should be given to on-loading passengers in a balanced and regimented fashion.

Although most submersible operations take place in balmy benign weather, it does not preclude more severe weather due to sudden squalls and storms. While on the surface, there are external wind and wave forces which can act to cause severe overturning moments. The submersible must have sufficient stability to withstand these heeling moments.

Depending on the design of the hatches and deck wetness, the maximum sea state can be further limited. USCG certificated passenger vessels are also limited to operations within a maximum sea state and the hatches must be high enough to prevent overtopping by 1.2 meter waves <ref 8, encl 2, pg 5>. Although the still water GM is generally much larger in the longitudinal direction, synchronous pitch heave motions have been observed on existing submersibles. Therefore, the critical motion of the submersible should be checked in both the longitudinal and transverse directions in order to set a limit to the operating sea state.

Stability while submerging below the surface

One of the most critical, and difficult aspects of the stability of a submersible is the transition between being on the surface and submerging below. As a submersible reduces its buoyancy, it begins to lose its freeboard and waterplane area. At the point where the moment of inertia of the waterplane area rapidly decreases, the metacenter M moves toward the center of buoyancy B. If G remained well below B while the submersible was on the surface the whole evolution will remain stable. This can be assumed if the soft ballast tanks are above the mid-height of the main pressure hull and the batteries are installed below it.

For designs in which G can be at or above B when on the surface, stability can become tenuous upon submergence. Refering to figure 5, you can see that if the passenger load is not balanced longitudinally and the soft ballast tanks are released in a fashion which would relieve the buoyancy at the opposite

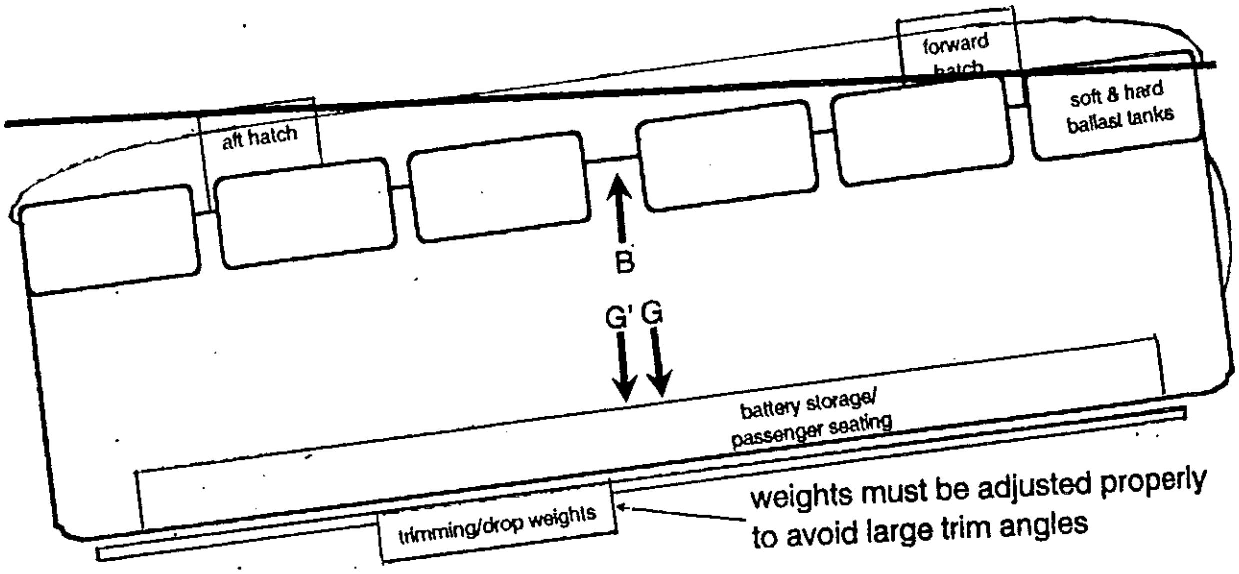


Figure 5

end, there is a critical period when there could be a large enough shift in the waterplane, the effect of which would cause very large trim angles. This danger can be minimized by an orderly sequence of deballasting soft ballast tanks through the descent and distributing passengers so there weight is centered near the center of buoyancy of the submersible.

Another obvious danger while submerging, is an improperly secured hatch not made watertight, thus becoming a rapid downflooding point. This danger can be easily mitigated through strict operational control and redundant safety checks prior to submerging.

Other hazards to consider

The "closed and locked-in" nature of submersibles severly limits the ability for self rescue. However, many of the emergencies such as minor flooding, being stranded on the bottom, loss of electrical or pneumatic systems, etc. can be mitigated through smart designs and planning for them from the beginning. In his book Manned Submersibles, Frank Busby thoroughly covers emergency devices and recommended procedures <ref 7, pgs 651-684>. We believe that as many of these devices as possible should be incorporated into designs. Some of the devices for emergency ascent should be required for all passenger-carrying submersibles. The devices which allow for external diver assistance are highly recommended and have proved lifesaving in many emergencies reported on other manned submersibles. However, a device used for pressurizing the hull and evacuating persons while submerged, should not be allowed to be used while the submersible is carrying passengers.

Recommended Criteria for Int'l Use

The following criteria are recommended to be used by designers, class societies and regulators for submersibles carrying passengers. Although it does not cover all conceivable operations, it is suitable for current operations with which the authors are familiar. We have tried to maintain a balance between simplicity and thoroughness.

1. Controlability. All passenger carrying submersibles are to be designed with at least two independent methods of controlling the balance between the vessels weight and displacement. The systems may be integrated to accomplish both deballasting and trimming functions. One method of deballasting must be provided with a means of being operated from inside the submersible with no electrical power available.

1.1. Design and Testing: The submersible must be designed and shown by operational testing to be capable of remaining at any fixed depth within its operational limits in all normal operating conditions. Adequate thruster control shall be provided so the submersible will be able to descend and still have positive buoyancy in the event the electrical power is lost. Manuevering thrusters shall be positioned so that when they are set at full power the submersible will turn smoothly without causing significant heeling or trimming moments. The center of the soft ballast tanks must be located above the mid-height of the main pressure hull. If hard ballast tanks are installed inside the main pressure hull, the venting system must be designed to prevent accidental flooding. During operational testing, the maximum trim angles that are achieved when using maximum trimming moments should be noted. The angles should be at least 25 degrees or the maximum allowable used in the underwater stability criteria.

2. Underwater stability. Adequate static and dynamic stability in the submerged condition is to be provided such that the submersible, in all normal operational conditions of loading & ballast, maintains the center of buoyancy above the center of gravity by a distance (GB) which is greater than .051 metres (2 inches) or the height as determined by:

GB $\geq$ n * w * N * d / (W * tan@), where:

n = 0.1 (represents 10% of the passengers moving)
w = 72.5 Kg (160 lbs) per person at .76 meters above the deck
N = total number of passengers
d = interior length of the passenger cabin (same units as GB)
W = total Weight of the sub, not including soft ballast water (same units as w)
@ = angle of 25 degrees or the safe trim angle allowable taking into account battery spillage, passenger seat design, or malfunction of essential equipment.

2.1. Design & Testing: The submersible must be designed & shown by calculations and operational testing to be capable of maintaining the above requirements. The following calculations and tests should be required as a minimum:

2.1.1. There shall be provided a spreadsheet of calculations for both weights and displacements. It is recommended that the spreadsheets be created during the design and construction of the submersible. They shall useable to demonstrate that the center of displacements (buoyancy) is always above the center of gravity by the required amount for all loading conditions. It is important to use the lost buoyancy method for including the soft ballast tanks (i.e. the internal volume of the soft ballast tanks are not included in the buoyancy spreadsheet and the weight of water in them is not included in the weights spreadsheet).

2.1.2. A deadweight survey and lightship measurement shall be conducted to verify the spreadsheet calculations. This shall be accomplished after the submersible is 100% complete and the arrangement of solid ballast has been finalized. The location, number and size of all items listed on the spreadsheet should be physically checked. The weight of the submersible can be determined by being weighed on a scale or its afloat waterline measured and used in conjunction with the hydrostatic model.

2.1.3. An inclining experiment shall be conducted to determine the vertical centers of gravity. Because of the complexity of the exo-structure and ballast tank arrangements of most submersibles, a submerged inclining is preferred. If the inclining experiment is conducted on the surface, very detailed modeling is necessary and attention to detail must be given throughout the evolution. For submerged inclinings, the submersible shall be tethered to a small buoy by maintaining a slightly negative buoyancy. Attention should be paid to recording the longitudinal position of all trim weights so the LCG can be established. The spreadsheet weight calculations should be adjusted for any minor difference found between the center of gravity determined by the inclining and that of the spreadsheet.

3. <u>Intact surface stability and while submerging</u>. All submersibles shall have at least one deck hatch and those which have a main pressure hull longer than 5 meters (16.4 feet) shall have at least two. The deck hatches shall be arranged on the deck so they are at least .75 meters (2.5 feet) above the maximum load waterline and will not take in water when the submersible is subject to rolls expected under seastate 3. The soft ballast tanks shall be sized and arranged so that the submersible has sufficient static and dynamic stability and adequate freeboard to ensure the safe transfer of passengers in the worst expected operational sea state. It shall be shown that the submersible, in the surfaced condition, has a GM transverse that is greater than .102 meters (4 inches) or the height as determined by:

GM $\geq$ n * w * N * d / (W tan@), where:

n = 0.33 (represents 33% of the passengers moving)
w = 72.5 Kg (160 lbs) per person
N = total number of passengers
d = distance to the outermost limits which passengers are allowed while on deck (same units as GM)
W = total Weight of the unit (same units as w)
@ = lessor angle of 14 degrees or the angle of heel at which the exo structure deck edge first submerges or when the top of the soft ballast tanks completely submerge.

3.1. Design and Testing: The submersible must be designed and shown by calculations and/or operational testing to be capable of maintaining the above requirements. The calculations of 3.1.1 can be dispenced with if the proof test of 3.1.2 is accomplished or the submersible is designed such that the passengers are restrained on deck by rails or guards to an area between the loading hatches which is no larger than N * .21 square meters (2.3 square feet).

3.1.1. Show by calculations using the hydrostatic information and spreadsheet of weights developed for the underwater portion, that GM transverse is greater than the amount required in 3. above and the mean freeboard is greater than .2 meters (8 inches)

3.1.2 Conduct the following test after completing the inclining experiment so that all solid weights are arranged in their final operation position. The hard ballast tanks should be filled to their operational levels with which the maximum number of persons are on board. Soft ballast tanks shall be blown dry so maximum freeboard is attained.

3.1.2.1 Place weights representing the maximum number of persons allowed (w * N) on the embarkation deck, so they are distributed about the center of the deck area at a height equal to the center of standing passengers (.91 meters or 3 feet). The mean freeboard to the top of the soft ballast tanks shall be at least .2 meters (8 inches)

3.1.2.2 Move the weights transversely representing a moment equal to 33% of the maximum number of persons times the distance to the outermost limits which passengers are allowed while on deck (.33 * w * N * b). In this condition, the angle of heel shall not exceed 14 degrees or the angle at which the exo structure deck edge first submerges or the angle at which the top of the soft ballast tanks completely submerges.

3.2 If, while on the surface with all soft ballast tanks blown, it is determined that the center of buoyancy is below the center of gravity, further investigations must be performed to show the submersible submerges below the surface without causing extreme motions or taking severe angles of heel or trim. This can be accomplished by operational testing or by calculations. The hard ballast and trimming systems shall be capable of controlling the weight of the submersible so that adjustments can be made rapidly to balance the buoyancy as the vessel submerges.

4. Emergency and Damage Condition Provisions. The submersible shall be outfitted with systems and fittings designed to mitigate emergency situations as outlined in the following sections.

4.1 Rapid surfacing. Should an emergency exist during operations while submerged, which would require the submersible to return rapidly to the surface, systems and associated controls shall be provided such that all soft ballast tanks can be blown simultaneously. The procedure for rapid ascent should be tested from various depths including the maximum rated depth. The time from the beginning of the procedure shall be plotted versus depth to obtain the maximum ascent speed. The motion and attitude during the ascent should be noted.

4.2 Emergency surfacing. Should an emergency such as minor flooding or ballast system malfunciton exist, systems shall be provided to give the submersible emergency surfacing capabilities separate from the methods used in normal operations. The system outlined in 4.2.1 is required. The systems outlined in 4.2.2 and 4.2.3 (and any others similar in intent) are recommended for submersibles carrying large numbers of passengers. All installed systems shall be designed such that the submersible has adequate stability and freeboard when the systems are activiated and that will allow for passengers to be evacuated from at least one of the deck hatches.

4.2.1 A system shall be installed which is capable of jettisoning sufficient mass (drop weight system) so that the submersible is able to ascend to the surface when the largest single volume, other than the main pressure hull, is flooded. The drop weight system activation shall have at least two separate manual actions, both independent of electrical power. If it is practical, this drop weight system should be tested in the water to verify the submersible does not attain a list or trim such that the hatches cannot be opened safely. The ascent rate should be plotted as in 4.1.1 above and the motion and attitude during the ascent should be noted. If it is not practical to test the drop weights in the water, they shall be operationally tested in the drydock and calculations shall be conducted showing the submersible has sufficient stability under any possible combination of dropped weights.

4.2.2 When the submersible is operated over depths not greater than 45 meters (150 feet), it is recommended that provisions be made for divers outside of the submersible to activate valves in the soft ballast system. In addition, fittings should be provide such that air from external scuba tanks can be used to blow the soft ballast tanks.

4.2.3. It is recommended that the external structure of the submersible be designed such that divers or remotely operated vehicles could easily attach lifting cables, salvage bags, etc. The position of such hooks, cleats and shackles shall be such that they will not easily snag objects in the operational area of the submersible and that, when used, will allow the deck hatches to remain clear for rapid evacuation.

Summary and Looking Into The Future

As of late, much discussion has taken place as to the importance of the human element in the operational safety of marine vehicles. Although it is necessary to design a submersible so it can operate with adequate stability, there is little said about how much safety is inherent in the design and how much is directly attributed to the keen skill of the pilot. We understand that there are many factors such as economics, overall weight, ease of maintenance, passenger comfort, etc. that will be considered in the design process. However, it is our hope, that designers will optimize stability to be nearly "fail-safe," so that submersible pilots and crew can give more attention to manuvering safely and ensuring that each of the numerous checks necessary for critical systems are accomplished.

We are aware of efforts underway at IMO to develop "Guidelines For Design, Construction and Operating Of Passenger Submersible Craft". It is our hope, that we have contributed to that effort through this paper, in order to facilitate it being both comprehensive and timely. We believe that the criteria proposed, is technically sound and easy to use during the submersibles construction and the administrative design review by the flag state.

References

1. Johnson, S. and Salerno B. - 1990. U.S. Coast Guard Regulation of Passenger Carrying Submersibles. Presented to Chesapeake Section, SNAME, March 13, 1990. Marine Technology, November 1991

2. National Transportation Safety Board - 1973. Entanglement of the Submersible JOHNSON SEA LINK With Submerged Wreckage Off Key West Florida on or about 17 June 1973 With Loss Of Life. Report No. USCG/NTSB MAR-75-2

3. 93rd Congress 1st Session - 1973. Washington, DC

4. American Bureau of Shipping - 1968. Guide for Classification of Manned Submersibles. ABS, New York, NY

5. American Bureau of Shipping - 1979. Rules for Building and Classing Underwater Vehicles & Systems. ABS, New York, NY

6. American Bureau of Shipping - 1990. Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities. ABS Americas, Houston, TX

7. Busby, F. - 1976. Manned Submersibles. Office of the Oceanographer of the Navy, Arlington, VA

8. U.S. Coast Guard Navigation and Inspection Circular (NVIC) 5-93. "Guidance For Certification Of Passenger Carrying Submersibles".

9. Transportation System Center - 1989. Passenger Carrying Submersibles: System Safety Analysis, Report No. CG-M-4-49, Final Report, August 1989. U.S. Department of Transportation, Washington, D.C.

10. Society of Naval Architects and Marine Engineers (SNAME) - 1990. Submersible Vehicle Systems Design. SNAME, New Jersey City, NJ

11. Society of Naval Architects and Marine Engineers (SNAME) - 1993. International Safety Standard Guidelines For The Operation Of Tourist Submersibles. SNAME, New Jersey City, NJ

Dr. V. Belenky, Technical University of Kaliningrad, Russia
Dr.A.Degtyarev, A. Boukhanovsky Marine Technical University, St.Petersburg, Russia

On Probabilistic Qualities of Severe Nonlinear Rolling

1. Knowledge of probabilistic qualities of severe nonlinear rolling is required for the formulation of the adequate model of capsizing in irregular waves. So it is necessary to revise probabilistic description of rolling which was developed for linear systems.

2. The distribution probability density strongly depends on the GZ curve form [1]. If the GZ curve has so-called "S - shape" form the probability distribution is non-Gaussian and can be described by Gram-Charlier expansion [2,3]. If the GZ curve has conventional form the distribution can be considered as Gaussian. The explanation of this phenomenon is that the ship spends more time near upright position equilibrium during her roll oscillations. If the GZ curve has "S - shape" form, the non-linearity near upright position has big influence on rolling distribution. If the GZ curve has no "S - shape" form, the non-linearity near maximal point of the diagram has small influence on the rolling distribution.[1]

3. The ergotic qualities of nonlinear rolling also should be questioned. Theoretically if we have nonlinear system with stationary ergotic input, we have no background to consider output as ergotic process as well. So we can not judge about probabilistic characteristics of nonlinear rolling by the realization from the whole ensemble only. The hypothesis of possible ergotic qualities of nonlinear rolling was disapproved by the authors independently using different models of irregular waves. V. Belenky has used the traditional model of irregular waves in form of Furrier series:

$$\varsigma_w(t) = \sum_{j=1}^{N} r_{oi} \sin(\sigma_i t + \varphi_{oi})$$

where amplitude r_{oi} according to frequency σ_i is taken from the proper spectrum, and φ_{oi} is the random number with constant distribution in range $[0,2\pi]$

A. Dgtyarev and A. Boukhanovsky have used "auto correlation" model of irregular wave [4]

$$\varsigma_w(t_i) = \sum_{j=1}^{N} \Phi_j \cdot \varsigma_w(t_{i-j}) + \varepsilon(t)$$

where $\varepsilon(t)$ is Gaussian white noise, coefficient Φ_j expresses auto-correlation relationship between value in moment t_i and in a moment t_{i-j}; this coefficient can be obtained by auto-correlation function.

All authors further simulated severe non-linear rolling by the numerical integration of proper nonlinear differential equation long enough and obtained different values for statistical moments for different realizations of input processes. All the authors repeated these calculations for linear dynamic systems and learned that described phenomenon can be associated with presence of severe nonlinear term in rolling equation. This phenomenon could be physically explained by possibility of bifurcation in nonlinear systems.

Acknowledgement.

The valuable advice and assistance of Dr. Alexander Degtyarev during the preparation of this paper is acknowledged and is greatly appreciated.

References

1. Belenky V.L., Calculation of Ship Capsize Risk Function in Beam Seas and Wind, Proc of International Workshop OTRADNOYE '93, Kaliningrad, 1993 paper No6, volume 1.

2. Haddara M.R., Zhang Y. On the Joint Probability Density Function of Non-linear Rolling Motion, Journal of Sound and Vibration (1994) 169(4), pp.562-569.

3. Belenky V.L. Piece-Wise Linear Methods for the Probabilistic Stability Assessment for Ship in a Seaway, Proc. of STAB '94, vol.5, Melbourne, Florida 1994.

4. Gurgendze A.T. Trapeznikov Yu. A. Probabilistic Models of Wind inducted waves, in book Theoretical foundation and calculation methods of wind inducted waves, Gidrometeoizdat, 1988, pp. 8-23 (in Russian)

5. Proceedings of the International Workshop of Mathematical and Stability Modelings, OTRADNOYE '93. Kaliningrad Technical Institute, Vol. 1 1993.

6. Proceedings of the International Workshop of Mathematical and Stability Modelings, OTRADNOYE '93. Kaliningrad Technical Institute, Vol. 2 1994.

Changben Jiang, University of Michigan, USA

The difficulties of ship capsizing study come from at least three areas: the randomness of the seas, the determination of the hydrodynamic forces, the solution of the highly nonlinear large amplitude ship motion equations. However, the challenges do not necessary mean that nothing can be done. Recently, under a joint research program of the University of Michigan and Michigan State University, a probabilistic nonlinear systems analysis method has been used to study the onset of capsize and the probability of capsize.

The results agree well with simulations. An application of this method to small fishing vessels will be presented on Wednesday in this Conference.

Dr. S. Grochowlski, NRC Canada

In general, I am not a great enthusiast of stability safety criteria based on probabilistic approach. Although wave conditions and wind have a probabilistic character, the behavior of a ship in conditions met is deterministic, i.e. ship response is strictly determined by wave profile acting on a ship at a given time and the ships inherent dynamic characteristics.

Therefore, probabilistic is the occurrence of certain wave and wind conditions, while ship response to those conditions is deterministic.

The probabilistic criteria are only as good as the deterministic model of ship dynamics in waves as good. Therefore, the main efforts should be dedicated to development of adequate deterministic model of ship capsizing in most severe, yet realistic wave conditions, and then the probability of occurrence of such conditions should be used in the transformation from the deterministic to probabilistic model.

The deterministic model should consider combination of various dangerous physical phenomena which usually may cause capsize.

There is probability to develop time criteria based on statistics from capsizing tests and full scale disasters. This, however, would require a huge data base developed fro various ships types. Furthermore the pure statistical approach is always based on some averaging process, which may leave a real ship in danger outside the statistical criteria.

I would like to emphasize that the physics of capsizing and an adequate deterministic model has to be developed first, before any probabilistic model could be considered as reliable.

S.Mordachov, Prof. N.Sevastianov, Dr. V. Belenky, Technical University of Kaliningrad, Russia

Assumed Situations in Probabilistic Norms of Stability

Probabilistic approach to stability norms supposes a stochastic description of set of external factors influencing on a ship. This sets also named as assumed situation Prof. Sevastianov suggested a concept of a vector of assumed situation S. To get practical calculability assumed situations have to make discrete.

However, due to a big quantity of parameters, number of calculations will be obtained too huge. The aim of this research work is to receive practical method of calculation of probabilities of assumed situation realization during ship's lifetime(or during other relevant period). The way to obtain it is described below.

We should write the vector S as a sum of two auxiliary subvectors: a vector of waves and wind(meteorological) and a vector of ship speed, heading and additional forces (operational). The first vector characterizes environmental weather condition, the second one characterizes circumstances of service, which are also depend on human will.

We can write same of possible components of vector. The component should be analyzed from the point of view of their independence on each other and of degree of their ability of varying in time. It helps us to reduce significantly number of calculations.

Such independence of arguments of the subvector of waves and wind can be found by analyzing meteorological statistical data. Arguments of the subvector of ship loading and additional forces are depend on human will and circumstances of vessel operation.

Their interdependency can be investigated by introducing some models of human behavior strategies.

Meteorological data today is results of long term observation averaged and represented by tables of special forms for certain season and geographical region. As a typical example of such data, handbook "Wind and Waves in Seas and Oceans" issued by Russian Register can be taken.

These tables contain data on statistical frequency (statistical probability) of meeting certain characteristics of wave height, mean wave period, mean wave velocity and wind direction. Data of correlation of these random values can be found only for several regions.

We take mean value of wind velocity as starting point for searching mentioned above interdependence, because wind is physical reason of waves at sea. Further we can get all other characteristics by using dependencies mentioned above.

So as meteorological factors is bind to geographical coordinates, we should use a concept of ship's route to obtain schedule of assumed situations. Time when ship is under given assumed situation is proportional to probability of assumed situation realization. But operational components (second) could be received only by taking into account human behavior.

Operating a ship, master chooses heading speed and course angle in absolute (geographical) coordinates. Making such a decision, master is aiming in reach his destination port in time and to avoid danger, which is treating to the ship and people on her board. In a real life such decision should be made to reach some kind of balance between safety and efficiency, between money and life. A level, where such balance is established, is dependent on huge number of circumstances, including economical reasons and human mind. By other words, human factor is more significant in this part of stability safety, and, evidently, probabilistic approach to stability could not be developed without taking human factor into account.

We can set some very simple assumptions, which make possible to cover majority of master's behavior that could be imagined. Such variants of behavior or strategies could be defined as follows:

1. "careful" strategy assumes that course and speed should be chosen to minimize risk of capsizing. Only one limitation should be taken into account: a ship should reach her destination after finite time.

2. "mercantile" strategy assumes that course is direct between starting point and the destination, speed is maximal and danger of capsizing is not taken into account.

Introducing of these two assumed strategies neglects two main motivations of human behavior at sea: willing to avoid danger and to get maximum of profit. But master is able to make a mistake as any other human. To cover possibility of mistake, we should introduce the third strategy:

3. "fool" strategy assumes that course and speed should be chosen to maximize risk of capsizing. Only one limitation should be taken into account: a ship should reach her destination after finite time.

Using describes above strategies, mathematical models of choice of heading course and speed can be developed. Such models could based on detail analysis of real ship operation with taking into account resent psychological research or be quite simple, it is a matter of special investigation.

So, these schemes should be considered as some meteorological proposal to take into account human factor. Using them we could get these values.

λ_C - averaged risk function for given voyage, assuming "careful" strategy

λ_M - averaged risk function for given voyage, assuming "mercantile" strategy

λ_F - averaged risk function for given voyage, assuming "fool" strategy.

These values allows to estimate influence of human factor to certain ship or design solution.

$\Delta_M = \lambda_M - \lambda_C$ - gives some estimation of ship's ability to resist to human's premeditated mistakes caused by neglect of danger of capsizing because of money or other external suppress.

$\Delta_M = \lambda_F - \lambda_C$ - gives some estimation of ship's ability to resist to human's non premeditated mistakes. This value can be considered as some estimation of degree of "foolproof" of a ship.

Intact ship survivability in extreme waves: new criteria from a research and navy perspective

Authors: J.O. de Kat, R. Brouwer, K.A. McTaggart, W.L. Thomas

Errata - corrections to STAB '94 paper

Date: January 27, 1995

1. *Caption of Fig. 4a:*
   -delete "dynamic" (i.e., should read "_. due to loss of stability...")
   - replace Fn = 0.4 with Fn = 0.3

2. *Third paragraph of section 3.3:*
   -replace first sentence ("In the capsize index plots...") with:

   These figures show the capsize indices involving all hull derivatives and existing ships, where the derivatives are represented by symbols and existing ships are denoted by "SHIP1", "SHIP2", etc.; each capsize index point is the result of approximately 100 simulations as explained in 3.2.

3. *Third paragraph of section 3.5:*
   - replace "_. the maximum allowable KG could be..." with:
   "... the maximum allowable KG should be..."

4. *Last paragraph of section 3.5:*
   - replace CI = 5 with CI = 15
   - replace CI > 5 with CI > 15

5. *Third paragraph of section 3.6:*
   - remove second sentence ("These plots..") entirely

9. Operational guidelines based on the polar diagram in the present form can be considered as an interim solution. In the future, a set of criteria based on analyses of the individual dangerous phenomena and their combinations, should constitute the ground for more accurate analysis of capsizing risk.

10. The development of one general polar diagram which would provide a criterion for all ships may appear to be very difficult. The dangerous zone may become unnecessarily large in order to provide a sufficient safety level for all ships in various dangerous situations. A too large dangerous zone does not provide sufficient space for advisable safe navigation. A solution to this problem may lie in a division of ships into two or three smaller, more specific groups. Considering the limits of size of natural waves, it seems that the dangerous zone for large ships will be smaller, and generally at higher V/T, while for small ships the zone will lie in the lower V/T values.

11. The results presented in this paper may be considered as representative for smaller ships with small L/B ratio.

Avoiding some unfavourable combinations of ship's speed and course angle significantly reduces the likelihood of capsizing. The development of an adequate operational guidance for masters is therefore of great importance for improvement of stability safety.

6. REFERENCES

1. S. Grochowalski - "Investigation into the Physics of Ship Capsizing by Combined Captive and Free - Running Model Tests". Trans. SNAME, Vol. 97, 1989.

2. Canada - "Intact Stability - Operational Factors Affecting Stability Safety and a Proposal for a New Definition of the Dangerous Zone". IMO doc. SLF 38/3/3, 16 Dec. 1993.

3. M. Kan - "Surging of Large Amplitude and Surf-riding of Ships in Following Seas". Naval Architecture and Ocean Engineering, Vol. 28, 1991.

4. Japan - "Intact Stability - Safety Operation Manual in Following and Quartering Waves".IMO doc. SLF 36/3/4, and SLF 36/Inf.4, 8 Nov. 1991.

5. Russian Federation - "Intact Stability - Safety Operation Manual for Avoiding Dangerous Conditions in Following and Quartering Seas". IMO doc. SLF 37/3/5, SLF/3/5/Add.1, SLF 37/3/5/Add.2; 16 October, 1992.

6. G.A. Thomas, M.R. Renilson - "Surf-Riding and Loss of Control of Fishing Vessels in Severe Following Seas". The Naval Architect, March 1992.

7. N. Umeda - "Probabilistic Study on Surf-Riding of a Ship in Irregular Following Seas". Proc. 4th Int. Conf. Stability of Ships and Ocean Vehicles, Naples, Italy, 1990.

8. N. Umeda, Y. Yamakoshi - "Probability of Ship Capsizing due to Pure Loss of Stability in Quartering Seas". Naval Architecture & Ocean Engineering, Vol. 30, 1992.

9. S. Grochowalski, C.K. Lee - "Analysis of the Influence of Some Operational Conditions on Stability Safety of Ships in Following/Quartering Seas". Rep. NRC-IMD, 1993.

10. S. Grochowalski, C. Wallace - "Ship Capsizing in Quartering Seas". Video tape, National Research Council of Canada & Canadian Coast Guard, Canada 1990.

WORKSHOP ON PROBABILITY IN STABILITY
SUMMARY OF DISCUSSION
Monday afternoon 7 November

Moderator: Professor L. Kobylinski, Technical University of Gdansk, Poland

INTRODUCTION

In the everyday language safety could be understood in many ways. Often, under safety one may understand exclusion of the possibility of an accident, in particular with regard to human life. However, safety, understood as safety against an accident, in respect of ships as well as humans and environment is a concept which could be evaluated quantitatively in the probabilistic sense. Historical experience shows that accidents occur notwithstanding which safety measures are undertaken. Safety could never be equal to 100 per cent.

When considering safety against accidents the element of randomness must be taken into account. Randomness is included in the inherrent uncertainity regarding future as well as in the deliberately undertaken risk which is accepted having in mind the technical and economical factors which may make reducing the risk impossible, impractical or uneconomical. However, the element of randomness allows us to quantify safety and probabilistic theory of safety is a tool which could be used for elaboration and establishing of numerical criteria. In this way rational basis could be obtained for establishing numerical criteria with the application of which there is full consciousness of the risk involved, numerically estimated.

This in turn creates the possibility to estimate the development of the new technology where there should be tendency to diminish the risk undertaken and to evaluate the cost of reducing risk and increasing safety which should form a basis for making decisions concerning various enterprises.

Probably the most serious problems in accepting the probabilistic concept of safety result from the human nature. The realisation for example that safety is never absolute in the quantitative sense seems not only to disturb some people but even terrorise them. This gives way to various speculations of the theoretical nature which are brought up when decisions have to be made. In certain cases even when evaluation of risk involved with the undertaking shows that the probability of an accident is extreemely small the undertaking is considered by the public as unsafe.

It must be also stressed that quite often the safety requirements or criteria established in technical enterprises depend on when and where the undertaking takes place and not on the evaluation of risk involved.

In this context I may refer to stringent safety measures imposed on European ferries after the HERALD OF FREE ENTERPRISE casualty, whether in South Asia ferries are still operated to very lax safety requirements (example - Dona Paz casualty in 1988).

No doubt, however, that the probabilistic approach to safety is only rational approach, because it allows logically and objectively to quantify the risk and to establish on this basis rational criteria.

There are serious arguments in favour of the application of the probabilistic approach to the safety against capsizing. Caldwell stressed that first of all the majority of factors affection safety against capsizing, external as well as internal are of random character. External factors, such as wind and seaway are obviously random quantities.

Less obvious is, that the stability characteristics of a ship are also of random character. For example, the displacement and the position of the centre of gravity vary randomly with the loading or unloading, consumption of water, fuel etc. and also with the gradual changes of the mass of the ship with age.

Variations of the metacentric heigh in service are also of random character because of errors in the estimation of the position of the centre of gravity of the light ship during the inclining experiment and errors in the estimation of the centre of gravity of various pieces of cargo and stores. Those variations introduce also the element of randomness into the current estimation of stability.

Secondly, because the real environment is of random character and the data on casualties allow us a posteriori to estimate risk level it is logical that the level of risk connected with the seafaring should constitute the basis for the establishing design criteria and operational requirements.

Thirdly, great progress has been achieved recently in the application of probabilistic methods in safety problems in other domains of technology and such methods were already accepted and widely used. The offshore industry made great efforts to apply probabilistic analysis in safety problems. In nuclear and aeronautical technology probabilistic methods become a standard used in the design process IMO Code of Safety for Dynamically Supported Craft recommended use of probabilistic approach to safety,

In maritime technology application of probabilistic methods was attempted quite long time ago. The subdivision requirements of the IMO resolution A.265 were based on probability of survival of a damage, so were more recently adopted subdivision requirements for cargo ships

Probabilistic approach to safety against capsizing was proposed by several authors long ago All of them, however, stressed practical difficulties in application of this approach to the development of stability criteria. It was the reason, why stability criteria as they exist at present, and in particular the weather criterion, are based on traditional safety factor or on statistical approach, although some probabilistic analyses are hidden there. More recently several attempts of computing probability of capsizing in certain situations have been published, none of them, however, led to practical criteria.

There are some questions which could be discussed at this workshop:

- should probability approach be applied to the development of improved stability criteria, and if so, how.
- should short term or long term prediction of capsizing probability be used as a basis for risk assessment.
- how to include external forces calculated in the deterministic way into probabilistic scheme.
- how to take into account human factor.

Discussion

M. Skrzypczak, Marine Atlantic, Canada

Discussed the problem of human factor. Inquiries whether there are data on many accidents are caused by improper action of the operator.

Commander R. Gilbert, US Coast Guard

Underlined that that human factor is an important factor, in particular collision accidents. There is a need to collect data on statistics of accidents and every possible element has to be considered. Those elements have to be categorized in various different ways.

M. Aecko Canadian Safety Transportation Board

According to Canadian Transportation Safety Board, human factor is responsible for 75-80% of accidents. He is not sure how to approach human elements in probabilistic sense. He underlined that collecting reliable data on human factor is extremely important. Canada organized special group to collect data on human performance.

H. Hormann, Germanischer Lloyd, Germany

The question is whether or not the probabilistic approach to stability is necessary. Good experience exists in application of probabilistic approach in damage stability and very little experience in application in intact stability. He stressed that in making the regulation better it is necessary to better copy the real life phenomena where several factors are random. The probabilistic approach is theoretical tool for taking into account the randomness of different factors.

However he expressed the note of caution regarding the application of probability. In the probabilistic approach it has to be accepted that accidents would happen. This fact is difficult to accept by the public. It is necessary to introduce the concept of acceptance level. It has to be recognized that acceptance level, a measure which hardly be influenced by professional talking, is different in different areas of industry. He thinks that the best way is to set up the combine criteria - main criteria based on probabilistic approach with safeguards in form of minimal level which by no mean to be undercut. He strongly suggested that following probabilistic approach as a basis certain deterministic part has to be maintained.

Probability is just a tool to reach some results instead of waiting for gathering experience. One option is to proceed on the basis of experience as it was done e.g. by Rahola and A.167 - where all embracing parameters were estimated on the basis of statistics. Another opinion is theoretical approach using probabilistics. Now there are too many new ships designs and we can not afford to wait 3 or 4 decades for collecting enough experience. Probability approach will shorten this time. Some progress would be made in application of probability if we apply it to just one parameter.

T. Allan, Marine Safety Agency, UK

Strongly supported views expressed by Mr. Hormann. Probabilistic method would not prevent accidents as Estonia casualty. Always deterministic minima has to be retained.

Dr. D. Vassalos, University of Srathclyde, UK

Regarding the basic question whether probabilistic approach has to be used which is synonymous to question whether risk at sea exists, the answer is yes. But to the question whether we ready to adopt probabilistic approach the answer is no. He is referring to John Caldwell attempt to apply the structured liability analysis to stability problems, which takes into account that most factors influencing stability are random. These are no problems - firstly we have to find how to quantify the problem itself. Little has been done in both fields. The probabilistic approach has not developed far enough as to formulate complete model which would present for consideration by the international community. In the meantime we have to live with deterministic criteria.

R. Sonneschinein., US Maritime Administration

In reference probabilistic subdivision requirements the randomness of draught and GM is taken to the extreme because not having minimum index for each draught extremely unfavorable loading conditions are not precluded.

Prof. D. Ananiev Technical University of Kaliningrad, Russia

In future, probabilistic approach should be considered as a single approach. However, we could not avoid consideration of physical phenomena. Analysis of casualties shows that nearly half of the accidents occur on following waves and other beam seas position and on the basis of these regulation nothing could be said if the ship safe in following waves. General probabilistic model of stability standards should be followed and because of the lack of complete knowledge at present the empty spaces could be filled in by rough approximations. In his opinion probabilities of capsizing may be not understood by the public, but the professionals know well what they mean.

A. Chatterjee, U.S. Transportation Safety Board

He wonders that if the probabilistic criteria are adopted and accidents happens, the public may be against not to the ways probabilities are calculated but to the index adopted.

Prof. Ch. Kuo, University of Srathclyde, UK

Probability is not the aim as itself. many things which we are doing require application of probabilistic approach in order to get and end. Certainly hazard have to be identified. One of the hazard is that it is necessary to establish risk level and for this aim probability has to be applied.

Prof. W. Cleary, Florida Tech. USA

Commenting the basic problem he is of the opinion that probabilistic approach is required because we can never get and absolute answer. At some future date the trading route should be analyzed in view of probability of the one ship hitting another. At present we take only probability of the size of damage in subdivision requirements. He wonders whether someone is considering the overall risk of the sea voyage.

There is also problem of high speed ships. We have to bring up operational probabilistic approach together with design probabilistic approach. For example what will happen when very high speed ship will run into oil tanker? We are ten years behind in application of probabilities.

Prof. V. Lipis, Central Marine Research and Design Institute, Russia

There are three directions in probability investigations. One is application of Markov processes to analysis of nonlinear theory of motions. The drawback of this method consists of absence of aftereffects in the analysis. The other method is up-crossings theory. The third method is the general usage of reliability theory. For all the above methods comprehensive statistics of casualties is required. First application of probabilistic approach reveal more variances than those estimated on the basis of deterministic criteria. Therefore it is very difficult to establish standards on this basis. However some critical situations are good subject for probabilistic approach. Next stage should be combination of probabilistic and deterministic approaches - basic requirements should be deterministic, additional requirements - probabilistic.

Prof. N. Rakhmainin, Krylov center, Russia

Probabilistic approach based on long term prediction is a tool to choose the proper parameters which have decisive influence on ship safety. Firsov in 1960 presented full probabilistic approach to ship capsizing. he choose two parameters, amplitude of roll and angular velocity as governing parameters, he took into account short term prediction of rolling in irregular seaway and build full model of capsizing. He checked hi theory against number of ships. In order to find out those criteria which were suitable for standardization (GZ curve, GM). GZ curves the characteristics which could be estimated with great accuracy and therefore it is possible by the designer make choice of this curve in order o satisfy some established criteria.

The long term probabilistic prediction has to be used for the purpose of checking the criteria and for novel ship types in order to find parameters which could be used as criteria.

Dr. J. de Kat, Maritime Research Institute, Netherlands

Damping coefficient is not always important parameter. It is important in beam seas but not in quartering seas where this roll velocity might be small. In joint navy project on ship capsizing it was found that safety is sensitive to calm water stability characteristics. Several Simulations in time domain using nonlinear model were made in this project. The results are presented in the paper submitted in this conference

Stability Analysis for High Speed Vessels
Tuesday morning 8 November

Chairman - Professor Martin Renilson, Australian Maritime University

About thirty people attended the above workshop which was run as three parallel syndicates. Each syndicate had a chairman/speaker who reported back to the workshop on the deliberations of his group.

The topics discussed were as follows:

i. *Stability of high speed monohulls (experimental techniques)* R Compton
ii. *Stability of high speed monohulls (theoretical techniques)* L Leitzia
iii. *Damage stability, collision and evacuation of high speed vessels* A Blyth

Both groups i and ii focused on the loss of transverse stability at speed in calm water. They argued that this gives a good indication of the loss of stability and general handling of the vessel in following seas.

Stability of high speed monohulls (experimental techniques)

This group had an interesting discussion with three of the organisations who are involved with vessel safety and stability. Most of the discussion centred on hard chine planing hulls. It was agreed that the major problem in dynamic stability of these vehicles is what happens in following and quartering seas at speed. Having said that, the ability to evaluate it experimentally is most difficult, especially if one is concerning about quartering seas in most towing tanks which are linear, and so it is difficult to get oblique angles. As a result, most of the discussion was on the fact that many of the findings that relate to the dynamic stability of these craft has been on the basis of the loss of stability at speed which needs to be considered in the operation of high speed planing boats.

There were several discussions on the effect of propeller tunnels, with a considerable body of evidence suggesting tunnels tend to exacerbate the stability problem. There was, however, a counter argument that there was at least one instance where the boat was more stable with than without tunnels on the basis a prototype versus production type of operation.

There was some discussion on stability in following and quartering seas that is definitely related to yaw. This is a broaching kind of a phenomenon that very often gets boats into trouble. There was an interesting discussion relating to how could experimentalists use relatively simple tests, to predict or anticipate possible problems in the much more complex and realistic following and quartering seas. There was some interesting discussion on applying moments to models in calm water and relating those to the fact that full scale experience on the same shapes indicated that what worked best in calm water also worked best in the realistic environment. This could bear some considerable amount of study in future application.

Constraining a model can mask dynamic problems. Laboratory testing is expensive, but radio control testing in a bay is even more expensive and probably, because of the small size of many of these vehicles, what happens is no testing is done at all - a prototype is built and tried out.

As far as round bilge work is concerned, one of the problems in all small model testing is scale effects. The scale effects that relate to spray generation become even greater in a round bilge environment, and consequently the round bilge has even more problems than the hard chine in the planing regime in waves because of spray phenomena.

Finally, there was some discussion on SWATH, and other boats that have active control systems. The question was: how do you recommend to operators and insurance companies, and others, that these boats are safe? There ought to be some way of making sure there is testing done with the system failed, and that it failed safe.

There is research going on, rules that have to be written, criteria that have to be established and the connection among those three major areas is a major problem. Focus on the rule preparation should not be at the expense of research in some of these basic hydrodynamic areas that still are very poorly understood.

Stability of high speed monohulls (theoretical techniques)

As the problem is treated analytically large assumptions have to be made because of the complexity of the situation. The discussion concentrated on the analytical approach of stability of monohulls at speed in waves, starting with the effect of speed in calm water.

Planing hulls were considered first, because there is probably less known about them than high speed displacement hulls. Some calculations of the pressure field on the bottom of planing hulls have been carried out and from this conclusions can be drawn about whether there is any loss of stability due to dynamic effects.

This has been done by Tekeda, and his work has been published for semi-displacement slender hulls. His results show that apparently one of the major influences is due to the hull generated wave in semi displacement hulls.

Passing to operations in waves, the major problem is waves coming from the stern. This is not an analytical result, however it indicates what to concentrate on. One aspect with this is the influence of wave impact forces, and on how their effects can be incorporated in manoeuvring related programs.

It was agreed that there is sill a lot of work to be done including the wave pressure field in the calculation of the pressure on the bottom of the hull. Reference was made to a recent paper by Faltkinson on this subject.

Finally, the group looked at stability criteria. Issues discussed were: how to formulate criteria; and how to make it easy for a designer to use the criteria. Analytical approaches to the problem are unlikely to be easily used by designers, however there was a strong feeling that as the experimental approaches are so expensive, some effort should be made to develop an increased understanding of the hydrodynamics to enable the analytical approach to be used.

Damage stability, collision damage and evacuation of high speed vessels

Unfortunately, discussion didn't get as far as evacuation. It centred mainly on the concern that the current damage scenarios considered in the high speed code may not be properly realistic with what will happen with high speed craft and practice.

In particular, the group felt that there should be a correlation between the probability of damage and the speed of the vessel. It was pointed out that there is a relationship between the speed of the vessel and the location where damage might be expected to occur. The faster the vessel goes the higher the probability of bow damage, and the higher the probability of forward bottom damage due to grounding. This isn't reflected in the regulations used at the present time.

The group was also concerned about the extent of damage assumed at the present time. Taking only one nominated damage case, for example in the high speed code taken for a forward collision with a two metre high rock or wall, can result in 'paragraph type' vessels which meet the regulations but which are quite unsafe in other respects. In this area there is a possibility that more than on probability should be considered. More than one damage extent needs to be considered, with different residual criteria as the extent gets more severe.

The main conclusion that the group came to is that a data base of known damage information is urgently needed to help resolve the question of what the damage extent should be. IMO has a procedure for this in the damage card system, but this system is not very well supported. Arguably this is because its very official doesn't always give the true bold facts as they are seen on site within a few hours. The group recommends that this workshop should include in its report a recommendation to IMO SLF that this question of damage scenarios applied to high speed craft needs further examination, and that there is an urgent need for a reliable data base.

Probably the best way forward to get the data base of information is at an informal level by communication amongst groups of this kind, but of course that needs some kind of financial support. Just for the record the small group was able to identify six or seven known serious cases of damage. All but one of those were bow forward bottom damage, which is not perhaps considered or reflected in the regulations sufficiently at the present time.

3 November 1994

Workshop session:

Stability of High Speed Ships

Moderator: Martin Renilson,
Australian Maritime Engineering CRC

9.00 - 9.30	**Introduction/select groups**
9.30 - 10.25	**Group discussion/deliberations**
10.25 - 10.35	**AM Break**
10.35 - 11.00	**Group discussions/deliberations**
11.00 - 11.30	**Group presentations**
11.30 - 12.00	**General discussion/summing up**

3 November 1994

Workshop session:

Stability of High Speed Ships

Workshop Aim:

The aim is to generate detailed discussion on specific aspects of the stability of high speed craft.

Workshop format:

The aim will be achieved by organising the participants into small groups, each with a specific aspects to consider.

At the end of the session each group 'spokesman' will report the main points of the group's discussion to all the participants.

The intention is to be as unprescriptive as possible on the topics to be discussed. Hopefully, these will be decided by the group members to reflect their own expertise.

26 October 1994

Workshop session:

Stability of High Speed Ships

Vessel Types:

Catamaran

Swath

Monohull

Hydrofoil

Surface Effect Ship

Hovercraft

WIG

3 November 1994

Workshop session:

Stability of High Speed Ships

Issues which could be considered for each vessel type include:

Existing Stability criteria;

Loss of transverse stability at speed;

Loss of transverse stability in a seaway;

Damage considerations;

Evacuation/rescue procedures;

Stabilizing devices;

Deck diving in following seas;

Surging/broaching in following seas;

Heel/yaw coupling;

Yaw/heel coupling & heeling in a turn;

Experimental techniques/limitations/scale effects;

STAB '94

Contribution to the Theoretical Workshop on Stability Analysis for High Speed Vessels

by Professor A.D. Papanikolaou, NTUA

Background

In contrary to the stability of conventional ships, the stability of high speed craft is characterized by the variety of the vessel types (various advanced marine vehicle, a large category of which are twin hull vessels), their limited size, the high operational speed and the variety of operational modes (hullborne - foilborne mode, planing, semi-planing and displacement mode), the rapid change of position within a navigational area, considering the possible rapid change of local weather conditions, the limiting weather conditions (seastate and wind force, wave heights and wind speeds, wave periods and predominant directions of wind and waves) that should be related to the seakeeping capability of the particular vessel under discussion. Despite certain efforts to define proper stability criteria for advanced marine vehicles (that might be considered herein identical to high-speed craft) it is necessary to improve the methods for the theoretical prediction of the seakeeping and consequently of the dynamic stability for all types of advanced marine vehicles under regular operational and survival conditions, to define proper dynamic stability criteria and seakeeping performance indices and to relate actual weather conditions to the safety of the vessel, given its particular design characteristics.

Possible Workshop Discussion Points

1. Variety of vessel types and their characteristics
2. Outline of hazards and their specification
3. Existing stability criteria
4. Prediction of seakeeping and of dynamic stability
5. Prediction of weather conditions (as a function time and site)
6. Revision of stability criteria
7. Operational guidance for high-speed craft masters

Proposal

STAB '94 secretariat might circulate the suggested workshop topics and ask for inputs from the participants. The proposer might help in the introduction into the subject and the moderation of the workshop

WORKSHOP ON CAPSIZE THRESHOLDS
8 NOVEMBER 1994, CENTRAL BAPTIST CHURCH AUDITORIUM

Chairman: *Dr Dracos Vassalos, Department of Ship & Marine Technology, University of Strathclyde, Scotland, UK*

SUMMARY

The aim of this workshop was to discuss critically the philosophy, approaches and safety margins to be adopted in establishing intact and residual stability criteria for representative groups of vessels. Discussions were guided by posing appropriate questions concerning the need for change and the nature of any such change, and then providing what were seen to be suitable answers. The workshop was subdivided into two sessions, each one involving an invited group of specialists. The format adopted in both sessions comprised:

- Brief introduction of the key issues.
- Directed round-the-table discussion by the panel of experts with audience participation
- Consensus and summary

In relation to the above the following were considered:

SESSION 1: *Intact Stability*

This session addressed two groups of ships, perceived to deserve special attention:

- **Fishing and other small vessels**
- **Container ships**

Following a brief introduction by the chairman, Professor Hamamoto proceeded to present a short video of capsize experiments, undertaken at the National Research Institute of Fisheries Engineering in collaboration with Dr Umeda and involving both groups of vessels, which provided the right platform for the lively discussion that took place during this session. In particular, answers were sought to the questions pertaining to the *nature of the threshold* and *relevant parameters/characteristics* to be used in establishing such thresholds. The following comprise the main findings:

- There is a need for vessel specific criteria, deriving from identification of relevant modes of capsize, determination of influencing factors and specification of appropriate limits
- Thresholds must invariably relate to the operating environment and reflect relationships between suitable environmental, ship design, stability related and possibly operational parameters
- It was agreed that theoretical/numerical tools generally exist or are being developed, capable of establishing such relationships

- Some participants supported that such thresholds ought to form the basis for achieving a better understanding of capsize safety and for improving the existing stability criteria. The strongest support, however, was voiced for continuing to use the GZ curve/characteristics to channel new advances.

SESSION 2: *Damage Stability*

This session formed the basis for a subsequent meeting of the whole conference which focused on the 'ESTONIA' disaster. In this respect, following a presentation by Professor Rutgersson of the Royal Academy of Sweden of the events leading to the worst civil disaster in Europe this century, the second session of this workshop attempted to provide answers to the following single question:

- **Should the main vehicle deck of Ro-Ro's be subdivided?**

Some calculations involving various subdivision strategies were presented by Mr Tom Allan of the UK Department of Transport and by Dr Vassalos, and discussions followed addressing the use of capsizal resistance enhancing devices, specification of allowable amounts of water on deck, determination of suitable subdivision arrangements and possible new designs and concepts.

The general consensus of this session was that the profession should not rush to apply drastic measures which might jeopardise the very existence of Ro-Ro vessels. Instead, it was suggested that maximum use be made of the well known ingenuity of Naval Architects when the end of the rope is reached.

The pertinent discussion on capsize thresholds and copies of relevant transparencies /slides are appended.

PANEL OF EXPERTS:

Professor M Hamamoto	Osaka University (co-chairman)
Mr H Hormann	Germanischer Lloyd
Mr A Blyth	Consultant, UK
Dr N Umeda	National Research Institute of Fisheries Engineering, Japan
Dr M Kan	Ship Research Institute, Japan
Prof. A Troesch	University of Michigan, USA
Dr S Grochowalski	National Research Council, Canada
Mr R Sonnenchein	U.S. Maritime Administration
Mr W Cleary	Florida Institute of Technology, USA
Prof. O Rutgersson	Royal Academy, Sweden
Mr Tom Allan	Marine Safety Agency, UK Department of Transport
Mr H Vermeer	Netherlands Shipping Directorate

APPENDIX: DISCUSSION ON CAPSIZE THRESHOLDS

INTACT STABILITY SESSION

Vassalos
Thank you Professor Hamamoto for sharing with us your research findings. This video clearly demonstrated fundamental differences in the mode of capsize between the Container ship and the Purse seiner models. Let us start, therefore, by examining the nature of the capsize threshold.

Grochowalski
I was impressed by the video which shows the mode of capsize for the fishing vessel (FV) to be similar to that observed in the experiments with Canadian FV models. Even though the Canadian FV is much smaller and the shape of the hull is quite different, the physics of capsize appear to be quite similar. This might appear to indicate that hull form characteristics and the amount by which individual hulls vary may not affect how the ship capsizes. Therefore, before establishing a definite safety threshold of capsize we need to agree on the physics of capsize. How is the ship affected by the environment (e.g. waves, steepness, shape, height, etc.), what are the possible wave/ship/sea situations? When we compile a list of various critical situations and phenomena which may occur, then we should proceed further to study how hull parameters and loading parameters affect the probability of capsize.

Vassalos
You mentioned that both fishing vessels tested by you capsized in the same way in spite of the differences in their hull characteristics - what did you mean by this?

Grochowalski
In both cases the phenomenon of deck or bulwark submergence was the major factor contributing to capsize. In both cases this submergence created a very strong additional heeling moment which actually prevented the ship from recovering to the upright position. I will go so far as to say that all low freeboard ships are probably vulnerable to this mechanism of capsize.

Vassalos
So we should include the possibility of this extra heeling moment in capsize studies of any low freeboard or high bulwark ship?

Grochowalski
Yes. Also it should be realised that roll characteristics of any high bulwark ship in waves are NOT symmetrical. Large yaw and sway moments occur during the roll motion and these moments cause the capsize.

Vassalos
Now we should continue the discussion by identifying more critical parameters.

Hormann
As we have just heard, the phenomenon of capsizing is often very complicated. There are many parameters to deal with both in regard to the ship and the environment. In

relation to this there is a need to study in-depth each parameter and then attempt to relate it to all the other parameters which may be part of the problem. Considering the complexity of the problem; however, the multitude of parameters and their inter-relationships, I have doubts that we will be able to achieve this in the foreseeable future. Therefore, the only reasonable near-term solution is to continue with model testing such as Prof Hamamoto and Dr Grochowalski have shown us. The ideal solution, in my opinion, would be to test each new ship (in model form) in all loading and seaway conditions. Right now this is impossible but we might arrive at general conclusions by doing many more model tests and collating the test data.

Vassalos
In other words, we need to establish which are the most important parameters to prevent capsize; what are the limits to these parameters; and we need to establish design limits.

Grochowalski
A further point, since we cannot test each individual ship, we must attempt to model the whole complex picture. Then compare each parameter with a selected survival curve (such as the GZ curve) and begin to give relative importance to each parameter on each ship. Then we should try to establish an envelope of safe operation. Subsequent parameters may be checked to find if they fit inside the "safe envelope" or not. Finally we must understand that often several parameters act together and cause the established "envelope of safety" to become different. Therefore, time domain testing is necessary with free running models before we can properly balance the interaction of all parameters.

Vassalos
We all agree that capsize is an event depending on many interacting and interrelated factors and we heard some suggestions on how to disentangle these. Let us now turn our attention to ways of establishing thresholds.

Troesch
With regard to how we should define the threshold of capsize, if a ship satisfies certain GZ or GZ curve conditions this in itself does NOT provide proof that the ship is safe (or unsafe). It just means that the ship satisfies a given standard. Adopting models for the ship and the operating environment and undertaking computer simulations or model tests, our goal is to determine the "edges" of the simulated world. But, determining "edges" by simulation is a trial and error process and as such it will never by efficient. It will always be necessary to try a few more variations. The GZ curve is accepted primarily as a means to establish thresholds because it can be readily calculated. Computations however are becoming more sophisticated, faster and cheaper and we should not confine ourselves to simplistic models and calculations.

Vassalos
Let me at this stage ask the audience for their definition of Capsize Thresholds.

Audience
Out of microphone range.

Vassalos
The answers appear to indicate that a "threshold" must be defined in relation to experiments which provide information on the major forces acting, their magnitude, their initiation and demise, their direction, their complexity (e.g. either linear or non-linear) and so on i.e. enough data to gain a better insight of what actually happens in a capsize situation.

Blyth
Nonetheless, for every ship the capsize threshold must vary in some relation with the centre of gravity. So we should still continue to use the limiting KG which will help survival of any sea condition.

Vassalos
This seems to suggest that we need to define capsize thresholds by considering both environmental and stability parameters.

Let us summarise where we have reached so far. The session started by a video that showed differences in capsizing between a container ship and a fishing vessel; then we heard explanations on how two different fishing vessels capsized due to the same environmental action (deck in water). Subsequently, it was noted that GZ and GZ curve characteristics remains an important parameter. It was generally agreed that there are many modes of capsize and it was stated that the limits (e.g. thresholds) are not always independent, they sometimes interact. We started to define the thresholds, noting that they are related to both the environment and the design of the ship. Finally, we noted that the definitive relationship between wave (environmental parameters) and ship parameters in a specific seaway is not yet defined well enough.

At this point let us turn our attention to the effect of operational parameters on stability.

Sonnenschein
The human element must obviously be considered. When a master is either very wise or lucky, the world never hears about why he is very wise or lucky. However, there are also famous disasters that were fully avoidable. Dr Grochowalski's experiments have shown that the ships became much more vulnerable when they changed direction. We have also heard some say that the Estonia ought to have changed direction but it is quite possible that turning the Estonia was not feasible.

Hormann
We seem to have agreed that there is no possibility of making every ship fool proof.

Blyth
But rescue lifeboats are designed to survive a complete capsize and still recover.

Hormann
Except for rescue lifeboats then but, since we know there is no possibility of preventing all operational mistakes in the design of the ships, we have to assume that the ship is always handled competently. To a certain extent, operational aspects have to stay out of the design criteria and the regulatory standards. The persons operating

the ships must take into account certain phenomena - for example, I think every master knows that the most vulnerable situation for a ship is in the following seas. We might be able to decide on certain key points of operational information to better inform the seafarer without taking each point into the design or regulatory criteria.

Vassalos
How about adopting an idea similar, say, to the concept of "Criterion of Service" as used in damage stability evaluation - this changes with the number of lives at stake. Should a risk factor be included in an intact stability standard?

Hormann
I feel that this is an unethical approach. One person is just as valuable as 1,000 persons.

Blyth
While I agree with Mr Hormann, internationally the regulations definitely change for the larger number of persons at risk and the value of human life is definitely less regarded in some areas of the world.

Grochowalski
I also support Mr Hormann's position. We should not look for different standards based on the number of lives at risk or how expensive the cargo is. Different characteristics of operation must be taken into account but the threshold should be treated uniformly across the board. Even if it is impossible, the designer must do everything to ensure a vessel does not capsize. To change to a slightly different aspect, I consider that Stability and Stability Safety should be defined differently. Stability is the inherent feature of the ship to resist capsize. Stability Safety is dependent on both the ship and its operation which must be optimised together.

Rutgersson
We cannot fool ourselves to think we always have a safe ship. Prof Troesch showed that even when we follow definitive criteria there are still accidents happening beyond the boundaries defined by such criteria.

Vassalos
The panel seems to agree that operational factors should be included with environmental and design factors when considering the threshold of capsize and that we should opt for uniformity. Now, can we go a step further and try to decide on which specific parameters of operation, environment, and design should be best included.

Umeda (showing a transparency)
This transparency shows that many capsizings in long-crested irregular waves are due to low cycle resonance, Figure A, but different results are found with short-crested waves, Figure B. This suggests that stability must be checked with actual sea states both long- and short-crested and both regular and irregular waves.

Grochowalski
I do not think the question of exact parameters to be used can be answered today. We are still in the earlier process of determining the complex nature of different capsize situations. Some of these we have thought we understood and now we find we do not fully understand. For example the influence of beam-to-draft ratio used to thought to be positive, but now in the most recent paper by deKat et al we find a conclusion quite the opposite. However, there are some items which could certainly be of influence on ship safety regarding stability. One is freeboard height in waves. Regarding the environment there is the wave height of course but wave steepness is perhaps more important, also wave length; a three way independent parameter combination is the ratio of wave length combined with wave height (more importantly wave steepness). Regarding the question of long-crested waves Vs short-crested waves, the results will be different as shown by Dr Umeda, but the results for long-crested waves will be more conservative so perhaps we could use only long-crested waves for the evaluation and determination of criteria. Finally the GZ curve evaluation still has a great merit.

Blyth
Most remarks in this session seem to assume a monohull ship, but more diverse ships are being designed and actually put into commercial service. Having done a lot of work on SES ships, I suggest that beam seas are most important for some newer ship types along with the VCG evaluation, or course. Also in some of our studies wherein the VCG was changed by small amounts until the design reached a point of readiness to capsize, we found that one ship had a vanishing angle of stability 50% higher than another and/or the GZ was 35-40% greater. One opinion attributes this to the large difference in damping coefficients. I do think that we can say for every type of marine vehicle there is a safe envelope of stability using the GZ curve into which most other parameters can be included. These envelopes within which the ship will usually survive will of course vary for different environments or loading conditions.

Vassalos
On this note, let me ask a simple but perhaps challenging question: would the panel be prepared to abandon the GZ curve and push forward attempting to define thresholds in terms of environmental parameters and/or other characteristic ship properties?

Hormann
Although you might expect me to say "no" I would be quite ready to abandon the GZ curve as soon as I am convinced that there is a better measure of relative stability including all we know and is easy to apply.

Blyth
We should live with Mr Hormann's approach provided all persons recognise the limits of the GZ application.

Troesch
Sometimes a ship does not satisfy the GZ criteria but I know it is often because of other attributes such as bilge keels or different mass distribution. The GZ curve remains an important factor but it is only one of many. Tools are developing that include other parameters so we should continually re-evaluate the GZ curve.

Blyth
We can continue with the use of the GZ curve provided the minimum requirements related to the GZ curve are always a function of the DOMINANT other parameters.

Cleary
Mass distribution (mentioned earlier by Prof Troesch) is important and is not now used as a dominant parameter though in my opinion it is a dominant parameter for container ships which have a variability of loading that includes many levels of containers high above the main hull of the ship. Additionally, we should be planning a complete watch officer warning system which includes engine room, environmental, course planning, loading, ballasting, stability, sever motions warnings, radar/collision, etc. The video screen should be on at all times but be blank until there is information which is either asked for or emergency information which the crew/master need to know promptly.

Grochowalski
Future criteria should be as simple as a GZ curve but must take the dynamics of ship motions in the actual seaways and the actual mass distribution into account. All such parameters must be taken into account; the GZ curve is not sufficient by itself.

Hormann
The GZ curve as a general tool is being mistaken for GZ as a rigid minimum criterion such as Res A-167/IMO. It has been shown that it is possible to use GZ curve as a tool with seaway and mass distribution factors. The GZ curve may be case-related or design-related, or environment-related.

Vassalos
But, should we continue to relate everything we learned in terms of the familiar GZ curve? After a more advanced analysis should we still present the findings in the form of a modified GZ curve or as something else.

Grochowalski
In the future, stability criteria must include some environmental factors and perhaps risk factors, etc. that are part of the criteria. Perhaps they can be related to the GZ curve, perhaps not, but they must be simple to present to the crew and easy to calculate and control operations. New forms of criteria should be encouraged, evaluated, and selected not necessarily based on GZ criteria. At the moment we have nothing better so we continue to use GZ. The newer criteria should reflect better the ship dynamics in waves.

Blyth
Res A-562 is a good reference in this regard. As well as it has served us, the Rahola approach was based on a narrow sample which is not longer as valid as it was when originally proposed. The curve must be related to roll gyradius and damping. We must move towards more sophisticated assessment of the dynamics of stability. We need to move away from purely static criteria. Dynamic criteria are needed quickly in many of the newer areas of ship design.

Hormann
First the scientist must find out what a particular ship type needs. Second we must decide what tool is to be used to present the information to the ship crew in the best way possible.

Vassalos
In summary, the panel appears to be in agreement that we should concentrate on using the GZ curve itself but not only as a definitive criterion but also as a tool to evaluate other parameters and this we should continue to do until we develop and understand which new parameters and thresholds will provide a better substitute.

With this I should like to thank the panel members and the audience for their active participation.

DAMAGE STABILITY SESSION

The chairman introduced the second session of the Capsize Thresholds Workshop and noted that there would be presentations by Prof Rutgersson, Mr Allan and himself, stating that in the light of the Estonia disaster this part of the workshop will concentrate on discussing the merit (if any) of subdivision on the car deck of RoRo ships.

Prof Rutgersson, Sweden re the Estonia Catastrophe
I will attempt to present information on the above (such as it was available at this early stage of the review) in three steps.

- What happened?
- Accident Commission - What questions are they studying?
- What kind of impact can we expect - short- and long-term?

Estonia was a combined truck and passenger ferry similar to many such ships in Scandinavia. She was built in 1980 with one large car deck which could carry 47 trucks or 460 cars. The maximum passenger capacity is about 2,000. Approx. 900+ were on board at the time of the casualty. The car deck is an open design. Later designs had some internal deck structure but not Estonia.

#1 Conditions of the Accident
The ship was more or less fully loaded on the car deck. There could have been more cars on board if the movable car decks had been deployed but this was not necessary. Upon departure from Talig of Estonia, there was already fairly heavy weather and increasing wind. At the time of the accident the wind was 20-25 km/sec and the wave height was Hs=6m. These figures were estimated by other ships in the area. After the accident, wind and sea continued to increase so it was even more severe during the attempted rescue operations. It is worth mentioning that there was a special condition regarding the pilot for Stockholm harbour. The Master was not a Stockholm pilot and his ship had to be at a specific meeting place in the archipelago east of Sweden at a specific time in order to get a Stockholm pilot. So the ship was making full speed to arrive at the pilot meeting place on time. During the voyage, the Estonia overtook one

of the Finnish Ferries going to Sweden which had slowed to 12 knots because of the steep seas. Estonia kept on at full power.

#2 Accident Commission Reports

The most interesting story was told by a seaman who had the task of walking around the ship to see that all was right. At 23:40, he was at the bow on the car deck. He noticed and reported to the bridge a very strong metallic noise. He was ordered to continue his inspection routine around the ship. Apparently no action was taken. At midnight, 24:00, he completed his rounds and reported to the bridge. The Captain was on the Bridge and the witness noted that his main concern was that full power be maintained to reduce the time of passage and to arrive at the pilot station on time. At 12:10, the Engine Room noticed that there was water coming in so they switched the TV cameras to show the car deck at the bow door area and could see great quantities of water on the car deck at the bow. The witness saved himself after the capsize by climbing out of the hull through the stack. At 12:24, Estonia sent a mayday call reporting that the ship had a 30 degrees list to Starboard. At 12:25, all electric power failed. Shortly afterwards the ship heeled to 90 degrees. By 01:00, the Mariella and other ships attempting to reach Estonia to assist realised that the Estonia had sunk. Some survivors were left in the water and some had been clinging to the outside of the ship hull until she sank. When the ship was at a list of 115 degrees, she sank and was found lying on her Starboard side at the same angle.

Commission Questions

- How did the Bow Visor detach from the ship? It was a mile away.
- Why was the seal fitted on the visor not quite the same as the drawings required?
- Design of Visor. What loads were to be expected? (The bow door behind the visor is thought to have been breached by the loose visor before it fell away from the ship).
- What is the flow of water that can be expected through the bow door?
- What were the dynamics of water on deck?
- What was the time scenario for the whole accident?

#3 Accident Impact

I consider that the accident will have a great impact on the design and arrangement of all future Scandinavian RoRo ships. It has had such a dramatic effect that both single nations and IMO will change regulations. Owners are anxious to show that their ships are safe and will take individual action; the maritime directorates will change regulations also. There has been a lot of talk towards making existing ferries safer. As for long-term action this accident shows that a much wider approach to safety is required. We seem to be far behind the aircraft industry in our ability to learn from each accident.

Factors in the accident

Human Factors - driving the ship into the storm just because of a time schedule
Technical Evaluation - ships condition must be able to be evaluated by non-scientists
Education of the Crew - needs upgrading
Fatigue & Boredom - probably were present and contributed

The ship master should not be free to order full speed ahead in such a storm. Owner/Operator should exercise maximum speed Vs weather control. There is a misconception among many maritime professionals that, if the ship designed and built to meet all the minimum international requirements, then the ship is "safe" and can be driven hard in any and all situations. It will certainly help maritime safety if administrators would explore the use of aircraft research and safety technology.

Vassalos
Thank you for the information on the Estonia accident and for your valuable comments on what must be done in future. As we continue our discussion on subdivision of the main deck, we must remember to remain logical and not base our judgement only on this casualty. Additionally, we should try to express our thoughts for improvements on both existing and future RoRo ships. Could we have the second presenter, Mr Allan please take the floor.

Mr Allan, MSA/UK, Department of Transport
UK has suffered the aftershocks of the Estonia perhaps as mush as Scandinavia. We almost had got to the end of the changes after the Herald of Free Enterprise which sank in 1987 and now the whole question of RoRo ship safety has been totally re-opened, the public are seriously concerned, the Royal Institution of Naval Architects has issued statements, etc., etc. UK has scheduled a Symposium at the end of this month (November 1994) on Phase II of the UK RoRo Research in which we looked only at survivability. At that meeting we are going to have a discussion similar to this one, so I would like to obtain the views of this international group before the meeting in London. We have to look at water on deck in the intact condition. We naval architects must now change our mind as to what is meant by a damaged ship. Formerly we looked at collision only and considered the ship damaged both above and below the bulkhead deck. Now within seven years there has been two very major casualties with no damage below the bulkhead deck. Therefore, we in UK have begun to consider two new cases.

[Editor's note. This is not required presently because both the Load Line and SOLAS conventions require the external hull to be kept watertight and the portion of the ship above the weather deck able to be made weather tight by the crew. Of course this implies enough crew to handle all "bristol fashion" exertions - not just a one man bridge and one man engine room].

In what I shall be presenting here the KM value is taken up to the second car deck which would be very similar to considering all scuppers blocked and all drenchers (fire sprinklers) running. In that process, damaging various compartments, we tried to introduce a variable survivability standard. For your information, STAB '80 is a standard we imposed on UK ferries because we felt the IMO had not fully answered the problem. SOLAS just asked for "positive residual stability" whereas we defined what that positive residual stability should be. In our current exercise, we also looked at variability of water depths on deck and variability of bulkhead spacing.

#1 & #2
In this ship we are considering 4 bulkheads on the car deck. We have already decided to try and phase out "1 compt" ships. So for this exercise, we have considered each of the 4 bulkheads damaged in turn.

#3
This shows an example with part of the car deck flooded. The thin lines correspond to the undamaged condition i.e. the KN values are taken up to the upper car deck. The thick lines on the other hand represent damage i.e. the intact stability of the vessel on the way of the damage has been lost. The values shown on the various GZ curves represent assumed depths of water on deck.

#4
This shows 4 survivability standards; the thin lines represent the intact ship; the thick lines the damaged ship. We can see here the effect of spacing of all the bulkheads and varying depths of water on the car deck in relation to survivability. For STAB '80 with 4 bulkheads, the ship can probably survive with 50mm of water on the car deck. SOLAS '90 on the other hand, can probably survive 0.5 meters of water on the car deck. This shows that the current standard in SOLAS for existing ships is very poor in comparison with SOLAS '90.

#5
This corresponds to flooding of the midships compartments and it can be clearly seen that in this case the effect of flooding is considerably more vicious.

#6
This shows depth of water flooding Vs angle of heel with various proportions of the car deck flooded. With 4 or 5 bulkheads on the car deck the ship has good possibility of survival even with 500mm of water on the car deck. Of course, all these are still water calculations, not storm sea and do not account for ship/seaway dynamics.

Vassalos
Continuing on the topic of the effect of Transverse Subdivision on survivability, I will now present some results from work undertaken at Strathclyde where both the seaway and vessel dynamics were accounted for. The ship in question is a sister of the Herald of Free Enterprise. In the scenario considered the transverse bulkheads were progressively moved towards the mid-ship (symmetrically about amidships) and at each position an investigation was carried out to identify the maximum seastate the ship could survive. The overheads show the results of simulations for damage below and above the vehicle deck as well as for flooding of only the vehicle deck.

#1
In this case with KG = 11.75m, (GM = 0.5m), it would appear that the vessel could only resist flooding of the main vehicle deck for very small compartment lengths and at only light seastates.

#2
At moderate KG's, the behaviour improves markedly with the vessel surviving moderate seastates with an undivided compartment length of 35m and all seastates with a compartment length down to 25m.

#3
At a low KG, albeit somewhat unrealistic, the vessel survives all seastates with a compartment length of 35m.

#4
Finally, when only flooding of the vehicle deck is considered, it becomes quite obvious that when progressing flooding takes place at the higher seastates, the undivided compartment length on the vehicle deck must again be reduced down to 25m for the vessel to avoid capsizing.

#5
From the results obtained, it would appear that hydrostatic effects are dominant and this means that the relationship between the static heeling moment generated by the water ingress and the vessel restoring ability is crucial. The parametric study indicated that there is an almost linear relationship between the amount of water in the undivided vehicle deck and the residual GM, as shown in this overhead. The critical amount of water on the vehicle deck before the vessel capsized appear to be in the range of 10% to 25% of displacement, depending on the value of GM.

#6
Considering flooding of the main vehicle deck only, provides a good insight regarding the cause of the vessel capsize when considering a long undivided compartment on the vehicle deck. This derives from an examination of the movement of the water on deck indicated by the locus of its Transverse Centre of Gravity (T.C.G.), shown in the overhead. When the compartment length is small (15m) the vessel's restoring ability resists the heeling moment of the water on deck and the vessel, after some initial transient motion, settles to performing small symmetric oscillations.

#7
Increasing the compartment length to 35m, the vessel can no longer resist the static heeling moment created by the water flooding the vehicle deck and she capsizes without preceding large oscillations, in an almost static manner. This is clearly seen by examining the trends shown in the graphs of this transparency. The fact that the locus of the T.C.G. of the water on the vehicle deck is asymmetric indicates that as long as flooding is progressive, vessel capsizal is inevitable. It is worth noting that the roll rate increases exponentially when the static heeling moment becomes critical and the vessel capsizes very quickly.

Mr Allan
Is that 25m at amidships?

Vassalos
Yes.

Allan
Then the compartment length forward of amidships could be longer.

Vassalos
It is evident that the compartment length on the car deck would vary with the beam of the ship.

Hormann
Both presentations are providing capsize safety by placing w.t. bulkheads on the car deck but we should not confine our efforts to only adding transverse bulkheads. We should decide on the general goal. In my view the goal should be that a certain amount of water can safely be taken on the car deck without causing immediate loss of stability. Before the Estonia, most of us were of the opinion that such an accident had to be prevented operationally, not by more regulations or design limits. Now we are convinced by real life (Estonia) that ship design must be changed to help prevent sudden capsize in future. But we should not do two steps at once. We should say what a ship should be able to sustain and not prescribe the ship configuration.

Vassalos
Regarding the question of subdivision, if the whole problem can be reduced to something static in nature, then it can be addressed at Naval Architects at the design stage.

Allan
It could be so, but there are ships with fore and aft casings on centreline which may be able to survive flooding of the car deck without adding transverse bulkheads. The question is, how must water can be taken on the car deck without immediate capsize? In Scandinavia there is a view that all vessels should be able to survive 500mm water on the car deck. Since it is impractical to consider unlimited flooding on the car deck, a decision must be made for calculation purposes prescribing either half a metre of "X" metres.

Vassalos
The majority of the research so far has addressed only open decks because the dominant effect is always that of the water on deck. So let us return to the original question. Are there objections to the provision of bulkheads, transverse of longitudinal on the car deck?

Allan
The ship cannot be subdivided completely fore and aft. The shape of the bow dictates that a transverse bulkhead must be added near the bow.

Rutgersson
Also, since the bow door accident has now occurred twice, it seems that a bulkhead near the bow is needed. There are other accidents just as likely, perhaps more so, such as shifting of cargo. If longitudinal bulkheads are included on the car deck they could also help prevent cargo shift.

Allan
Whatever new system is required, it should not have any adverse effect on the other systems.

Hormann
In any case, I do not think it will be possible to say, 1m or 2m or ½m of water. There are several parameters influencing the possible amount of water on deck for example, freeboard. The higher the car deck is above the waterline the less water may enter the car deck.

Allan
SOLAS '90 required raised freeboard. There is about a 1m difference is freeboard between Stab '80 and SOLAS '90 for the conventional European ferry.

Vassalos
Whether you consider flare or freeboard or any other safety device and the car deck remains undivided, the ship will capsize given a high enough seastate. So we are back to the same question. Will ship owners and operators accept bulkheads on the car deck? If nothing is done to reduce the access of water to the car deck, the ship will capsize. In this case, we must ensure by some means that the ship will not capsize at least in the way the Herald and Estonia did.

deKat
Perhaps we should ensure that the ship will be able to survive for "X" hours after a breach of the hull.

Rutgersson
Another problem of the Estonia accident was that the water very quickly entered the engine room. We do not understand why it entered the engine room so quickly.

Allan
This was discussed before on the Herald and it must be discussed again. All access to below the car deck on the Herald was from the car deck. I think no access to the engine room should be permitted from the car deck.

Hormann
We would be well advised to decide upon acceptable scenarios of what amounts of water can enter. By scenarios I mean we should think not just of the bow door but also other accidents. More probable by far is the chance of a collision in bad weather with the ship being hit aft of the collision bulkhead. We have had such accidents in the North Sea. In case of damage above the waterline, what would happen in certain seaways? Frequently, wind and sea states have to be accepted as possibly causing water to enter the car deck.

Vassalos
Are you addressing a divided deck or not?

Hormann
It is the designers task to decide if bulkheads are needed, if the flooding from the scenario will endanger stability, perhaps grids on the car deck would be the better answer.

Vassalos
I keep bringing up the subject of subdivision back but the panel keeps putting forward alternative answers. Therefore, they seem to suggest that it is important to realise bulkheads are not the only answer.

Sonnenschein
It seems that a collision bulkhead behind the bow door should be considered. However, if there is a collision and water is getting on the deck it only buys time; the water will continue to fill the ship through the grid until it sinks.

Vermeer
In my opinion, there is always a scenario that is greater that which is assumed.

Vassalos
In this respect, what is the answer?

Vermeer
Water on deck must be removed from the ship eventually.

Allan
There must be other ways to achieve protection from car deck flooding. In my view, the solution must be a passive (built-in) system. Too often an active system such as pumps will malfunction at the critical time.

Vassalos
Prof Pawlowski's system is an example of a passive system. Would you go along with his suggestion.

Allan
Yes, it sinks the ship upright rather than permitting capsize.

Audience, double hull? / engine room.

Allan
That is why I said that we must be careful not to hinder something else. I am not convinced that fitting transverse bulkheads would cause RoRo's to disappear. Especially those that have a long turn around time in port. It might cause difficulties for the quick turn around ships. But no matter what choice is made, some vehicle lane space will be lost (perhaps 10-15%).

Rutgersson
Should we accept a lesser standard RoRo ships which are only cargo ships, not carrying passengers.

Hormann
Definitely no. It makes smaller headlines but each life should be equally valuable.

[Ed note SOLAS has many such regulations wherein cargo ship do not protect life to the same extent as passenger ship]

Rutgersson
But it must be very different to evacuate 2,000 passengers that 20 seamen.

Hormann
The problem being considered here in this workshop is the physical phenomenon of capsize which is fatal to most people no matter how skilled they are in sea matters. Capsize occurs in 1/2 a rolling period. So this should not be acceptable from the regulatory point of view.

Vassalos
This is probably true for intact ship capsize but in a damaged ship capsize may be much slower. Often there is a gradual increase in heel that could last up to one hour.

Rutgersson
Saying this, there is of course another very real question. How long would it take to evacuate 2,000 passengers in a snow storm in the Baltic.

Vassalos
As we have only a few minutes left I should like to ask Mr Sonnenchein to say a few short words.

Sonnenchein
Returning to the basic question of subdivision on the car deck it seems clear from the discussion here that there are a lot of unanswered questions and that we should "punch the numbers on" to discover relative merit of each idea. Before a decision is taken we should review the results of several analyses.

Vassalos
With that statement, we have an excellent opportunity to sum up the discussion. We should not rush to conclusions, we should look for alternative ways to prevent capsizing of RoRo ships when water gains access to the car deck.

My sincere thanks to the panel and to the audience as well.

TRANSPARENCY BY DR UMEDA

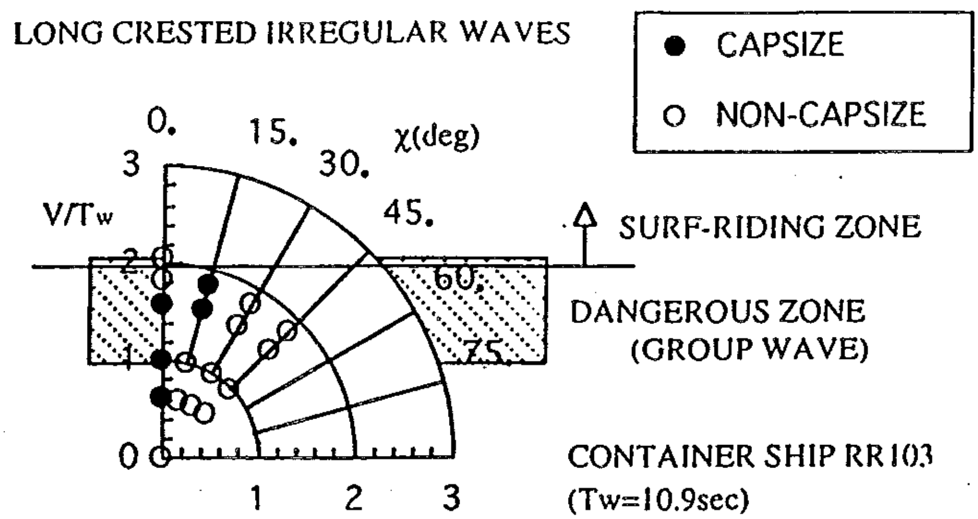


Fig A: Experimental Results and the Proposal from the IMO Draft Guidance ($H_{1/3}$ = 13.3m)

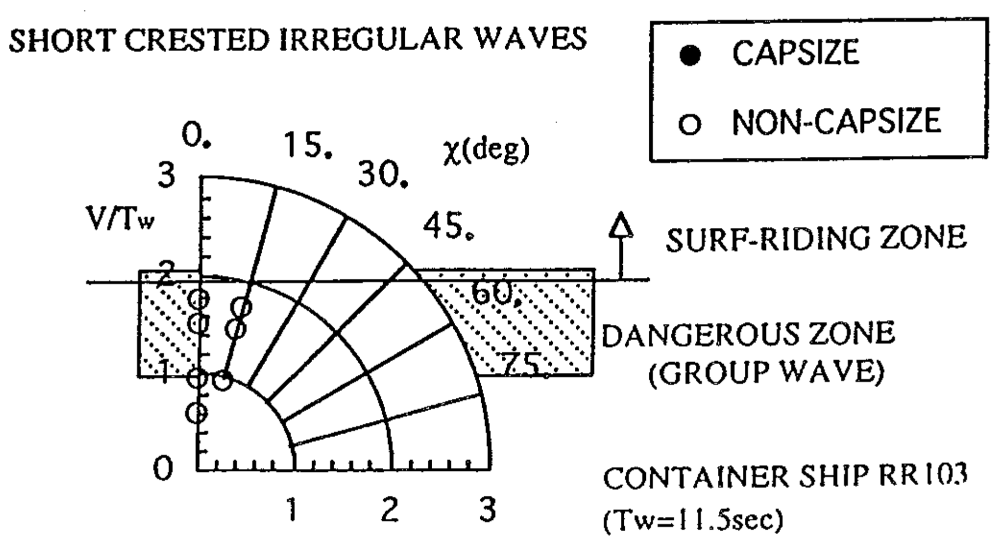
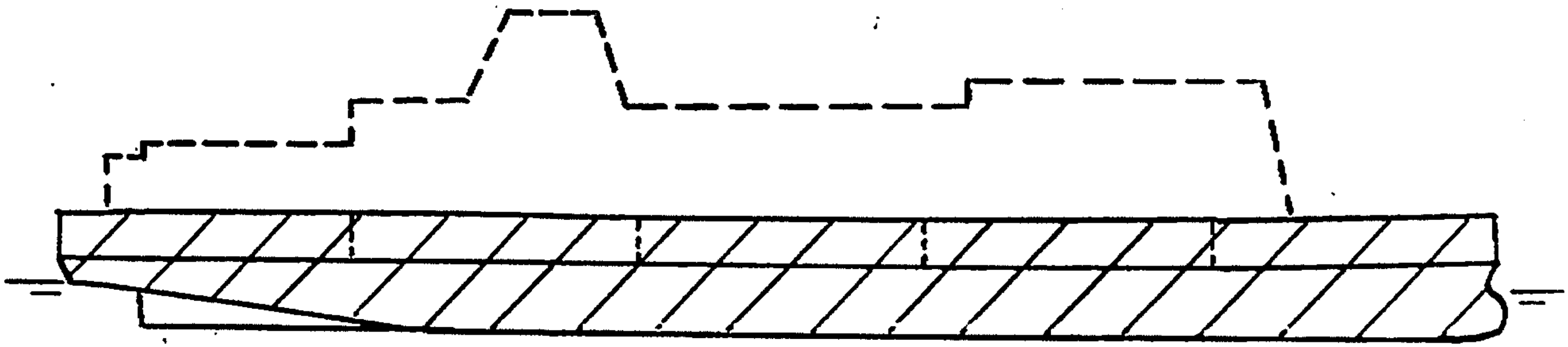


Fig B: Experimental Results and the Proposal from the IMO Draft Guidance ($H_{1/3}$ = 13.7m)

Water enters but the structure of the vessel remains substantially intact. ie The righting levers (KN's) remain virtually unaffected.



#1  Part of Vessel included in KN's

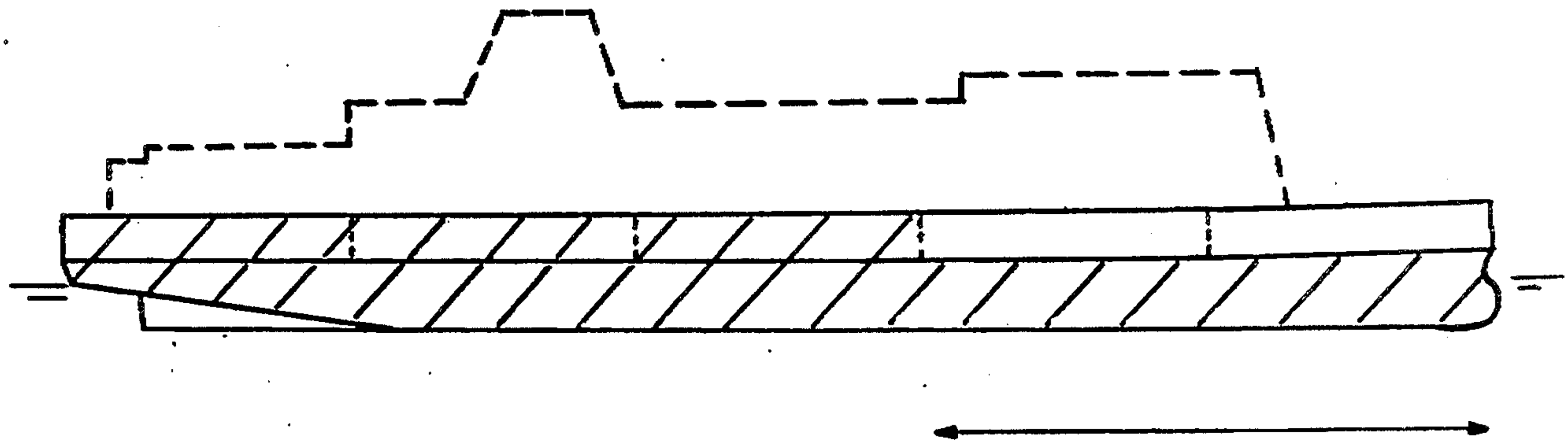
MSA
MARINE SAFETY AGENCY

Case 1

TRANSPARENCIES BY MR ALLAN

The flooded portion of the vessel is assumed completely open to the sea, such that it no longer makes any contribution to stability.

However, any water entering the flooded space is considered to become trapped due to resistance presented by cargo, debris etc.



#2  Part of Vessel included in KN's

MARINE SAFETY AGENCY

Case 2

TRANSPARENCIES BY MR ALLAN

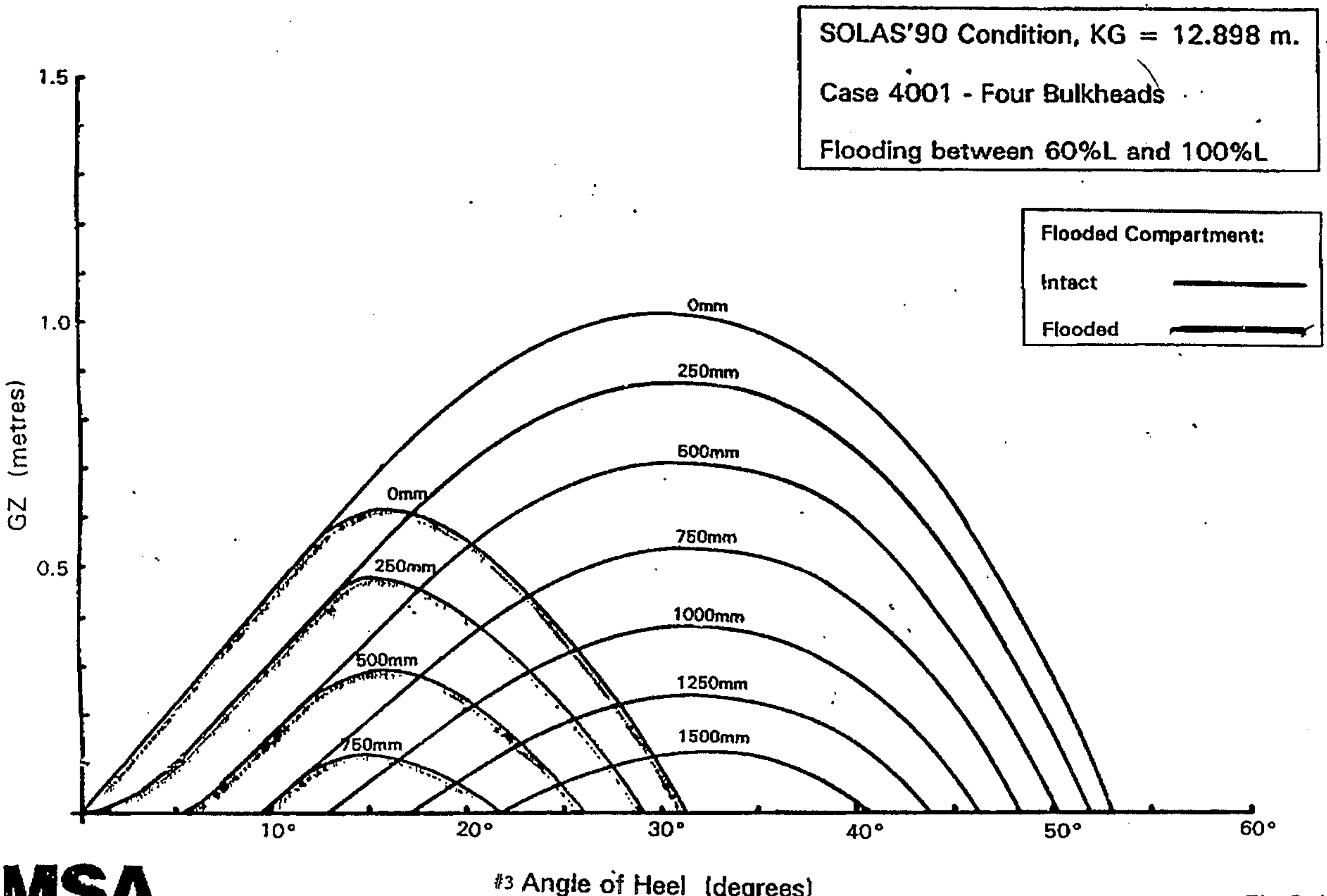
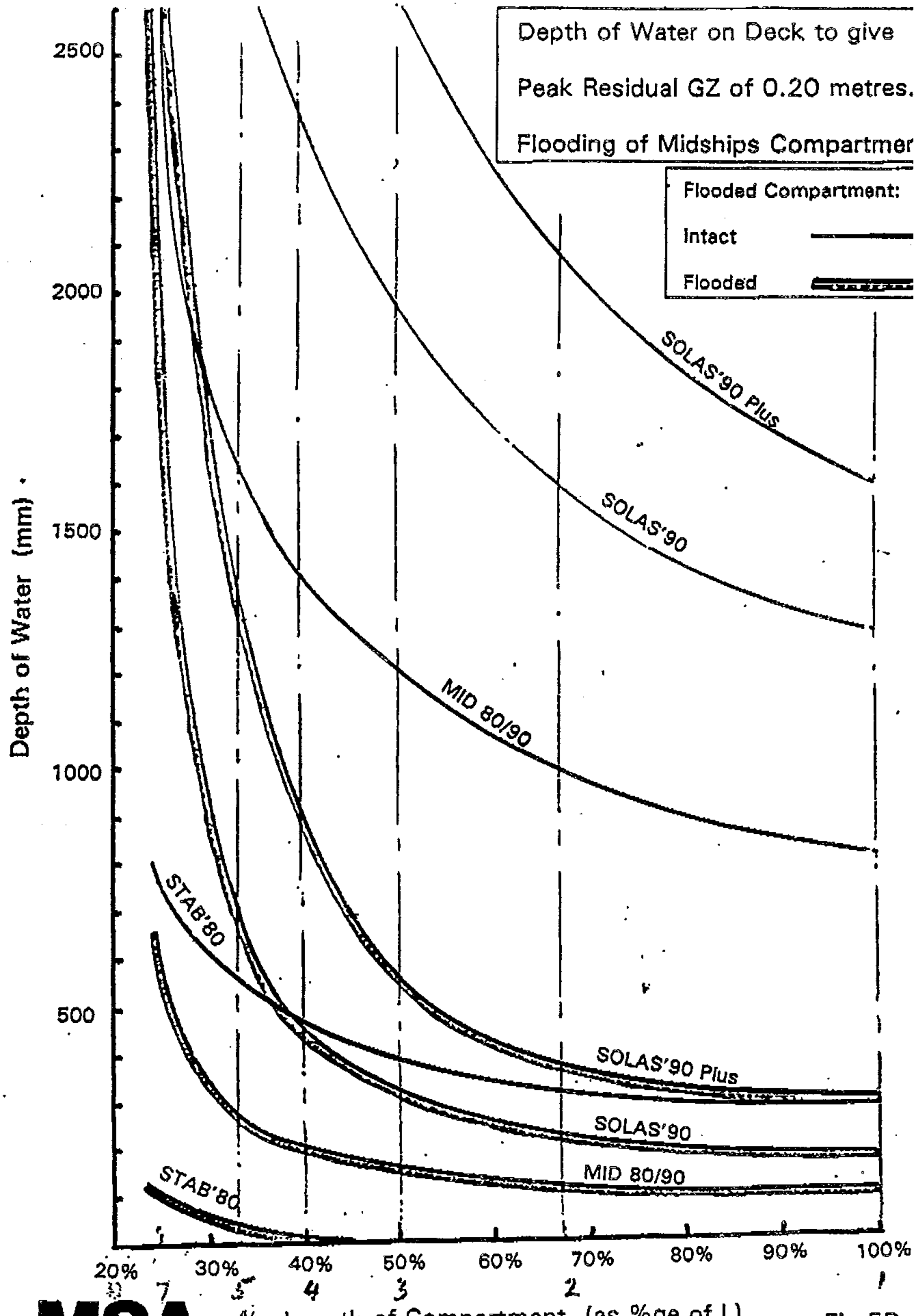


Fig 2.1

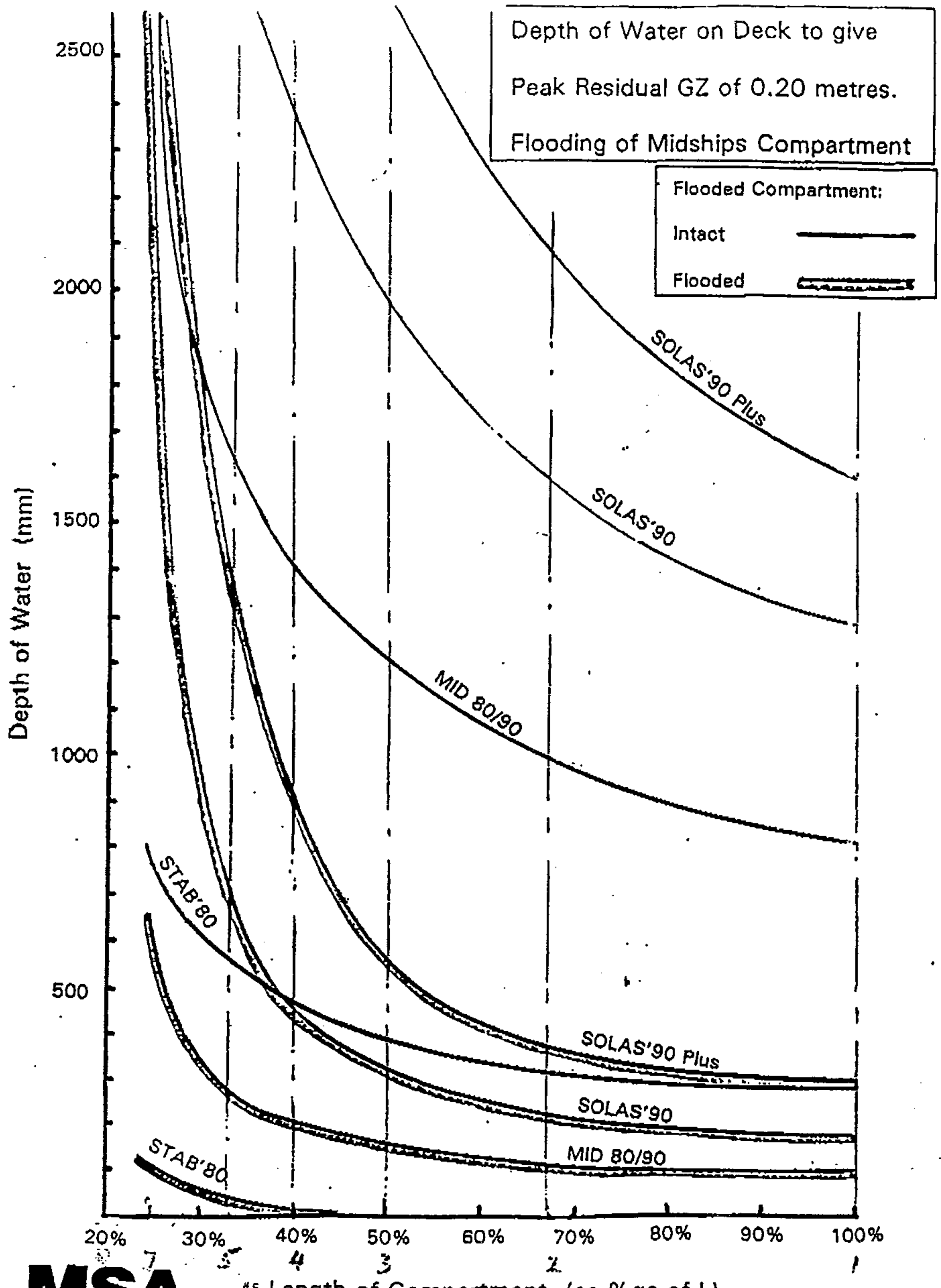
MSA MARINE SAFETY AGENCY

TRANSPARENCIES BY MR ALLAN



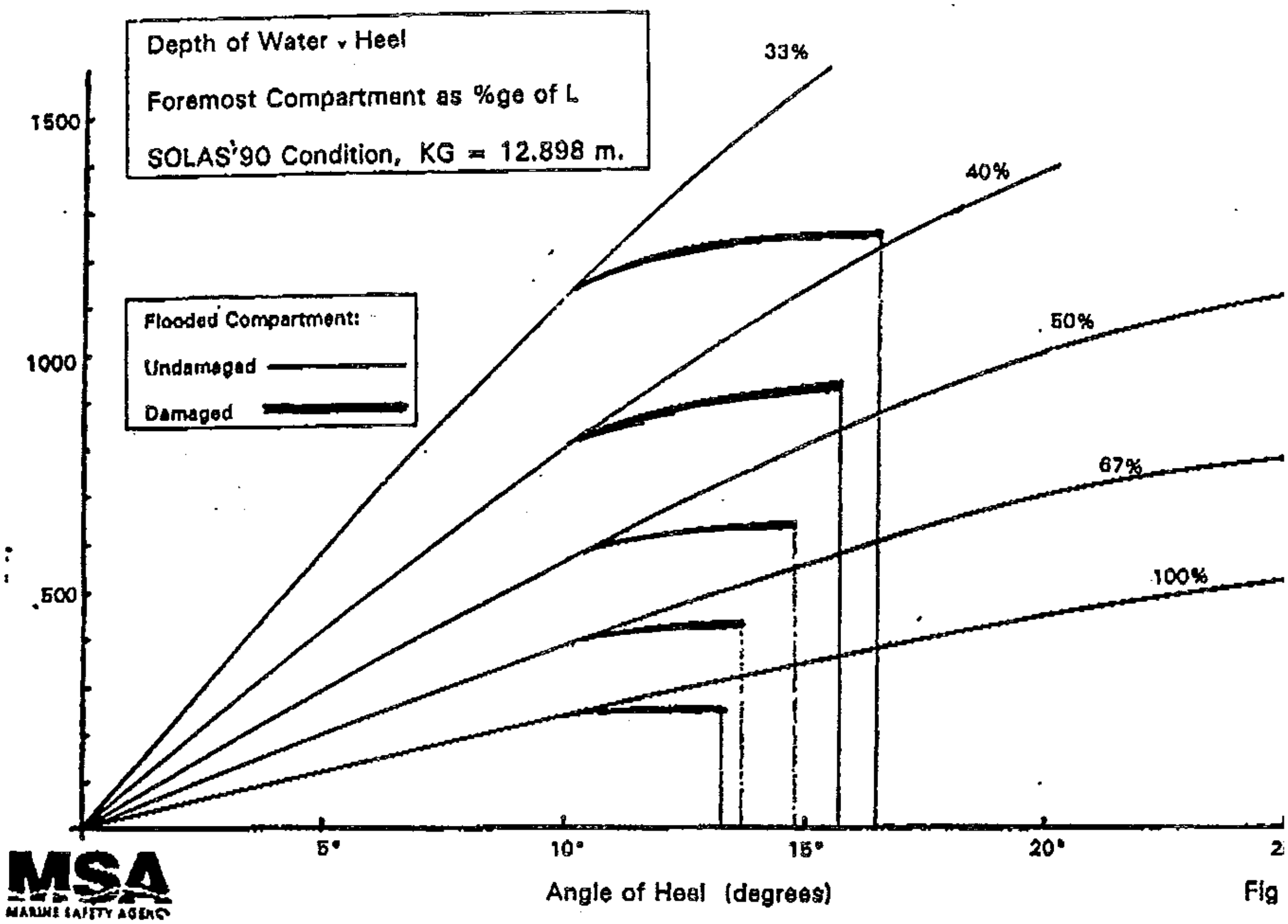
Depth of Water on Deck to give
Peak Residual GZ of 0.20 metres.
Flooding of Midships Compartmer
Flooded Compartment:
Intact
Flooded
Depth of Water (mm)
2500
2000
1500
1000
500
SOLAS'90 Plus
SOLAS'90
MID 80/90
STAB'80
SOLAS'90 Plus
SOLAS'90
MID 80/90
STAB'80
20%
30%
40%
50%
60%
70%
80%
90%
100%
7
5
4
3
2
1
#4
Length of Compartment (as %ge of L)

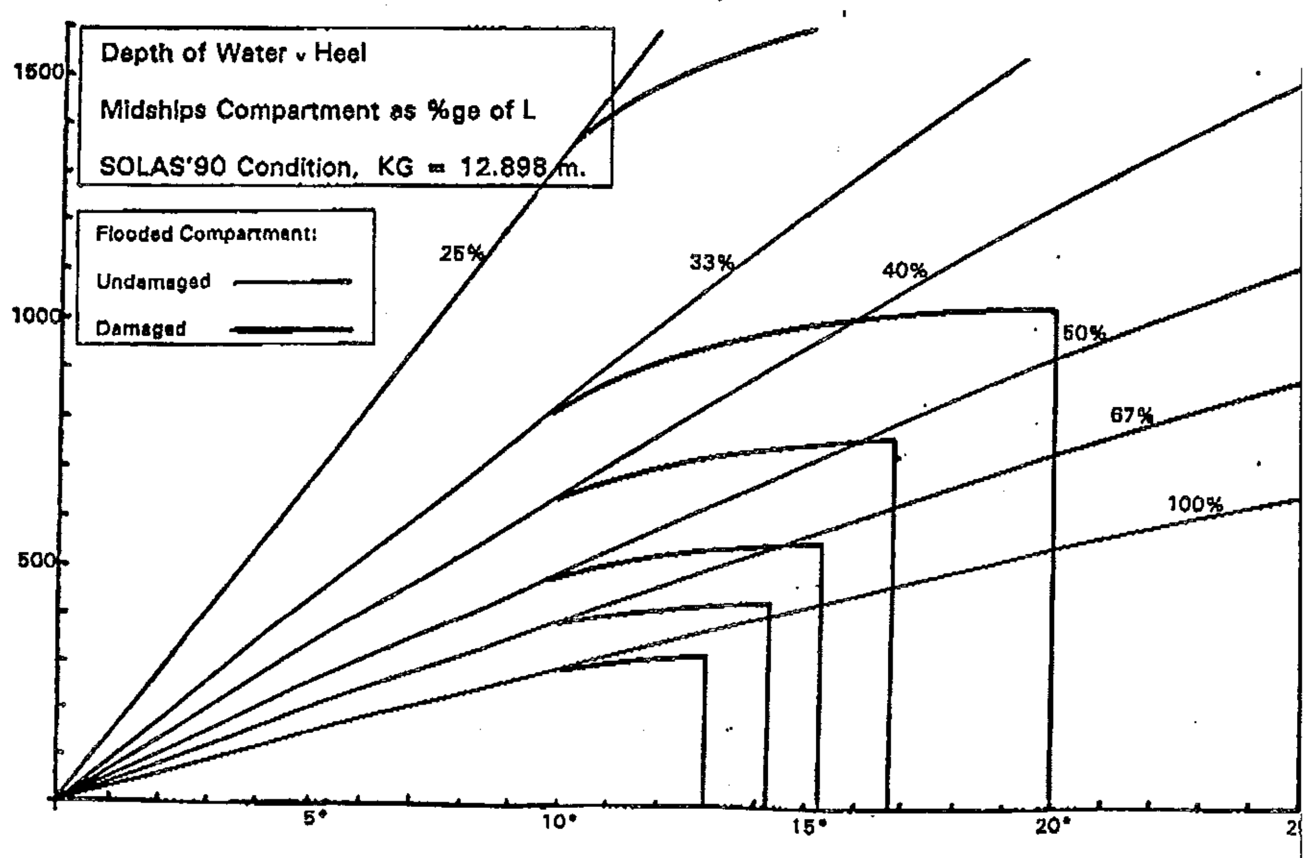
Fig 5B



MSA MARINE SAFETY AGENCY

Fig 5B





#6 Angle of Heel (degrees)

TRANSPARENCIES BY MR ALLAN

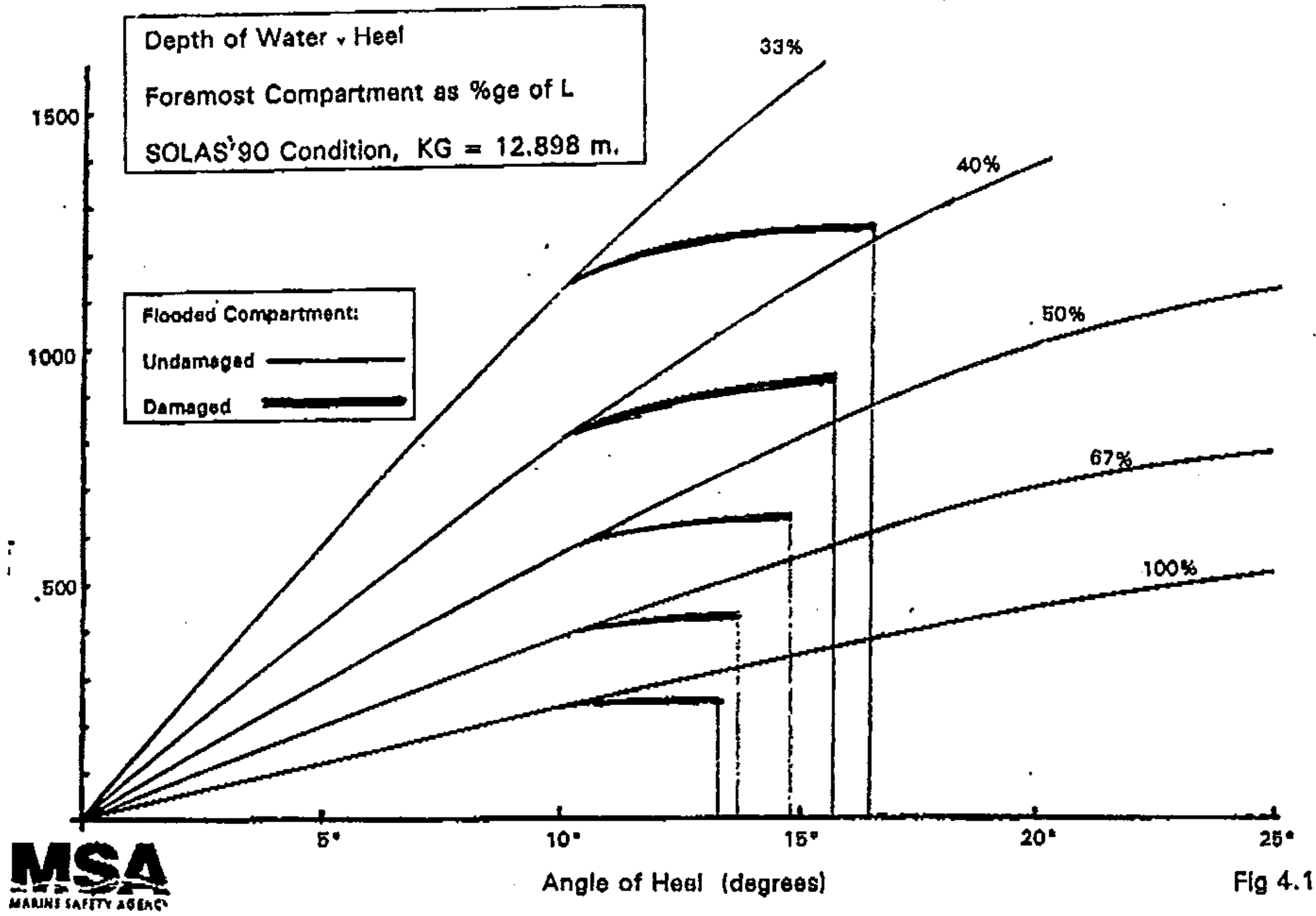
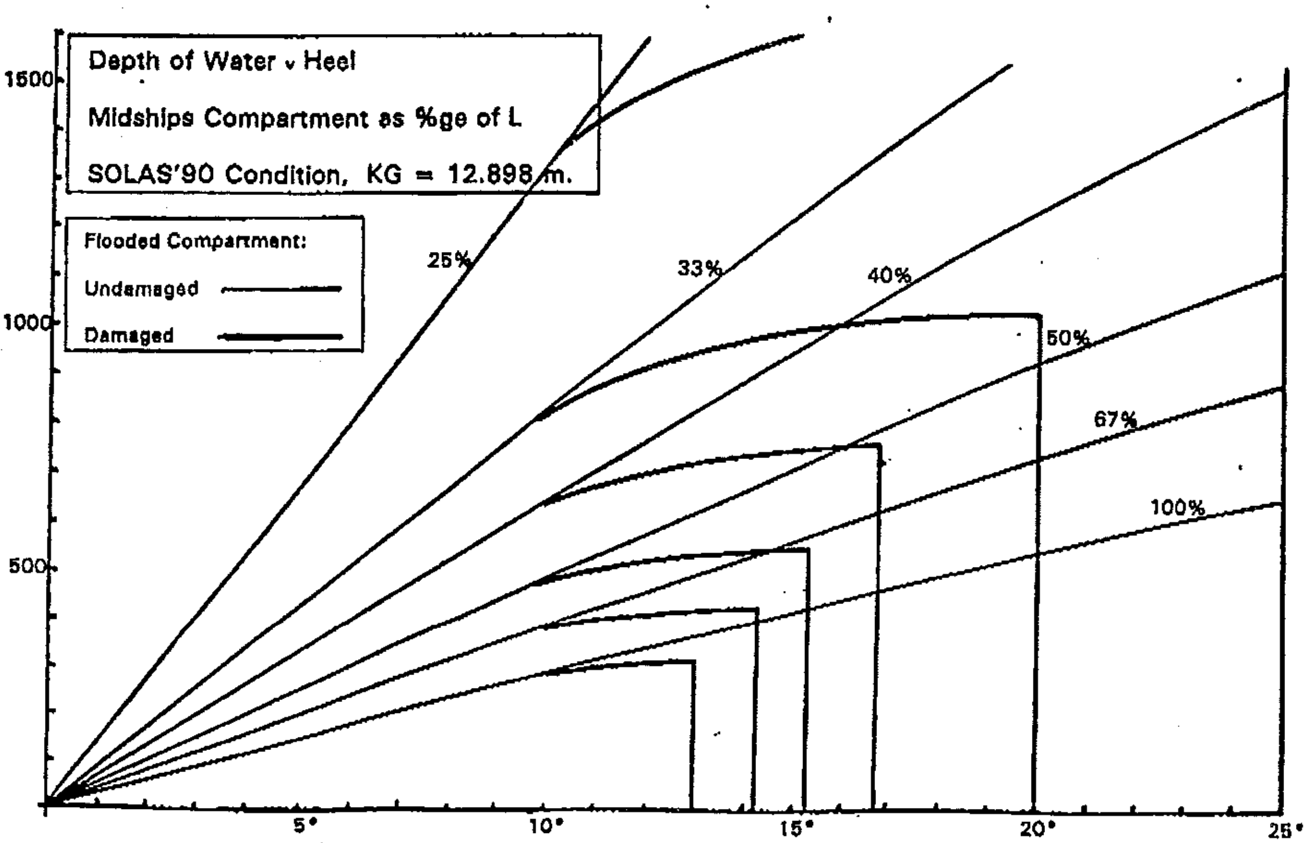
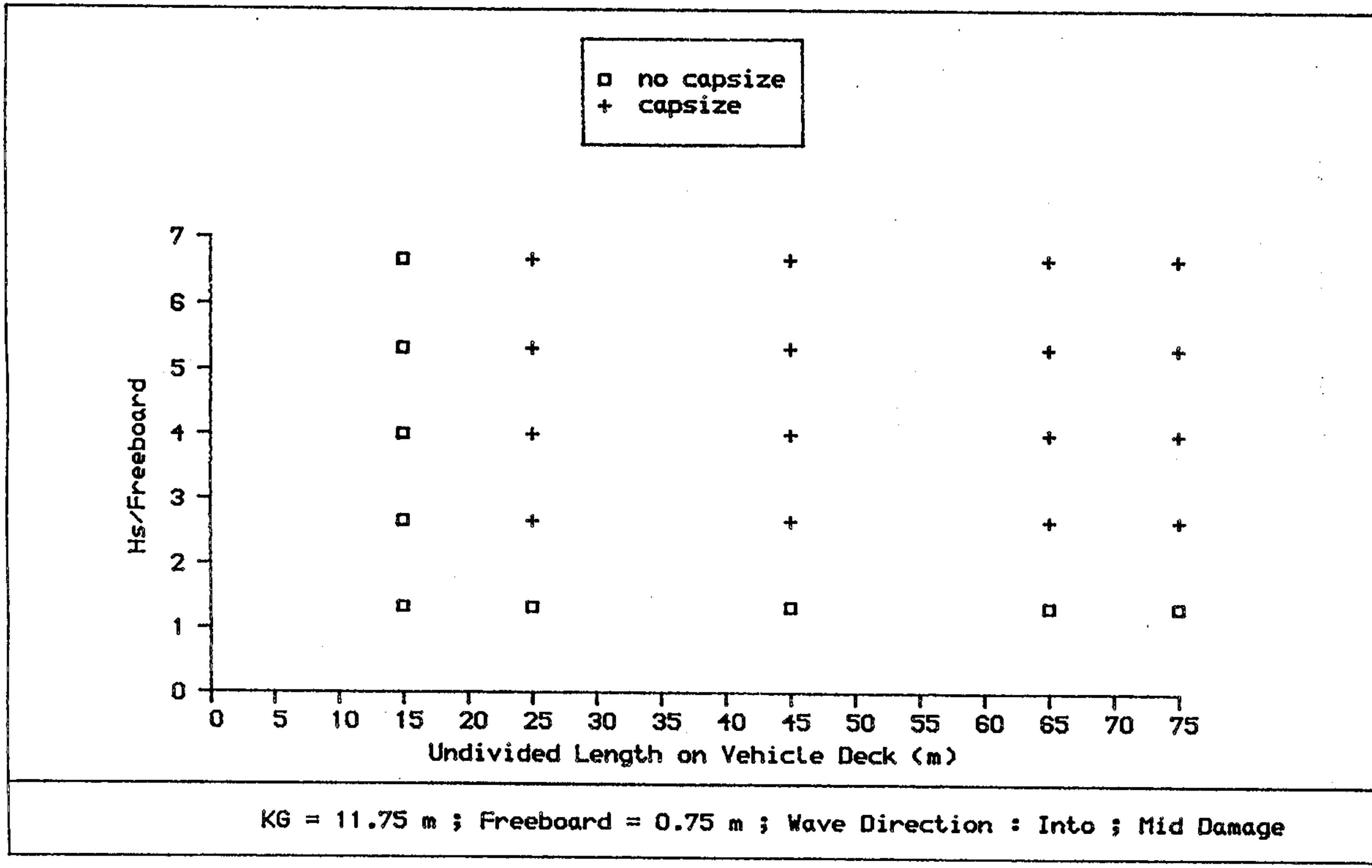


Fig 4.1

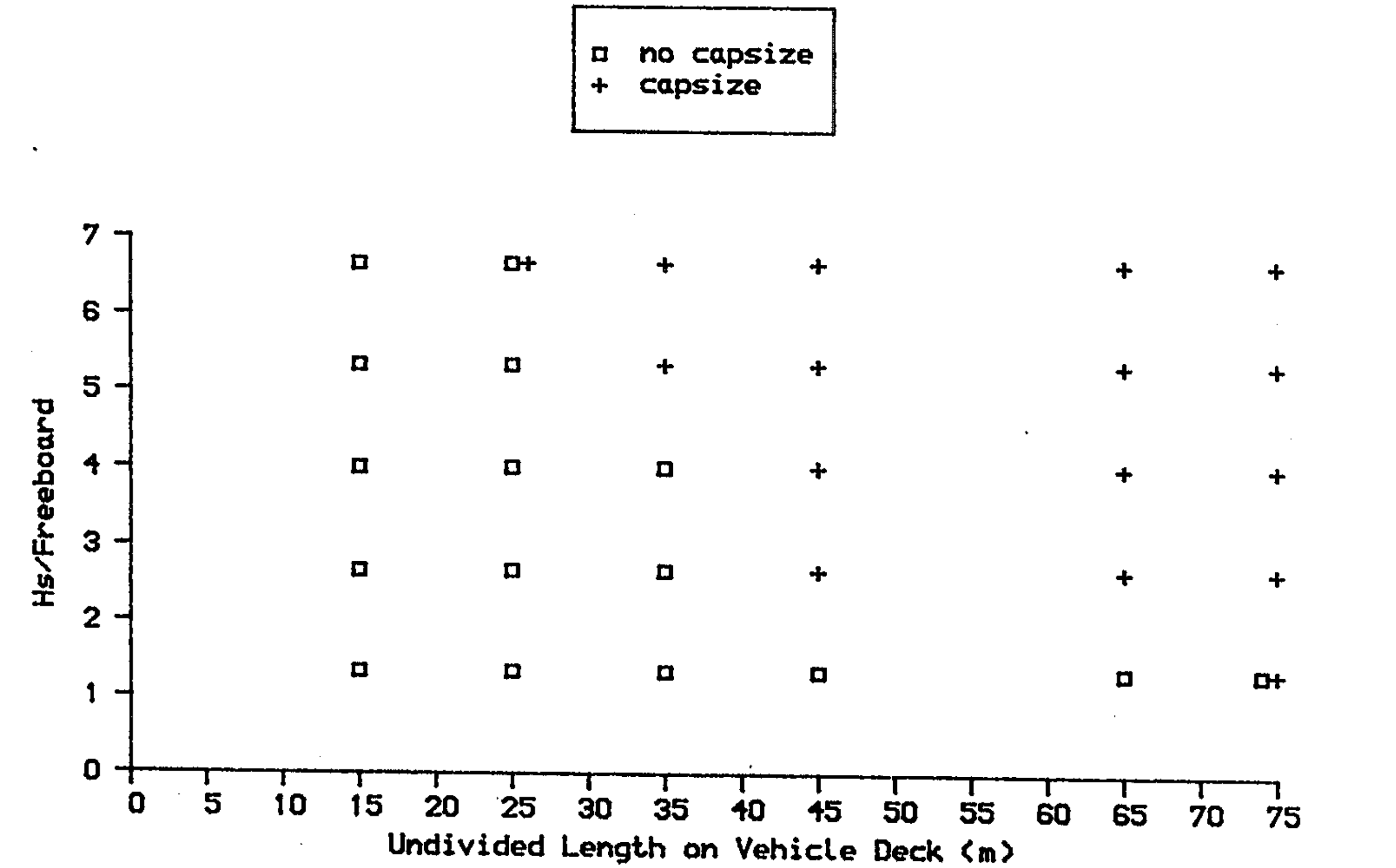


TRANSPARENCIES BY DR VASSALOS



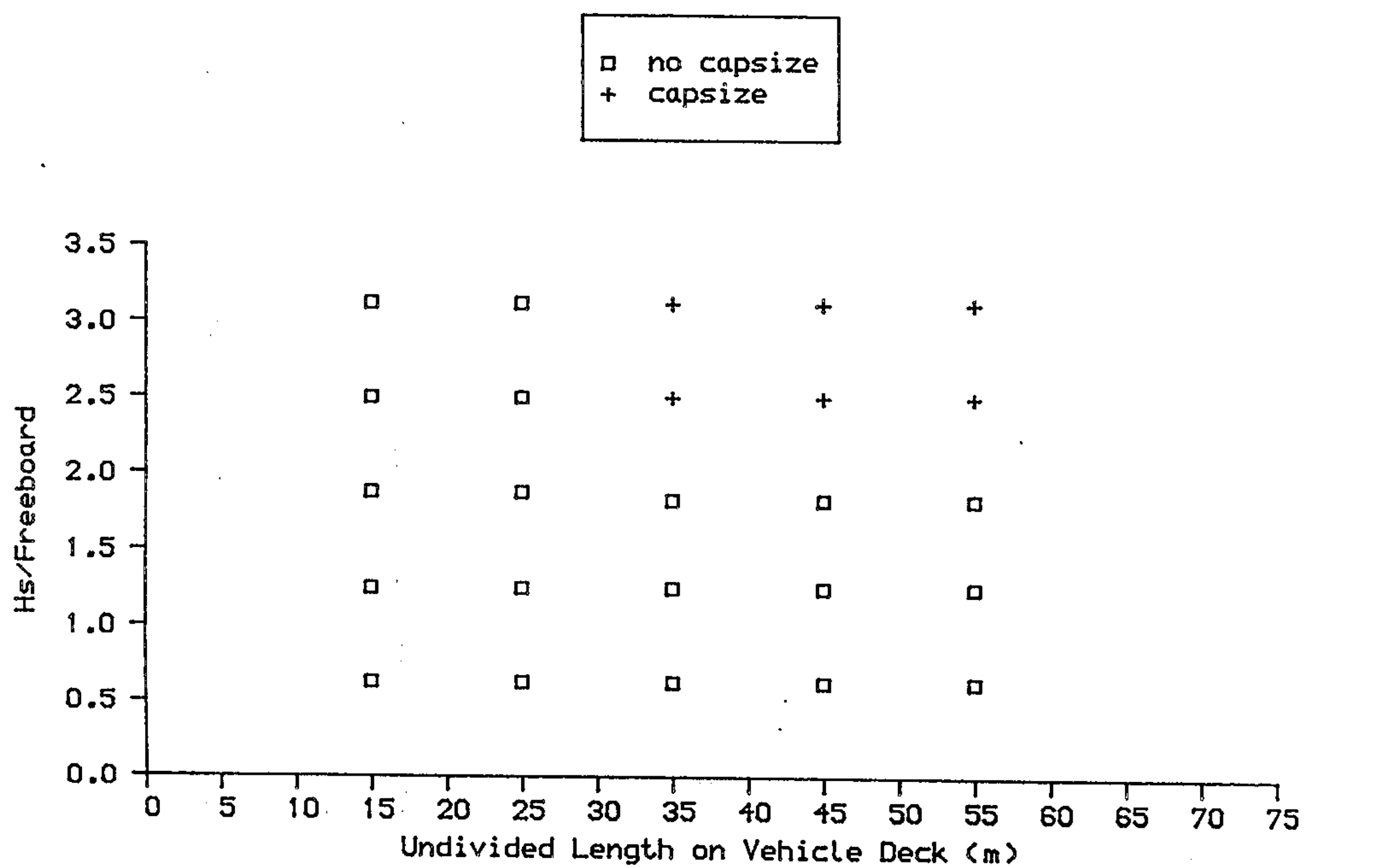
#1 Effect of Transverse Subdivision Above the Bulkhead Deck on Survivability

TRANSPARENCIES BY DR VASSALOS



KG = 10.5 m ; Freeboard = 0.75 m ; Wave Direction : Into ; Mid Damage

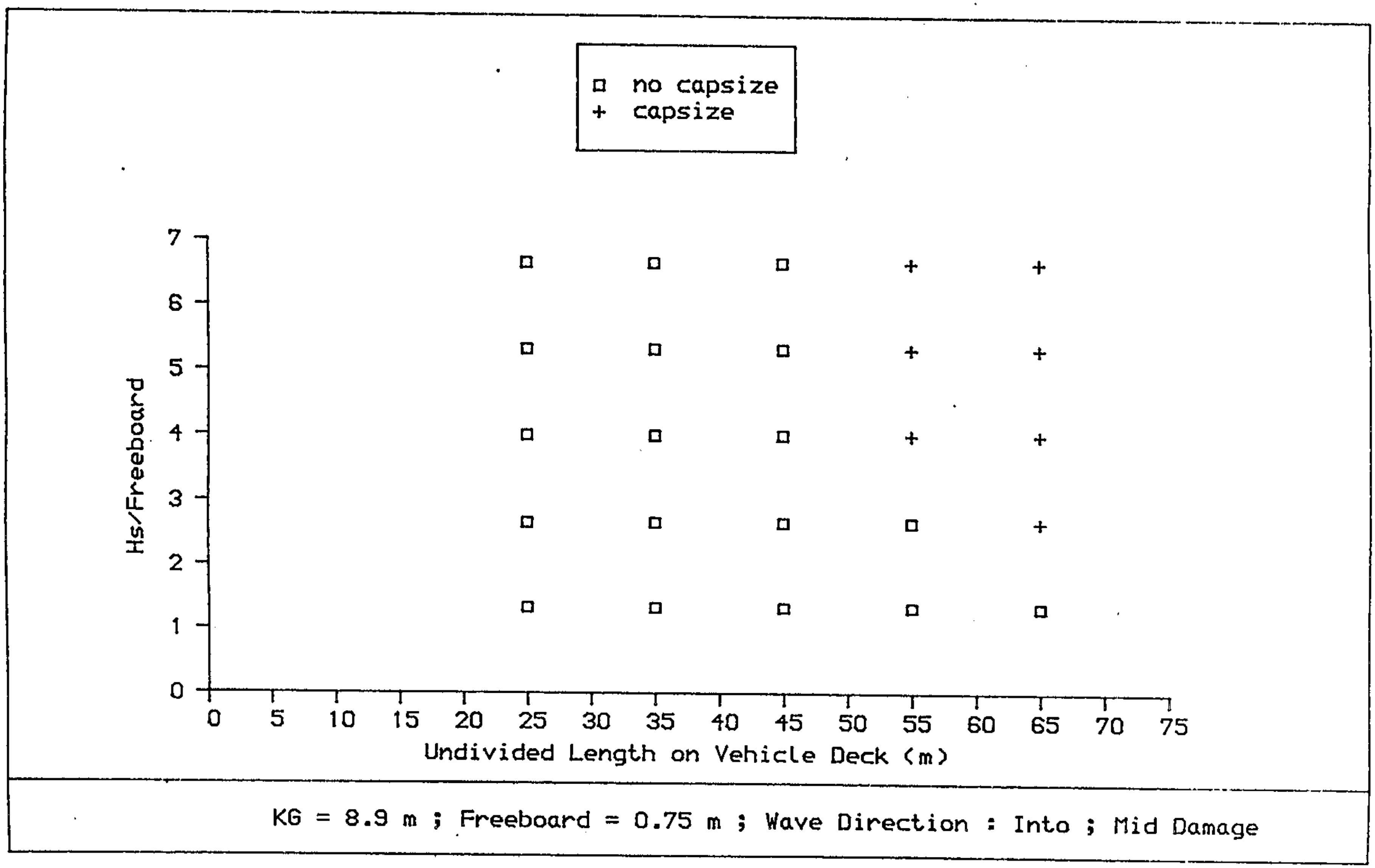
#2 Effect of Transverse Subdivision Above the Bulkhead Deck on Survivability



KG = 10.1 m ; Freeboard = 1.6 m ; Wave Direction : Into ; Mid Damage

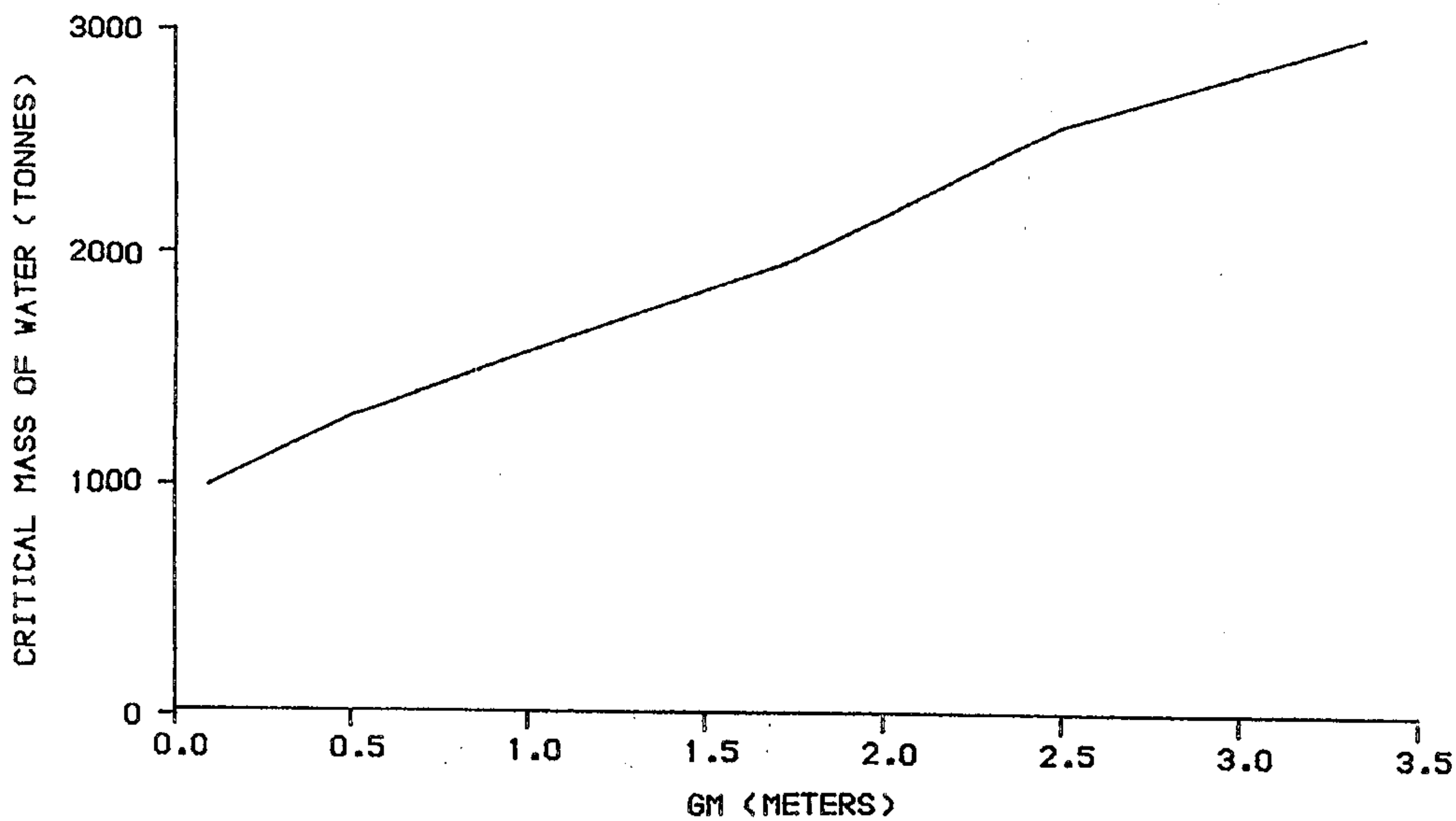
#4 Effect of Transverse Subdivision Above the Bulkhead Deck on Survivability

TRANSPARENCIES BY DR VASSALOS



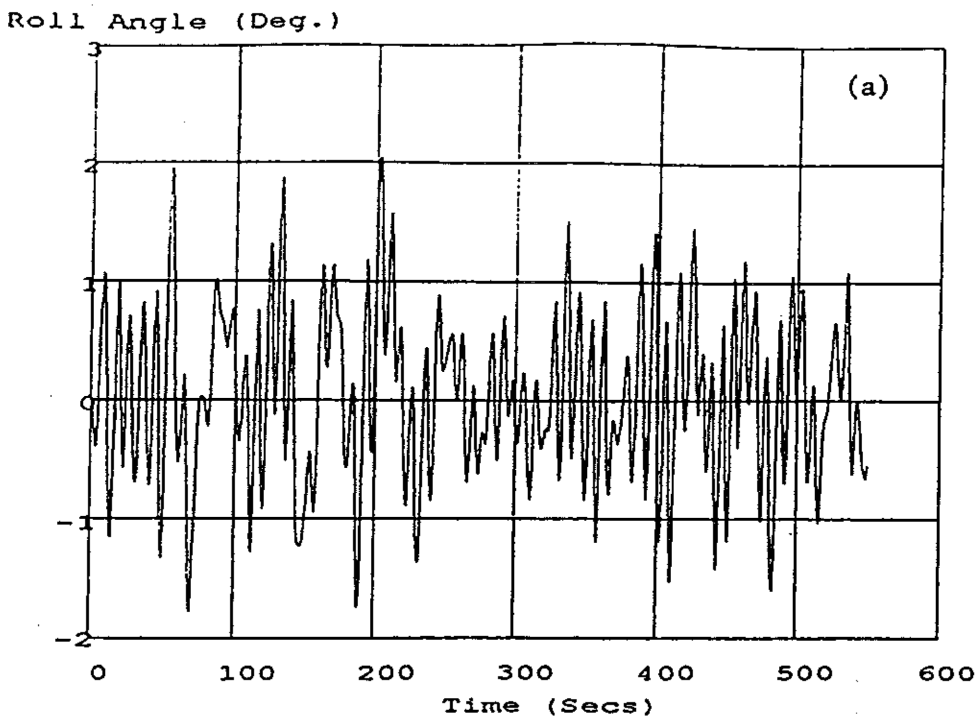
#3 Effect of Transverse Subdivision Above the Bulkhead Deck on Survivability

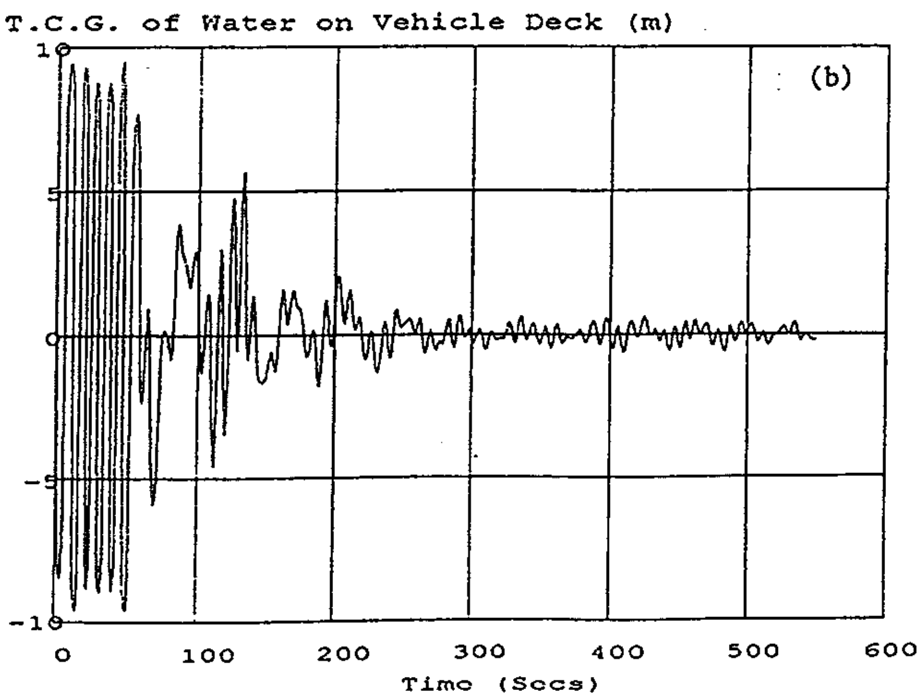
#2 USER: CLHR04 PLOTFILE: DOTHAT ENTRY NO. 31932 QUEUED ON 14/10/92 AT 13:00 PLOTTED ON 14/10/92 AT 13:00



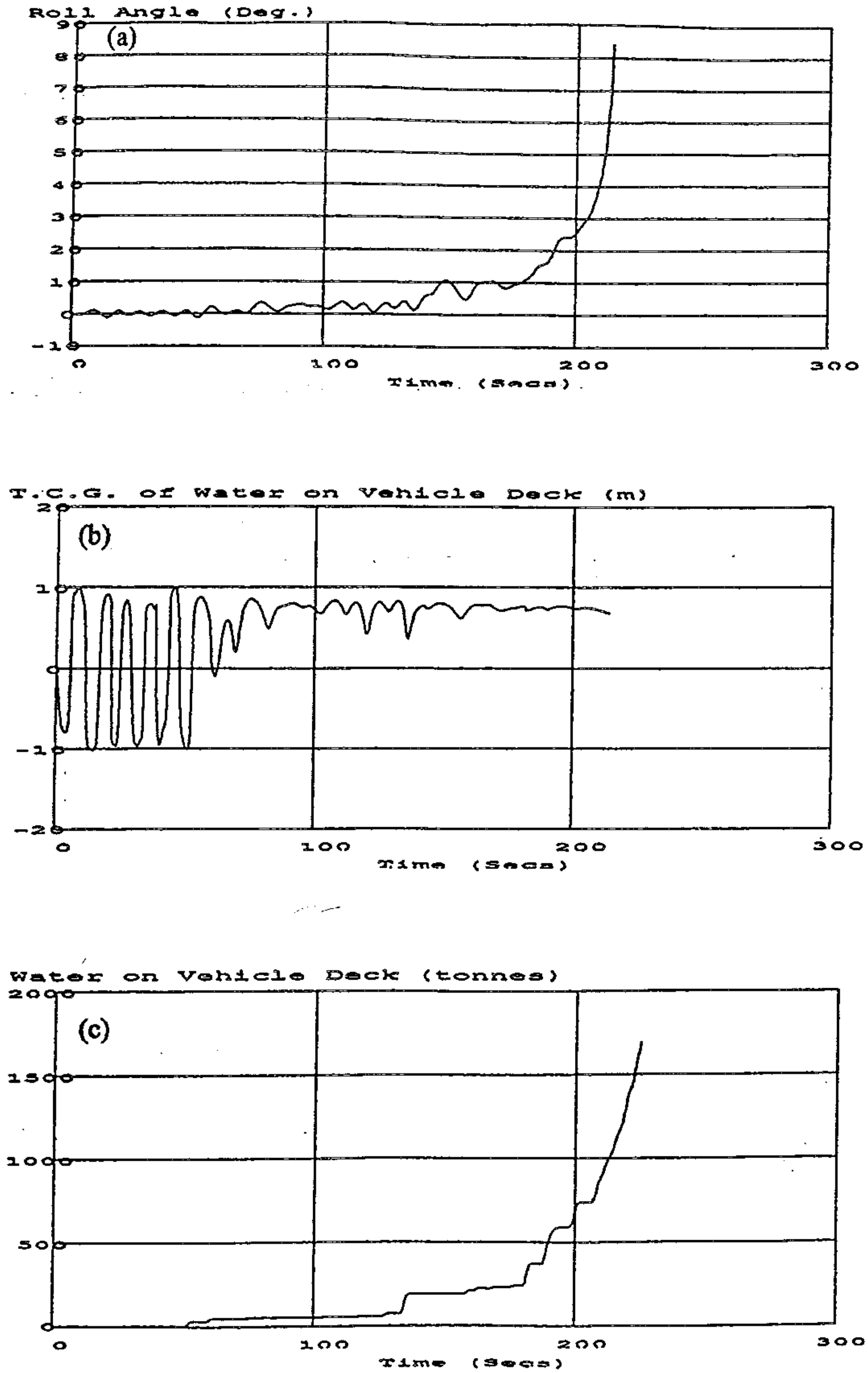
#5 Effect of GM on the Critical Amount of Water on Deck

TRANSPARENCIES BY DR VASSALOS





#6 Compartment Length = 15m; Hs = 5m; To = 6.5 secs;
GM (Int.) = 1.72m; Freeboard (Int.) = 1.6m



#7 Compartment Length = 35m; Hs = 5m; To = 6.5 secs;
GM (Int.) = 1.72m; Freeboard (Int.) = 1.6m

TRANSPARENCIES BY DR VASSALOS

STAB '94
Supplementary Workshop
on RoRo Stability Safety and Hull Integrity
Tuesday evening 8 November
Moderator: Mr. W. A. Cleary, Florida Institute of Technology

Introduction

As a result of the flooding, capsize, and sinking of the M.V. Estonia in the Baltic Sea approximately a month before the opening of STAB '94, at the opening session of STAB '94 the delegates requested an extra workshop during STAB '94 on the specific subject of RoRo stability including watertight and weathertight integrity.

Accordingly the STAB '94 Secretariat scheduled an evening workshop on Tuesday 8 November in the auditorium of the Central Baptist Auditiorium, also the venue of all 7 regular workshops.

Approximately 90 of the 110 delegates to STAB 94 attended. The workshop was chaired by STAB '94 chairman, W.A. Cleary. The following is an executive summary of the speakers comments and presentations of this workshop.

Introduction to the workshop (W. A. Cleary)

Mr. Cleary showed (by several transparencies) the overall safety functions; those related to capsize and car deck flooding. He noted that the safety functions which may have contributed to the ESTONIA casualty were:

1) Hull integrity
2) Strength
3) Weathertight integrity of topsides
4) Arrangement (e.g. internal bulkheading)

Another transparency showed the three step international safety regulatory approach:

1) prevention of accidents
2) minimize the consequences of the accident
3) escape for all human beings on board

Another transparency showed the "old cargo ship concept" of standard bulkheading in ships before 1969 when the classification societies dropped their rule for a full watertight bulkheads spaced approximately 100 feet (30m) apart throughout the ship. These bulkheads were expected to be full height - keel to weather deck (or tween deck) bulkheads. The strong economic pressures of 1966-1970 caused the rule changes and the bulkhead rules were eliminated for the early RoRo ships which were treated as cargo ships carrying lorries (trucks) and truck drivers but very few passengers. Horizontal flow of cargo was generally accepted by the maritime world by 1970.

Doors, internally fitted throughout the ship to facilitate movement by individuals as well as cargo should be closed five minutes before any accident, i.e. they should be closed at all times at sea. Example - European Gateway casualty.

Prof. C. Kuo - University of Strathclyde

- Noted the opportunity for this distinguished group of experts to state opinions on RoRo safety.

- Very few of us can have accurate information on the specifics of the ESTONIA sinking so soon after the casualty.

- Worthwhile to discuss fundamental, philosophical points.

- Goal of ship operator is economically competitive ship which meets safety requirements.

- RoRo ship concept provides a competitive solution because it competes successfully with other methods of transport. It can load and unload very quickly.

- The question is "is this method acceptably safe?"

- Safety level would be discussed in his workshop the next morning.

- Options include transverse bulkheads or longitudinal but there are probably many ways to provide internal safety.

- Believe RoRo ships can be made safer but remember that "at the end of the day, the ship must be competitive".

Tom Allan - Maritime Safety Agency, U.K.

- Referred to the just completed workshop on Capsize Thresholds in which he spoke at length on the effect of water on deck.

- Evacuation: should we be looking at other means of getting 2000 people off one of these ferries?

- Downloading: should we have access to spaces below from the car deck?

- Scuppers in car decks should be able to free 500-600 tons of water. We know that on some ships the fire sprinkler "drenchers" almost immediately create six feet of water on the deck.

- Although he accepts (with Prof. Kuo) that continuing research is needed, the two major casualties in the last seven years calls for immediate solutions.

- The public has lost confidence in RoRo carriers. We must address the problem now.

- Mr. O' Neil (IMO) has created an emergency panel of experts. We need to feed ideas to the panel to come up with a quick solution. The safety legislation resulting from the HERALD OF FREE ENTERPRISE (1987) just cleared parliament (1994).

- administrations need your views on the items above to come to a quick solution.

- Europe cannot survive without RoRo's.

- There must be some immediate design solutions.

- Although collision is still the most likely scenario for sinking (hence for safety review) neither the HERALD nor the ESTONIA accidents were collision; both involved failure of hull integrity (one in calm seas, the other in storm seas).

- in the opinion of Mr. Allan - access to compartments below the bulkhead (car) deck should not be permitted from the car deck itself but rather from higher decks.

- quick flooding of engine spaces from water on car decks results in loss of electrical power, pumps etc. and propeller on maneuvering as well

- doors: all kinds will be looked at by UK/MSA.

Prof. M. Pawlowski - University of Gdansk, Poland

- Showed several transparencies showing a novel car deck construction arrangement with drainage grids to encourage instantaneous automatic drainage of water on the car deck to lower spaces in the hull. The principle advantages were the prevention of the virtual loss of GM from the large free surface on the car deck and the prevention of the actual rise in KG because of the weight of water supported on the car deck.

- Stated that RoRo vessels presently arranged with a tight car deck cannot maintain a reserve of stability to enable them to reach a final stage of flooding. They capsize while in the intermediate stage of flooding.

- One of the reasons is the creation of trapped air cushions under the main deck as the vessel begins to flood.

- The combination of trapped air underneath and water above (both free surface and added weight) is quite lethal.

- Prof. Pawlowski provided the STAB '94 Secretariat with a recent published article, which is attached.

- B/10 tanks: keel to second decks above waterline along sides of ship is a solution.

- Also a buoyant deck above the car deck can prevent the ship capsize.

- All the above changes can be used to prevent capsizing without introducing any transverse bulkheads to impede horizontal cargo flow.

O. Turan - University of Strathclyde

- Research takes time but it is never too late.

- UK is only country providing funding.

- Vessel operators should also provide funding.

- Some of items (e.g. TV cameras) decided in 1987 do not do enough to prevent capsizing. Engineers/crew should be trained as to what to do in each event.

- Human error should be more deeply investigated.

CDR Gilbert - U.S.C.G.

- When the ESTONIA casualty was first reported, his reaction was that it should have been known that it would happen again.

- It should have been no surprise to anyone in the maritime industry because of the way RoRo ships are designed and the tight scheduling in their operation.

- Regarding the previous comment that it is not too late for research: we must consider that it might be too late. As an example of this, the Exxon Valdez caused the

U.S. Congress to make an absolute design decision in requiring double hull ships. Therefore the naval architects and the operators should be aware that if we do not reach quick and effective solutions, the opportunity to decide may be taken away and decided by legislatures.

- Supported Prof. Pawlowski's proposals.
- Regarding problem solving: we need to keep asking "why" until we arrive at the root problem.
- WHY did the vessel capsize?
  Answer- because there was water on deck.
- WHY did that water cause the capsize?
  Answer- water was not able to flood down so the ship totally lost all stability reserve.
- WHY was water on deck, could it have been prevented?
  Answer- either the door was damaged or some hull integrity item failed.

- These questions are examples of the problem solving process.
- After HERALD OF FREE ENTERPRISE we really thought the door problem had been solved.
- Another question will be WHY did the door fail
  Answer- will possibly involve strength or the operation of the ship involving cargo shifting wherein trucks/lorries damage cars because of movement at sea etc. and doors.
- WHY does the master not have the authority to slow the vessel in heavy seas?
- We must solve the root cause to be most effective.

<u>Prof. Rutgersson - Royal Academy of Sweden.</u>

- Raised two questions:

First: When each serious accident is investigated it is determined that there were warning events (perhaps as many as 400-1000 warning events). This means that we have had between 400-1000 ESTONIA type casualties which did not result in sinking but were an indication that a serious accident could occur. But we did not react properly until ESTONIA accident actually occurred. If we had a system in which persons on ships could report the many near casualties so that naval architects and regulators could evaluate the possibly serious consequences and take remedial action before the serious accident, it might prevent or reduce the consequences of casualties that do occur. We should learn from the air transport industry in regard to this reprinting of near casualties.

Second: How to evacuate the ship? Journalists are asking How do life saving systems actually work? Are they really effective?
Operator personnel on ships have said that standard life saving systems probably work in calm water such as is usual in the Mediterranean Sea, but in storm seas such as winter in the North Sea or Baltic, current life saving systems may be of little use. Although the first requirement is to have a safe ferry, we must also be certain that the life saving systems can be relied upon in a storm sea sinking.

Tom Allan - MSA/UK

- Reply to Prof. Pawlowski and CDR Gilbert
- Did not wish to create the thought that research is closed. U.K. has funded much of RoRo research for new ships.
- In the afternoon workshop -(Dr. Vassalos - Capsize Thresholds) we had already discussed many items.
- New ships can be subject of safety research.
- Existing ships need safety fixes right now
- We need public confidence returned
- Accepts that operational safety must improve but feels strongly that naval architects must contribute practical answers to ship safety.

Dr. Grochowalski - National Research Council of Canada

- Whole concept of RoRo ships is ill conceived design. Presently RoRo vessel is doomed if water gets inside the car deck.
- Sometimes wonder how such a basic concept in naval architecture - the stability case when water penetrates into hull - how is it possible that no one took into consideration the fact that this water (freely moving inside a hull) is certain disaster.
- Yet the economical aspects took precedence over safety aspects.
- We do not have to abandon the RoRo concept, but we need the car deck space divided so that cargo is free to move longitudinally but longitudinal subdivision is one of the better solutions.

A. Blyth - consultant - UK

- Referred to old research (U.K.) on damaged ferry models showing that they would not survive (in damaged condition) in more than one meter sea.
- (Tom Allan corrected this to 1.5 - 3.0m referring to STAB '90)
- Mr. Blyth asks three questions:

First: Is STAB '90 at IMO really good enough? How many ships are out there in less than 1.5m seaway?

Second: Why has IMO - STAB '90 not been implemented quickly throughout Europe? Why did every European country (at least) not immediately support STAB '90?

- Opinion: if every ship met IMO - STAB '90 in a seaway that is only exceeded 30% of the time on each specific route, then most ships would surely have survived water on deck to a much greater degree. The problem is not the naval architecture - we know what is needed - rather the problem is "how to get the correct safety feature into and enforced by regulations through IMO."
- RE: discussion about not killing RoRo the way things are going at present if just on more accident like ESTONIA occurs, he considers it more than likely that most ferry

users will say "that's it - no more RoRo ferries." Therefore what price losing 10-15m of lane length by installing portable w.t. bulkheads at ends of car lanes.

- Think we are dabbling in shallows of this problem and we should be a lot bolder at European Union and IMO.

Prof. Rutgersson - Royal Academy of Sweden

- could not attend afternoon workshop (Dr. Vasallos) because he was the paper session chairman.

- What initially failed on ESTONIA was watertight integrity, not stability.

- One important fact is that the bow door type was an old type (not used for last 10 years) and was quite vulnerable.

- Also the question of incident reporting is important .

- Sistership DIANA II nearly lost its bow door in a storm two years ago.

- Different classification societies have different standards for bow door construction. Some have doubled the design load as that used for the ESTONIA.

Mr. Cleary - Summary of Session

- Thanked all discussors.

- Suggestion for rearrangement (Prof. Pawlowski) of car deck construction with grating to release air and water.

- B/10 side tanks and/or buoyant upper deck

- Some speakers have said the roro concept may die.

- Gave an anecdote:

> Many years ago a professor told my class that 90% of the cost of getting cargo from USA to Europe or back was the short gap between ship and dock. That economic concern was the primary reason for the change to horizontal cargo flow made possible by the new load line convention definition of freeboard deck (1968) and the removal of the class society bulkhead requirements (1969). They were going along with what the world wanted. In effect what we (the maritime community) did was to throw away the secondary protection against flooding which had been in place for half a century.

- A Short while ago I said all the proposed physical changes (e.g. bulkheads, gratings, wingtanks, etc.) are only 10% of the RoRo safety problems. Other problems contributing to RoRo safety failure are:

> 1- Flag states are at fault for not guaranteeing inspections complete and accurate even though they have pledged this in SOLAS.
>
> 2- Owners do not permit ships to be stopped for inspection. In my opinion any ship which is not stopped for at least the part of the hull inspection under machinery - has not been inspected.
>
> 3- Owners keep schedules to the detriment of safety (partially because of "delayed cargo claims"). Delayed cargo claims, in my opinion, actually cause owners/operators to be reckless in some cases.

4- Owners do not permit schedule interruption for maintenance. It is necessary if the ship is to meet minimum standards and maintain itself.
5- Ship repair firms do not realize they may be responsible for a ship not meeting SOLAS - example- a contractor has removed an item from a w.t. bulkhead in order to repair it and the ship continues to voyage.
6- Maintenance - difficult to maintain because of low manning and continuous operation.
7- Manning - Operational crew is too few. We have a one man bridge and a one man engine room and 200 people to trim your fingernails - but no one to properly handle emergency situations at sea.
8- Speed - In 1948 the best speed for most ships was 15 Knots. Now we have ferries (already in service) carrying hundreds of autos and passengers moving routinely at 30,40, 50 knots. At this time (1995) we (the safety people) do not even have a correct picture of the righting moment diagram of such a ship moving at high speed in a seaway.
9- In IMO, the LSA subcommittee expects you (naval architect) to provide 30 minutes after a standard accident in order to disembark all persons into lifesaving craft. But as Prof. Rutgersson just told us, the LSA equipment on large passenger ships is considered completely worthless in a storm by those whose lives depend on these systems each voyage.

Prof. Dr MACIEJ PAWŁOWSKI
Faculty of Ocean Engineering and Ship Technology
Technical University of Gdańsk
also Ship Design and Research Centre
Gdańsk

SUBDIVISION OF RO-RO SHIPS FOR ENHANCED SAFETY IN THE DAMAGED CONDITION*)

SUMMARY

The paper shows that ro-ro ships can be as safe in the damaged condition as other ship types without restricting their design features, i.e. with no transverse and/or horizontal subdivision within the cargo space liable to damage, if there are provisions for reserve buoyancy above the vehicle deck - the first deck above the deepest waterline. For this purpose these ships should embody a double hull over the entire length of the cargo region of the ship, terminated at the second deck above the waterline and, in addition, double decks - at least the first deck above the waterline - preferably inclined upwards in the longitudinal direction. The double hull and double decks should be sufficiently densely subdivided by watertight bulkheads into watertight compartments. They should be preferably cross-connected and of a breadth less than B/5. Cargo spaces below the double decks should be provided with efficient air escapes for removing air cushions from the undersides of the decks. A deck (or decks), if any, below the first deck above the waterline and also this deck should be designed as open to the passage of flooding water, i.e. incorporating efficient down flooding arrangements.

Introduction

Ro-ro ships are considered by the maritime profession and travelling public as the most unsafe ships in operation and this is not surprising when one considers their very low values of indices of subdivision, usually far below the required values. This comes from the fact that these ships were badly designed with little or no concern of damage stability. The large open vehicle decks of ro-ro vessels make them particularly sensitive to presence of water on such decks which may appear there due to collision damage or other accidental operational reasons like fire fighting, intake of water due to the bow door left open (as in the case of the Herald of Free Enterprise), or leakage of water through the aft gate deprived of weathertightness as it was most likely in the case of the Jan Heweliusz, a Polish ferry which capsized in January 1993 during extremely heavy weather, causing the death to 55 passengers and crew members, with only nine persons rescued. These two disasters clearly illustrate the potentially devastating influence of an open deck on the damage stability of a ro-ro vessel. In the absence of transverse subdivision, even a very small amount of water on such a deck can lead to rapid heeling and loss of stability usually associated with a large loss of life. This paper aims to show how significant improvements could be made to the survivability of existing and future ro-ro ships without impairing their present successful operational features.

Current subdivision arrangement of ro-ro ships

For some forty years cargo ships and passenger ferries intended primarily for the carriage of roll-on/roll-off cargo have had no transverse watertight bulkheads within cargo space. Until 1 February 1992 there were no subdivision requirements for cargo ro-ro ships. That is why ballast tanks on such ships were frequently applied due to psychological reasons rather than due to subdivision considerations. They could save the ship only in cases of a minor damage in one of those tanks. Car - passenger ferries (of ro-ro type) are subject to subdivision and damage stability requirements contained in the 1974 SOLAS Convention. Space below the bulkhead deck on such ferries is usually densely subdivided by transverse bulkheads extending from side to side. In such a case, wing tanks are not applied and many of the compartments below the bulkhead deck are neither used for the carriage of cargo nor for other purposes. On the remaining ro-ro passenger ships, compartments with breadth not less than B/5 are applied below the bulkhead deck. The compartments are relatively short and cross-connected to avoid asymmetrical flooding. This type of subdivision arrangement is shown in Fig. 1. The above described solutions however do not provide sufficient safety for passenger ro-ro ships in case of collision. On the contrary, these solutions appear to be extremely dangerous as they do not secure a ferry against rapid capsize in the case of sea water accidentally entering the bulkhead deck. A good evidence of this was the tragic capsizing of the European Gateway in 1982 and the Herald

*) An abbreviated version of the paper presented at the RORO'94 Int. Conf. in Gothenburg, Sweden, April 1994.

of Free Enterprise in 1987, to mention only two recent well known disasters. The two ships had the same type of subdivision, derived from the SOLAS Convention, where the ship due to low freeboard, is densely subdivided with transverse bulkheads below the bulkhead deck in order to get one compartment standard and with no reserve buoyancy above it.

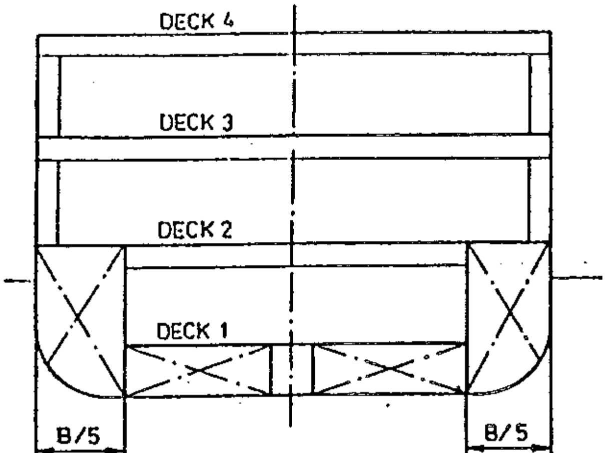


Fig. 1. A typical subdivision arrangement on some large ro-ro ships, extremely dangerous, influenced by the SOLAS Convention.

As the compartments are then very short, probability of flooding more than one compartment is therefore high, resulting in very low probabilities of surviving for such ships and thus objectively confirming their bad performance in case of collision. In addition, the dense subdivision causes the machinery space to be divided into smaller watertight compartments and this in turn opens up an area for human error. A good example of this illusory subdivision was demonstrated by the sinking of the European Gateway [1]. The ship received a small damage below the bulkhead deck but between the bulkheads of the machinery space of the ship. Instead of surviving this potentially safe standard case of damage, she sank very quickly (within some twenty minutes) as all watertight doors within that part of the ship were left open, leading to the flooding of four compartments instead of one. The crew undertook desperate action to close the doors but tragically failed to do so. The new probabilistic rules [2] which entered into force in February 1992 require the same level of safety for all dry cargo ships irrespective of their type. Thus new ro-ro ships will have to be equally safe (have the same indices of subdivisions) as the remaining dry cargo ships. The indices of subdivision for existing ro-ro ships are very low, if not marginal, frequently not exceeding a value of 0.1 whilst for other dry cargo ships this index value is above 0.5. There is no possibility whatsoever of increasing the indices of subdivision so markedly within the presently applied concept of ro-ro ship subdivision, except through a considerable increase in freeboard or by the application of removable transverse bulkheads in holds intended for ro-ro cargo. Such solutions are clearly contradictory to the basic operational features of ro-ro ships and should be applied only in the last resort.

Provision of double hull and deep-sinkage-after-flooding ability

A feasible and efficient remedy for the poor safety of ro-ro ships is application of the idea of deep sinkage after flooding, presented in detail in [3], and briefly summarized here. It comes simply from the fact that the damage stability of the ro-ro ship with the bulkhead deck immersed, which is a typical case, increases the deeper the ship sinks. This startling observation is not difficult to explain. An increase in damage draught for any constant damage displacement allows the centre of buoyancy to move closer to the centre of gravity thereby improving stability. Moreover, experiments have shown that in ships with the much deeper draught associated with the final stage of flooding any roll motion in waves almost completely disappears so that only heave motion remains. It is therefore very unlikely such a vessel to be capsized by wave action when it is floating deeply immersed in a near upright position. In the light of the above remarks an increase in the number of bulkheads below the vehicle deck is found to reduce damage stability dramatically. This situation is opposite to that for conventional ships and is confirmed by model tests [4]. It is evident from the foregoing that the primary safety feature of a ro-ro vessel should be a mandatory double skin extending from the inner bottom to the second deck above the waterline (the upper deck). The wing compartments so formed should be transversely subdivided throughout and incorporate modest flare if possible. Apart from this the number of transverse bulkheads should be limited to the forward and aft peak bulkheads and those required to adequately subdivide the non - vehicular spaces such as the machinery spaces. The strength of these bulkheads should of course be adequate for the pressure loads imposed by the deep draught in a damaged condition. No further transverse bulkheads should be provided, as their function is replaced by the wing compartments. This type of subdivision arrangement is shown in Fig. 2. The breadth of the wing tanks is preferably equal B/10, half as large as in the previous case. As such ro-ro vessels are capable, as a rule, of surviving a major flooding at least in a partial loading condition, there is no need for increasing height of the double bottom. On the contrary, from the standpoint of damage stability, the minimum height is preferable.

In order to limit the effects of flooding, the wing

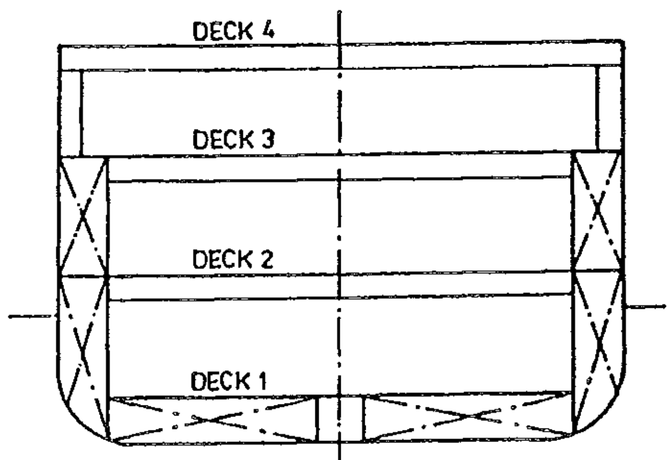


Fig. 2. A typical subdivision arrangement for ro-ro ships based on the deep-sinkage-after-flooding concept.

compartments should be relatively short, identically subdivided on both sides, and cross-connected to prevent asymmetric flooding which is always detrimental to a ship in a damaged condition. In the case of passenger ro-ro vessels, the current SOLAS regulations require that lower wing compartments should have a breadth of not less than B/5 and no wing tanks above the bulkhead deck, as shown in Fig. 1. If one assumes that major flooding of inboard spaces represents the loss of a ro-ro ship then it would be necessary to require for ship safety the wing compartments below the car deck to be as wide as possible to minimise the risk of such a possibility. However, that is not the case and therefore there is no need to impose such broad wing compartments in this position. To withstand major flooding, It is most important for a ro-ro ship to ensure positive stability at the final stage of the event when the bulkhead deck is immersed. It has been shown that this is quite practicable and requires only that narrow wing compartments be fitted below and above the vehicle deck, as shown in Fig. 2, to ensure both stability and sufficient reserve of buoyancy. Such is the purpose for providing these wing compartments.

Intermediate Stages of Flooding

Thus far, stability during the intermediate stages of flooding has not attracted the attention it deserves. Work done to date supports the intuitive notion that the intermediate conditions are usually not a problem, if the final condition is acceptable, provided the angle of heel is not so large as to cause cargo shift and the flooded water can freely spread over the entire compartment. The deck edge then remains above the waterline all the time during transient flooding [5]. The same applies also to ro-ro vessels with the double skin arrangement provided that the decks are made transparent for the flooding water which is crucial for the safety of these ships. Thus, if there are efficient down- or cross- flooding arrangements, it is entirely sufficient as far as damage stability is concerned to check only the maximum angle of equilibrium during flooding, and focus attention on the safety of the ship in the final stage of flooding. Hence, the above theoretical development considerably simplifies damage stability assessments. Owing to physical reasons, stability during the intermediate stages of flooding should be analysed for the freely floating ship longitudinally balanced at each angle of heel, using the added mass method. There are usually marked differences between the GZ-curves calculated for the free trim condition and for fixed trim particularly if the deck edge is immersed and the ship has large longitudinal asymmetry. However in the case of horizontal subdivision without efficient down-flooding arrangements, it should be assumed that after the immersion of the edge of the watertight deck the level of water above such a deck coincides with the level of water outside. This covers the case of a small hole below and a very large one above the horizontal subdivision, a typical damage when the striking ship has a bulbous bow associated with a large flare - see the case of the European Gateway [1]. The current regulations [2] overlook entirely this problem. This is the reason why naval architects consider horizontal subdivision, particularly on ro-ro ships, as beneficial to their safety. Unfortunately, this is not the case and it is now high time to tell this loudly and clearly in an attempt to divert the way things are developing.

Perforated Vehicle Decks

An important point in all ro-ro vessels concerns the watertight integrity of the main and other vehicle deck,i.e. the presence of horizontal subdivision. From the previous discussion it should be clear that any deck, including the vehicle deck which may suffer flooding from whatever source, should be non-watertight. Furthermore, such decks should be designed to allow both water and air to pass freely through them. How this should be accomplished in practice is an interesting challenge for the designer. The drainage systems must be capable of allowing very large quantities of water to drain directly into the lower cargo spaces without access to machinery or other critical spaces, which must be effectively sealed from the cargo spaces at all times. This has the effect of maximizing the damage metacentric height by both eliminating isolated free water surfaces and lowering the centre of gravity.

Watertight vehicle decks or tweendecks cannot be recommended for the following reasons:

- Decks below the vehicle deck are not usually designed to withstand the pressure forces that would be imposed by serious flooding either above or below them.
- When flooding occurs above such a deck, a large free water surface is formed which immediately reduces the vessel's metacentric height, usually causing a large angle of heel or capsizing.
- These decks can trap during sinkage large quantities of air beneath them, maintaining an additional free surface effect, which would be eliminated if the compartment were free to fill completely. In addition, these air cushions contribute to the creation of an additional heeling moment of significant value as they are formed usually at the outmost areas beneath the decks close to the side opposite to damage. As a result, these air cushions are extremely dangerous and lead to the capsizing of the ship, otherwise safe, before reaching the final stage of flooding.
- Watertight ramps and decks are more expensive than their non-watertight counterparts. In view of these points, there seems to be no good reason to retain the concepts of either horizontal or vertical watertight subdivision applied to internal vehicle spaces. In particular, retaining the vehicle deck as a bulkhead deck is particularly dangerous and should be abandoned as a design objective.

There are two further reasons why the bulkhead deck within the cargo space should be made transparent to the flooded water. Such a deck virtually eliminates the accumulation of the flooded water above this deck due to the action of waves which is found to be dangerous as it leads eventually to the capsizing of the ship [6,7]. Due to a very similar reason the watertight deck is also detrimental to stability during the intermediate stages of flooding which is rarely analysed during designing and overlooked by the current regulations.

The idea of deep sinkage was implemented at the Gdańsk Shipyard, Poland by designing a passenger-cargo ro-ro vessel of 12 000 DWT and with the overall length of 183 m, based on the double hull arrangement, as shown in Fig. 2. The bulkhead deck was designed, however, as watertight and thus it was only partly fulfilling the necessary requirements for a really safe ro-ro vessel. To make this deck open to the passage of water appeared to be too challenging for the designers.

Provision of buoyant decks

It is rather difficult to achieve deep sinkage after flooding on real ro-ro ships due to the large longitudinal unbalance between the aft part containing the big machinery room and the forepeak. As a result, the ship assumes after flooding an extremely large trim by the bow which is not as beneficial to damaged ship safety as deep sinkage at even keel. It is worth considering, therefore, fitting additionally the ship with a buoyant deck or decks, at least the bulkhead deck, transversely and longitudinally subdivided by watertight bulkheads - see Fig. 3. As previously, cargo spaces should be provided with efficient air escapes (vents) placed at the sides, close to the top of cargo spaces, to eliminate detrimental air cushions which may occur during flooding. The breadth of the double sides is definitely less than B/5; they should be subdivided into wing tanks by transverse bulkheads and preferably be cross-connected. The height of the double decks is preferably not greater than the depth of deck girders for relevant single decks. The double bottom should be preferably of the minimum height required by the classification rules.

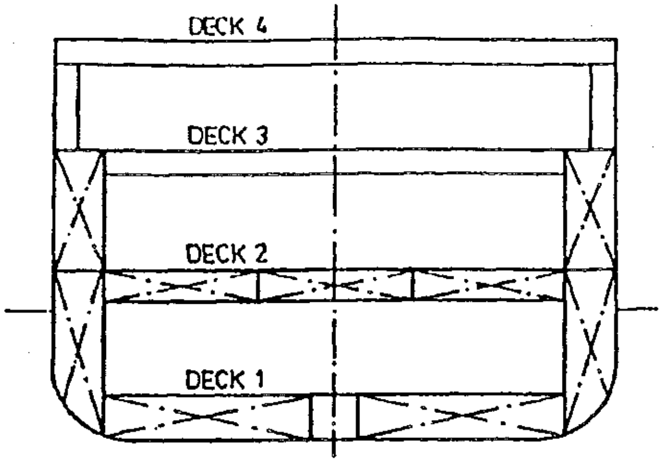


Fig. 3. Subdivision of a ro-ro ship based on the extended double shell concept.

The bulkhead deck and a deck below, if any, should be designed as permeable (transparent) for the flooded water to ensure free flooding, i.e. uniform spread of water over the whole compartment during intermediate stages of flooding. With the provision of buoyant decks, sinkage after flooding is obviously reduced and, in the extreme, can be as small as to keep the bulkhead deck emerged.

Ro-ro ships, in general, have deep deck girders because of the large unsupported deck spans. In view of the problem of cargo handling, cargo stowage is usually restricted to spaces below the flanges of these girders. There is opportunity, therefore, of sealing off the space upwards from the flanges of the deck girders to the deck plating into a buoyant chamber that can provide additional buoyancy and, depending on its location, height and extent, be of some advantage in terms of damage survivability.

The problem of location of this buoyant deck is a fairly involved exercise. However, it can be shown that for such a buoyant deck with a displacement of v the stability coefficient will be increased, if the buoyant deck is located at a height H_{deck} satisfying the relation

$$H_{deck} > T_{dam} + \frac{\Delta J}{\Delta V} - \frac{\Delta I}{\Delta V}$$

where

T_{dam} – draft of the ship in the damaged condition without the buoyant deck;

ΔJ, ΔI – change in the moments of inertia of the undamaged waterplane and the free surface of the water due to change in displacement of $\Delta V = v$ caused by fitting the buoyant deck.

Because $\Delta I \approx 0$ if the vehicle deck remains submerged and $\Delta J/\Delta V$ is positive then it is practically impossible to satisfy the above inequality unless there is a large reduction in the free surface moment of inertia due to the partial emergence of the buoyant deck. Unless this inequality can be satisfied, a buoyant vehicle deck will have a nearly neutral effect on initial stability in the flooded condition and consequently on the ship safety. Even though effective increase in freeboard, due to the provision of the buoyant deck, increases stability at large angles of heel, it is rather unlikely that this will be of much practical benefit in ship survival except situations when the angles of flooding are very small.

However, it is not difficult to design for significant reductions in the free surface moment of inertia. This is because in the majority of damage cases there will be a trim by the bow due to the comparatively large machinery space. In an appropriate combination of a buoyant vehicle deck and wing spaces, a situation may be reached that for a large number of damage cases the next higher deck comes into contact with the flooded water. If this higher deck is also made buoyant in the forward part of the ship, a significant gain in the index A value may be obtained and also an advantage from utilization of spaces which are usually non-productive anyway from the cargo carriage point of view. Another possibility is to use a buoyant vehicle deck which is slightly inclined upwards in the longitudinal direction so that after damage the entire deck continues to remain above water in spite of the vessel's trim by the bow.

Moreover, active consideration might be given to designing the forward upper part of a ro-ro cargo ship as a rectangular box, like in an aircraft carrier [8], to improve matters further in cases of deep sinkage after flooding.

The effect of a buoyant bulkhead deck is relatively modest in the cases where the deck is chosen with no concern regarding the reduction of free surface. It can be of the order of a 5% increase in index A values [9]. The improvement, obviously, may be considerably greater, if multiple buoyant decks are used, as may be feasible in some ro-ro vessels, or when the vehicle deck is inclined and remains above water in the majority of damage scenarios.

Advantages of the Novel Subdivision Arrangement

The benefits of subdivision arrangement based on the extended double shell concept are twofold:

- from the design and operation standpoints:

• It is possible to obtain high indices of subdivision for ro-ro ships required by the new subdivision regulations, without impairing their successful operational features, based on non-subdivided horizontal cargo spaces.

- from the technical standpoint:

• The cargo space is not reduced. The double decks make use of the space on the underside of single decks, contained between the huge deck girders, useless for cargo anyway. Confinement of this space by relatively thin watertight shell plating, replacing the thick flanges of deck girders, converts this inefficient space into a double buoyant deck of a considerable volume, reducing the trim by the bow after flooding.
• The weight of the ship is only marginally increased thus nearly the same deadweight is maintained.
• Overall ship and deck strength is improved.
• Smooth sides make cargo handling and insulation works easier.

In result, it can be expected that the overall labour consumption and thus the cost of ship production may be fairly reduced.

Numerical examples

To see how this concept works, a ro-ro ship designed at the Gdańsk Shipyard was examined whose main particulars were as follows:

subdivision/overall length	177.50/183.00m
length between perpendiculars	171.30 m
moulded breadth	28.70 m
depth to main/upper deck	8.90/15.23 m
depth to weather deck	21.20/23.10 m
design/scantling draught (T)	6.80/7.40 m
supply/water ballast tanks	1880/9500 m^3
ship's deadweight at scantling draught	12400 t
breadth of wing tanks	2.80 m
KG for full load condition at T=7.40 m	13.65 m
KG for partial load condition at T=6.11 m	13.67 m

permeability μ 0.80
required subdivision index R value 0.545

EXAMPLE 1: The ship with the subdivision arrangement as in Fig. 2, with no cross flooding, deck No. 3 (upper deck) watertight (which is not realistic in this case). For such a ship the attained subdivision index value is much below the required one and equals:
A=0.513

EXAMPLE 2: The ship as above but with cross-flooding. The index value is then:
A=0.581
As it can be seen, cross-flooding caused here a significant increase in the index value. That, if assumed as the rule cross-flooding, is always beneficial for the ship safety, and therefore, it should be applied whenever possible.

EXAMPLE 3: The ship as in Example 2 but with Deck 3 treated as non-watertight which is in compliance with the actual design. The attained index value is now much lower and equals:
A=0.512
which should obviously be expected. It is then quite sensible to make the upper deck watertight, if possible. Moreover, as the ship has typically a large bow trim after flooding and thus small angles of flooding, active consideration might be given to a deck or decks made buoyant at the forward end, to increase the height to openings above the damage waterline, thereby improving stability.

EXAMPLE 4: The ship as in Example 3 but with Deck 2 as pontoon, creating a buoyant double deck of depth 1600 mm as shown in Fig. 3. The attained index value is now:
A=-0.519
that is only marginally higher than in the previous case. This is because the buoyant deck as it is , due to the bow trim, in the majority of damage scenarios still remains under water on the majority of its length, thus insignificantly contributing to the reduction of the free surface effect.

This example provides a good lesson: not every buoyant deck can be expected to contribute significantly to ship safety. To do so, the whole subdivision arrangement must be carefully chosen so that the buoyant deck could remain above water in prevailing cases of flooding.

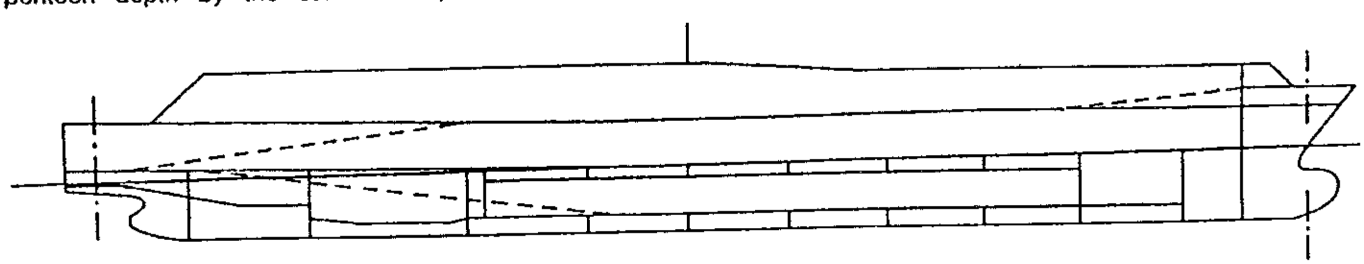
However, it is not difficult to do so. Keeping the remaining subdivision unchanged, there are two immediate possibilities: - a slight increase of the height of Deck 2 maintaining the underside structure of the deck with the original depth which is equivalent to an increase of the pontoon depth by the same value; - and/or a slight inclination upwards in the longitudinal direction of the topside of the deck. The application of medium speed engines for ship propulsion provides another possibility. If such engines are located in the wing compartments, then the lower cargo hold can be significantly extended abaft thus largely reducing the trim by the bow after flooding.

EXAMPLE 5: The ship as in Example 4 but with the ship's depth to Deck 2 increased by 0.2 m from 8.9 to 9.1 m. The depth of the pontoon is simultaneously increased from 1600 to 1800 mm, keeping the underside structure of the deck at the previous height. The attained index is now:
A=0.556
which is higher than the required value R=0.545. It is worth noting the incredible increase of the index due to the increase of the depth to Deck 2 by only 0.2 m. This example shows how sensitive is ship safety to some parameters of subdivision arrangement containing a buoyant deck and that is why it is so easy to be disappointed with it, if it is not properly chosen. The most important of all is to keep as far as practicable the buoyant deck dry (to remain above water) in the majority of damage cases.

EXAMPLE 6: The ship as in Example 5 but with Deck 2 inclined upwards in the longitudinal direction by 1 m at the foremost end of this deck, as shown in Fig. 4. The attained index value is now:
A = 0.621
and it is thus drastically higher than in the previous case. Such a result should obviously be expected in the light of the previous remarks. From the examination of some of the most representative cases of flooding for the previous case study, it followed that the depth of the flooded water at the forward end of Deck 2 did not exceed a value of 1 m. This is why the free surface effect could be reduced now in the case of the 1 m sheer of Deck 2 to nearly nothing in most cases of damage, thus markedly increasing the index value.

The rise of Deck 2 by 1 metre at its foremost end is not much. Examining Fig. 4, one can hardly believe that this deck is inclined at all. All other decks above Deck 2, must have obviously, the same sheer, to keep them parallel to one another.

In all the examples, Deck 2 was treated as open for the passage of water and air, to eliminate the many adverse effects, discussed above and not accounted for in the current regulations. Owing to that reason, horizontal subdivision due to Deck 2 was simply ignored, and this was for the benefit of the ship.



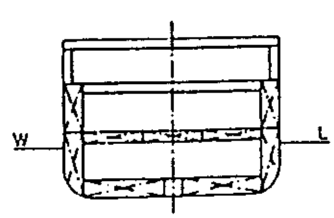


Fig. 4. Example of a large ro-ro ship subdivision based on the extended double shell concept.

Conclusions

The probabilistic subdivision regulations for dry cargo ships [2] provide a framework for the rational assessment of competing ro-ro ship designs from the damage survivability point of view. It is clear from the results above reported that it is possible to achieve a satisfactory subdivision index value for such ships without transverse or horizontal subdivision below the upper deck. Their intended function is replaced by the wing compartments extending from the bottom to the upper deck and cross-connected, and a buoyant deck or decks, open for the passage of water and air below the upper deck, leaving this deck area clear for through transport.

The judicious distribution of reserve buoyancy in the longitudinal, transverse and vertical direction is important in the design of these ships and since there are many different ways of doing this satisfactorily, there is the obvious scope for optimization of the arrangement of such vessels. The performance of these ships in the damaged condition is very sensitive to some particulars of the subdivision arrangement containing a buoyant deck, depending on presence of water on the deck in a flooded condition. It is important to note that the current survivability regulations merely set standards, though imperfectly, and are not prescriptive as regards an actual arrangement. The designer, therefore, retains the opportunity to meet the range of design objectives. Subdivision arrangement based on double hull and double deck seems to be particularly efficient and beneficial for these ships.

REFERENCES

1. Spouge J.R : The technical investigation of the sinking of the ro-ro ferry European Gateway. Trans. RINA, vol.128, 1986, (also in Naval Architect, March 1986, ibid).
2. Resolution MSC 19(58) on the adoption of amendments to the 1974 SOLAS Convention regarding subdivision and damage stability of dry cargo ships. London 1990.
3. Pawlowski M.,Winkle I.E.: Capsize resistance through flooding - a new approach to ro-ro safety. Proc. of 9th Int.Conf. on Through Transport using Roll on/Roll-off Methods, Ro-Ro 88', Gothenburg June 1988, BML.
4. Grochowalski S., Pawlowski M.: The safety of ro-ro vessels in the light of the probabilistic concept for standardizing unsinkability. Int. Shipbld. Progress, vol. 28, March 1981 No. 319.
5. Pawlowski M.: Bezpieczeństwo niezatapialnościowe statków (Safety of ships in the damaged condition). Journal of Tech. Univ. of Gdańsk "Budownictwo Okrętowe" No.42/392, Gdańsk 1985.
6. Turan O., Vassalos D : Dynamic stability assessment of damaged passenger ships. RINA Spring Meeting 1993.
7. Vassalos D : Damage survivability of passenger ships in a seaway. Proc. of Int. Workshop on the problems of physical and mathematical stability modelling, paper No.10, vol.1, Kaliningrad 1993.
8. Wahl J.E.: New catamaran ro-ro design for Norwegian coastal service - a breakthrough in hull design. Proc. of 9th Int. Conf. on Through Transport using Roll-on/Roll-off Methods, Ro-Ro'88, Gothenburg June 1988, BML.
9. Sen P., Pawlowski M., Wimalsiri, W.K.: Ro-Ro cargo ship design for enhanced survivability in the damaged condition. Proc. of 9th Int. Symp. on Ship Hydromechanics, vol.II, Gdańsk September 1991.

Safety Case Workshop

Wednesday 9 November, 1994

Moderator: Professor Chengi Kuo, University of Strathclyde, Scotland

Managing Stability Using the Safety Case Concept

- 0900-0930 Introduction to the Safety Case concept
- 0930-1000 General debate on the concept's applicability to stability
- 1000-1100 Exercise by participants (in groups of 3 or 4)

NO BREAK : refreshments available during exercise

- 1100-1145 Group presentations
- 1145-1215 Discussions and conclusions

Chairman's note

Professor Kuo volunteered to conduct this safety case workshop at STAB '94, In the stability function alone. Professor Kuo offers seminars in the safety case concept including all of the safety functions as part of his consultant activities. The participants were well pleased with this exercise.

STAB '94

Workshop on Information to the Master

Wednesday, November, 9th, 1994

Moderator: Professor N.N. Rakhmanin, Krylov Shipbuilding Research Institute, Russia

1. THE AIM

The workshop aim consisted in exchanging looks, opinion, ideas on how to improve and develop further the information of stability and ship safety against capsizing for the sake of the shipmaster and all lives on board in mind the latest applied scientific results in shiphydrodynamics, computer hard and software technology, electronics and ship control systems development.

2. INTRODUCTORY COMMENTS

The workshop was open by the moderator introductory comments that suggested the following provisions describing the role of the information to the master (the INFO) and those, who were responsible for its composition, in providing ship safety at sea.

.1. Stability is a key factor for ensuring the ship safety.
.2. Stability is the subject of the first rate care for all involved in creation of a ship and her safe operation, namely: shippowners, designers, Administrations, shipbuilders, ship operators.
.3. The shipmaster bears the ultimate responsibility for the ship fate and lives on board.
.4. The INFO is the document containing all necessary data for ship management in accord with existing standard stability requirements acknowledged and approved by the Administration.
.5. Any system of the standard requirements for stability as the INFO content is far from ideal and can't guarantee 100% level of safety. This stands for the Master knowledge, experience and skill may play, in extreme sea conditions, the decisive role for ship survival. The shippowners and Administrations responsibility may be considered in this case only in oblique ways.

On the other hand, one should remember that in the preamble to the IMO code of Intact Stability for All Types of Ships it is said the following in relation to nowadays situation in the field of safety:

"... design technology for modern ships is rapidly evolving and the Code should not remain static but be reevaluated and revised, as necessary..."

This statement may be refered to the scope of any documents and activity of relevant parties responsible in some way for ship safety at sea.

3. THE WORKSHOP FINDINGS

Summing up the discussion one may formulate a number of provisions that can help to increase the effectiveness of the INFO and the methods of organizabion of safety at sea as well.

.1. Apart ship particulars the INFO should provide the Master with:

.1.1. Reliable computational information on stability covering all actual service conditions and including cases of load;
.1.2. Recommendations on organization of stability control on ships arrival at the departure from the port, data on means of control and instructions how to use them;
.1.3. Data on damage stability in the most dangerous cases of flooding and measures to prevent capsizing in the cases;
.1.4. Information on all dangerous phenomena in dynamic behaviour of a ship in waves of open sea and while manoeuvring in restricted waters.

.2. Computerized decision support systems are practically the only possibility to facilitate the transfer of all relevant new information from shipping company to the ship master. The traditional way of improving the INFO by means of incroaning the number of chapters, manuals, guidelines, etc. just increases the information which becomes in this case less and less accessible to the master in normal service conditions not speaking about critical situations.

.3. To avoid said above, training of specialists to provide them with practical knowledge of stability principles and ship dynamic behaviour in waves should play the significant role in organization of ship safety at sea. The training should include the usage of expert systems, simulators etc. and cover not only ship navigators but designers and shipowners as well. It is important that all relevant information should be based on terms easily understood by the master.

.4. IMO should explore the means to increase the responsibility of shipowners and National administrations for improving the knowledge and skills of the master by imposing mandatory periodic training and certification requirements.

.5. In addition administrations should make a special effort to publish significant findings of stability related accidents and causes in a form that is easily accessible and understood by ship operators and owners.

Workshop on Maneuvering and Survival in Storm Seas

Thursday a.m., 10th November 1994

9:00 - 12:30

Moderator : J.O. de Kat, Maritime Research Institute Netherlands
Co-mod.: W.L. Thomas, David Taylor Model Basin

1. Dr. J.O. de Kat, MARIN Mr.W.L. Thomas, DTMB	*The use of numerical simulation tools in the derivation of operational guidlines for severe weather conditions* - introduction - broaching and capsize physics, identification of critical wave conditions; simulator; animations - polar diagrams for surfriding/broaching/capsize avoidance - seafarer training
2. Mr. W.H. Buckley previously DTMB	*Testimonies on severe sea ship handling* - extreme wave photographs - definition of limiting extreme sea states - court testimony analysis of ship losses
3. Mr. R. Stanley, American President Lines	*Views from a container ship operator* - heavy weather experiences on board APL ships - role of modern ship motion simulation tools - requirements for further research
4. Mr. D.J. Witmer, BP Oil	*Views from a tanker operator* - heavy weather experiences on board VLCCs - slamming and green seas loading - role of hull monitoring systems
5. Dr. Y Takaishi, Nihon Univ	*IMO Guidance to the Masters for Avoiding Dangerous Situations in Following and Quartering Seas* - technical background, objectives
6. Dr. S. Grochowalski, NRC	*Model tests involving small ships in heavy weather* - broaching/capsize model tests with fishing vessels - recommendations for safe handling

STAB '94 Workshop on Maneuvering and Survival in Storm Seas

Synopsis by J.O. deKat (moderator)

The aim of the workshop was to focus on ship handling and maneuvering in storm seas, as seen from research and ship operator perspectives. Through presentations and discussions the following key questions were addressed: what are practical experiences and stability/strength problems encountered during ship operation in heavy weather, which operational needs exist to counter any problems and to enhance safe operation, what kind of technical information and assistance can the research community provide (mathematical models/simulations, model tests, full scale observations), and how can research tools and knowledge be implemented. An overview of the presentations is shown at the end of this synopsis. A summary of the topics discussed is shown below, followed by a more detailed account of the discussions.

- *Storm wave characteristics*
  - extreme waves (full scale and model test observations)
  - survivability envelope (limiting significant wave heights)
  - group speed effects in following seas
  - range of applicability of linear (Gaussian) model

- *Heavy weather experiences*
  - maneuvering for safety: following seas, head seas
  - court testimony on ship loss
  - container ships: cases with container damage due to rolling in beam and bow seas; local slamming effects; fatigue; coaming distortions; (infrequent) parametric rolling in head seas

- *On-board measurement/monitoring and decision-making systems*
  - VLCCs: continuous measurement of motions and stresses; fatigue problems due to bow slamming; warning system to ship master; implementation and acceptance by officers
  - container ships: warnings on rolling and advice to avoid critical conditions

- *Operational guidlines*
  - IMO proposal
  - role of model tests: small fishing vessels are more prone to long steep (breaking) waves than large ships, influence of hull form on broaching; influence of calm water and instantaneous ship speed on capsizing

- *Time domain ship motion simulations as a practical tool*
  - polar survivability plots
  - interactive (real time) PC simulator for operator education/training
  - evaluate design alternatives

- container ships; development of lashing criteria, evaluate critical stress areas, prediction schemes for operator, more focus is required with respect to ship motions and slamming rather than to reliability of service only

The following pages contain a more detailed description of the various presentations. Any omissions or incorrect statements are due solely to the interpretations and recollections of the moderator.

1. Moderator J. de Kat (MARIN) started off with outlining the general format of the workshop and presented information on the following topics.

- *Modeling of storm wave characteristics*

By examining joint probability density functions (pdf's) of spatial wavelength and wave steepness on the basis of experimentally obtained model test data and numerical simulations, he suggests that linear random wave theory does quite well for low to rather steep sea states (i.e., significant steepness of $s = H_s / (gT_p^2 / 2\pi)$ up to 0.04). For very steep sea states ($s > 0.04$), the joint pdf of wave height and zero -crossing period is still rather good, but linear theory underestimates spatial wavelengths due to the absence of nonlinear effects - this results in a roughly 10% underprediction of spatial wavelengths. Assuming that ship motions tend to be governed by crest-to-trough wave height and associated length, linear random wave theory will provide a reasonable model for ship motion simulation purposes in severe seas. Recent analysis of full scale storm wave measurements ($H \geq 10$ m, $s \approx 0.04$) supports this assertion.

- *Ship handling simulator*

A demonstration was given of the PC-based ship motion simulation and animation program SHIPMATE. Whilst in its infancy, the first release of this program allows for the real-time interactive maneuvering of a ship in random waves and wind - the user has control over rudder and propeller RPM. It was developed as part of the Cooperative research Navies project on dynamic stability. Possible applications are educational (for use at seafarer/deck-officer schools) and, in the longer term, operator training. During the demonstration, the sample ship ended up in a broach and capsize because of executing a turn with the rudder hard over in following seas - something which was bad seamanship on the demonstrator's side!

2. Mr. L. Thomas (DTMB):

- *Tactical Decision Aids (TDAs)*

US Navy uses frequency domain (linear strip theory) seakeeping predictions to develop motion limiting criteria in the formulation of TDAs. TDAs provide ship operators with alternate choices of headings and speeds, which will not result in the exceedance of specific motion limits, with the objective of allowing ships to perform certain operations in higher sea states; the "most seakindly" heading and speed might not be obvious to the master.

Time domain ship motion prediction tools, as developed under the auspices of MARIN, are being incorporated by the US Coast Guard and Navy in a Tactical Decision Aid that provides ship operators with guidance to avoid surfriding, broaching and capsizing. Although this software is in its preliminary stage of development, the ultimate goal of Coast Guard and Navy is to develop a real-time on-board system that takes real time measurements of the seaway and ship loading conditions, and which generates polar plots that indicate safe headings and speeds for the master for selected motion criteria. These criteria will include broaching and capsizing avoidance, and avoidance of damage due to slamming and green sea loading.

Examples of polar plots were shown for a frigate-type ship, indicating surfriding and capsize regions in a severe sea state. These plots are based on a large number of systematic time domain simulations, comprising a matrix of ship speeds and heading angles in a random seaway (heading increments of 10 degrees ranging from following to head seas, Froude numbers ranging from 0.1 to 0.4) for a given loading condition. The process for generating such polar plots has been automated to such an extent, that with the availability of a powerful PC or workstation one can consider the use of time domain simulations as a feasible and practical approach.

3. Mr. W. Buckley:

• *Characters of extreme seas*

Extreme waves can be split into two major groups (see also STAB '94 paper by Mr. Buckley):

- steep, breaking, short crested - produced by strong, rapidly increasing winds
- episodic storm waves, which tend to be more long crested and repetitious in nature

Based on at-sea encounters and testimonies, three types of episodic waves were discussed:

• steep, long-crested waves

- this type of wave may just break/spill at the crest, gathers or retains significant energy while staying long crested, and may recur as every 7th or 9th large wave in a storm seaway (photographic evidence was shown)

• group of three extreme waves ("three sisters')

- group of three long-period waves intruding into existing seaway at an angle of about 30 degrees from principal wave direction (account by experienced US Coast Guard officers: "the waves come walking at you"), which may occur in storms with mean wind speeds of 60 knots of more

• rogue wave

- big, single, breaking wave intruding into existing seaway at angles up to 50 degrees from principal wave direction; has been encountered in extreme seaways (photographic evidence taken from M/V SELKIRK SETTLER)

Where do waves at such a distinct angle from the main direction come from? Experiments reported by Su et al. (Journal of Fluid Mechanics, Vol. 124, 1982) may provide an explanation -- long-crested waves generated in a wide wave basin were observed to become unstable when the wave steepness becomes large. During its evolution in space and time, the initially 2-D wave train shows local, small-scale wave breaking at the crest, evolving into a 3-S unstable wave pattern with rows of crescent shaped breakers on top of the basic long-crested waves. The breaking waves are similar in appearance to spilling breakers in the open ocean and appear to come from a different direction. Further evolution shows the tendency toward 2-D long-crested waves again, with the formation of oblique wave groups, which travel at an angle of 30 degrees from the primary wave direction.

Rogue waves have been observed to occur in the open ocean and can be dangerous to a ship's integrity (damage to deck house and deck equipment, flooding). Encountering a group of "three sisters" can result in a critical situation - for example, cargo shifting.

- *Ship handling*

During the storm in which the M/V TUXPAN was lost (no survivors, extreme sea state), ships that did survive used three scenarios of ship handling:

(1) SELKIRK SETTLER: kept in dead following seas, which were described as "very perilous"; critical situation of astern seas, danger of surfriding and broaching at high ship speed and loss of holding course at too low a speed.
(2) EXPORT PATRIOT: held in head seas slowly going West, bridge windows were smashed and bridge flooded, situation described as "very scary".
(3) M/V WESTERHAM: tried to hold head seas, but did not have sufficient power and could not hold course, so she was forced to turn and run before the storm.

The characteristics of this storm were such that the storm belongs to the category of limiting seaways, coinciding with the survivability envelope defined by a boundary of significant height as a function of peak period - see STAB '94 paper by Mr. Buckley. The large significant wave height (approx. 15m) and steepness ($s \approx 0.05$, the highest significant steepness possible) cause such a storm to be - rightfully- perceived as very dangerous.

An interesting comment by the master from the SELKIRK SETTLER was that he found it necessary to hold course allowing maximum deviations of only 3 degrees in order to maintain course keeping control, while high speed would cause the ship to surfride and broach.

This information on ship handling agrees with results from numerical simulations; Mr. Buckley drew attention to one of the overhead transparencies shown by J. de Kat during his paper presentation (this figure is attached to the back of this synopsis). This figure shows the computed capsize index (an artificial measure of capsize risk) for a fictitious frigate in following to beam seas as a function of GM and ship speed. Also in this case it is clear that a relatively small change in heading angle from zero to 15 degrees can result in a marked increase in capsize risk, especially at higher ship speed (the risk is highest in stern quartering seas at high speed).

4. Mr. R. Stanley (APL):

• *Heavy weather experiences on board container ships*
While there have been no real problems regarding ship survivability, there are a number of cases related to damage in heavy weather:

- localized bow slamming damage (plastic deformation of local bow plating following wave impact)
- container loss due to
  . roll motions of 25 to 35 degrees single amplitude (beat phenomenon, repeating/increasing in beam seas
  . turning maneuver
- container damage in bow quartering and beam seas (steep waves would run up high freeboard of 12 m - water forces itself between container and deck, slamming); the moderator commented that similar observations have been made during model tests where under some conditions steep beam waves would cause a vertical jet of water along the side of the ship
- unexplained loss of a hatch cover

General bad weather experiences:

- hatch cover motions relative to ship (coaming distortions)
- fatigue fractures of poorly detailed structures, including side shell near midship

Unexplained rolling motions:

- parametric rolling in head seas at an encounter period of approx. 7 seconds, with 20 degree roll amplitudes (natural roll period was approx. 20 seconds)

• *Concerning seakeeping and hull response/strength issues, there is a need for further tool developments and on-board applications:*

- more accurate lashing criteria
- more accurate prediction of hull stresses, hatch cover motions relative to coaming distortions and of hatch cover stresses (more attention needs to be paid to critical areas of the hull)
- sound basis for stability requirements for non-standard hull forms
- development of prediction schemes and guidance to ship operators, i.e., real-time warning on e.g. rolling and slamming; informed choices to mitigate effects of adverse weather and warn about possible consequences for ship (including effect on fatigue life)
- interface such a system with weather routing schemes
- bigger ships give less feed-back and experience difficulties while the operator is unaware
- requirement for operator training tools
- verification of actions by on-board monitoring systems; usage of simulation tools for optimum layout of hull monitoring equipment
- more accurate prediction of local slamming loads and hull deformation
- in general, while APL's main interest has been reliability of service and the prediction of the reliability of a particular ship, more attention should be paid

to effects such as ship rolling, pitching and wave impact loading

5. Mr. D. Witmer (BP Oil):

- *Experiences with hull monitoring system in heavy weather*

VLCCs on the route to and from Valdez along the US West Coast face generally rough wave climate. Fatigue-induced damage accumulation within the hull structure is a major concern; a main contributor to fatigue can be slamming-induced whipping, where the hull vibrates at its natural period (2-node vibration) for some time following a slam. this can occur especially in the ballast condition, where the forefoot can emerge and subsequently slam. Side shell fractures take ships out of service for significant periods of time. Besides fatigue, tankers have experienced damage at the bow because of green sea loading.

To counter these problems, a ship motion and structural response monitoring system has been installed on seven BP tankers, which discharge at various West Coast ports and occasionally in Panama and Hawaii. This system provides guidance and feedback to the master. An overviews of the hull monitoring system layout and operation was presented. A detailed description of the system can be found in the following paper: "The BP Oil Tanker Structural Monitoring System," presented at the Los Angeles Metropolitan Section of SNAME, January 1994 (D.J. Witmer and J.W. Lewis). Since its commencement in 1991 the system operates satisfactorily; 2 more ships will be outfitted in 1995.

A discussion ensued regarding the introduction of the monitoring system to (and its acceptance by) the operators. The operators (masters and officers) were involved as of the initial stages of the project, enabling them to specify their views and wishes, and provide feed-back on proposals. Further acceptance was gained during the operation of the system - in a particular case, the system provided slamming warnings and recordings while the master was unaware of slams occurring (a consequence of ship size). Education of officers continues.

6. Professor Y. Takaishi (Nihon Univ.):

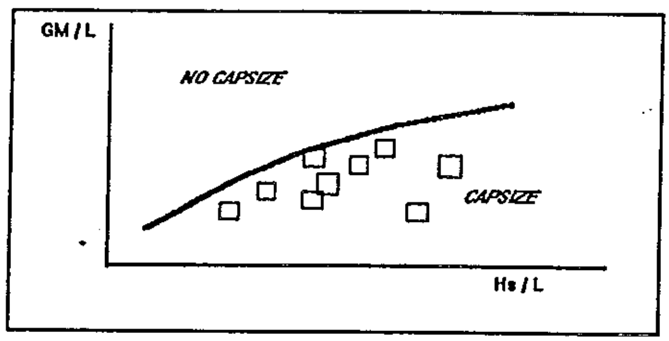
- *IMO Guidance to the Master for Avoiding Dangerous Situations in Following and Quartering Seas*

Based on the original proposed guidance by Japan to IMO (SLF 37) and on further discussions by the IMO Correspondence Group, a "final" proposal has been put forward to IMO (to be considered at SLF 39 in 1995). An overview was given of the contents of this guidance and of its intended use. It should be viewed as the first general guidance of its kind, it may be subject improvement of replacement in the future.

The guidance concentrates on indicating possible critical areas of operation in following and stern quartering seas, using mean wave period, ship speed, heading and natural roll period as the main parameters. A flow diagram of the proposal is shown at the end of this synopsis. Surfriding (and subsequent broaching) is addressed in Fig. 2 of the flow chart, while the possibility of wave energy concentration effects - the repetitious encounter of large amplitude waves - is indicated in the dangerous zone of Fig. 3.

Part of the discussion focused on the definition of ship speed. In the derivation and validation of the guidlines, the ship speed in still water was used as the reference speed. Dr. Grochowalski pointed out, however, that his experience with small ship capsizing in astern seas (model tests) suggests that the instantaneous ship speed at sea - before the crest of a large amplitude wave reaches the stern - is of importance with respect to a (non)capsize or broach; in his opinion there is little correlation between the still water ship speed and attained speed in waves for small ships (fishing vessels). It is noted that using the calm water ship speed as a reference speed, the master must know the relation between propeller RPM and ship speed -- this information is likely to be present on board large ships (and definitely also on board Navy ships, as attested by Mr. Thomas).

A second topic of discussion was the definition (or lack thereof) of severe weather: when should a master be concerned about actually using the guidance? Wave height is not part of the parameters, as was recognized by Prof. Takaishi. Dr. M. Renilson suggested a simple GM versus significant wave height criterion to indicate the possibility of critical conditions. By analyzing a number of capsize data (using some external model test sources), he ended up plotting the following parameters : GM/L as a function of H_s/L, where L is the ship length. The interesting observation was that a wide range of ship types would show a fairly well defined demarcation line, as shown schematically in the figure below.



A preliminary analysis suggests that the demarcation line is given approximately by: $GM \approx 0.2H_s$. Therefore, a "severity" criterion could look like: if $GM < 0.2H_s$, caution is required and the guidance should be consulted. An interesting observation was that it was not possible to get definitive trends by for example including ship heading angle or speed. More validation of such a criterion would be needed before its inclusion in a formal guidance; more information from Dr. Renilson is anticipated. It should be noted that a high value of GM is in itself not necessarily a sufficient safeguard against capsizing.

7. Dr. Grochowalski (NRC):

• *Capsize model test results for small vessels*

Subsequent to the discussion on the IMO Guidance, additional comments in relation to the pending paper by Dr. Grochowalski et al. ("Operational Factors in Stability

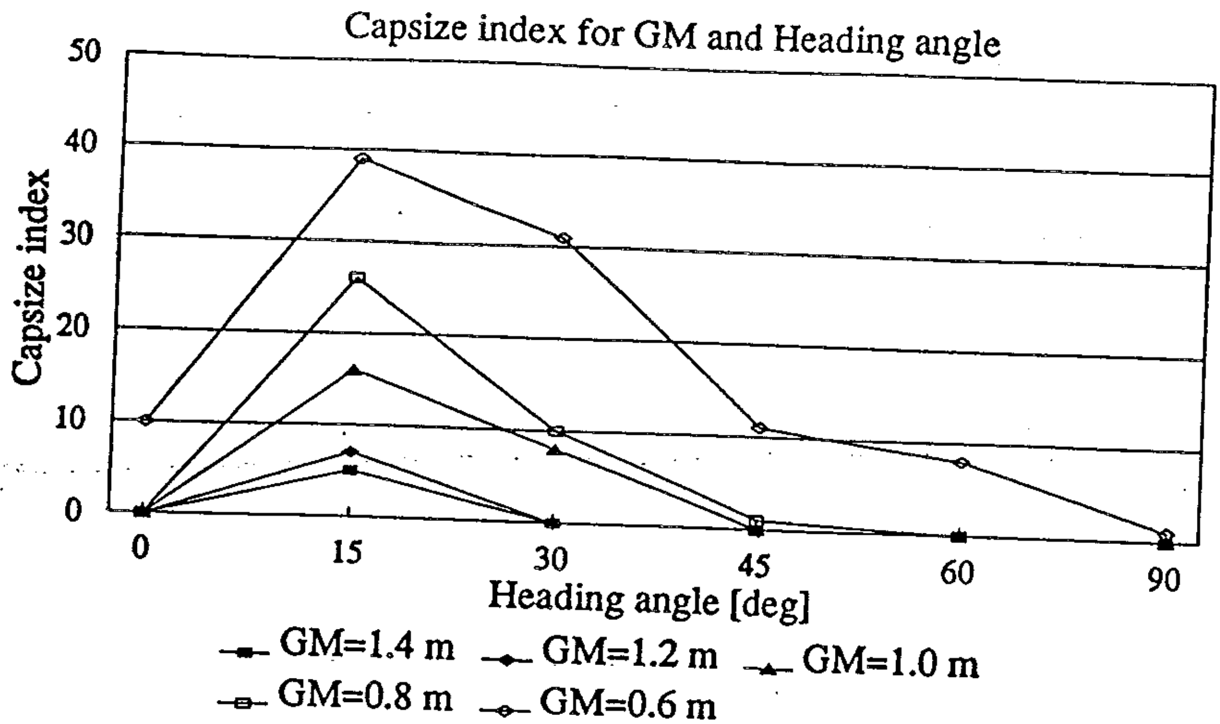
Safety of Ships in Heavy Seas") on small boat model tests and capsizing were discussed. A definition of "design stability" was given, i.e., the inherent stability based on hull geometry and loading condition. The need for operator guidance was stressed, the IMO proposal fits in this context.

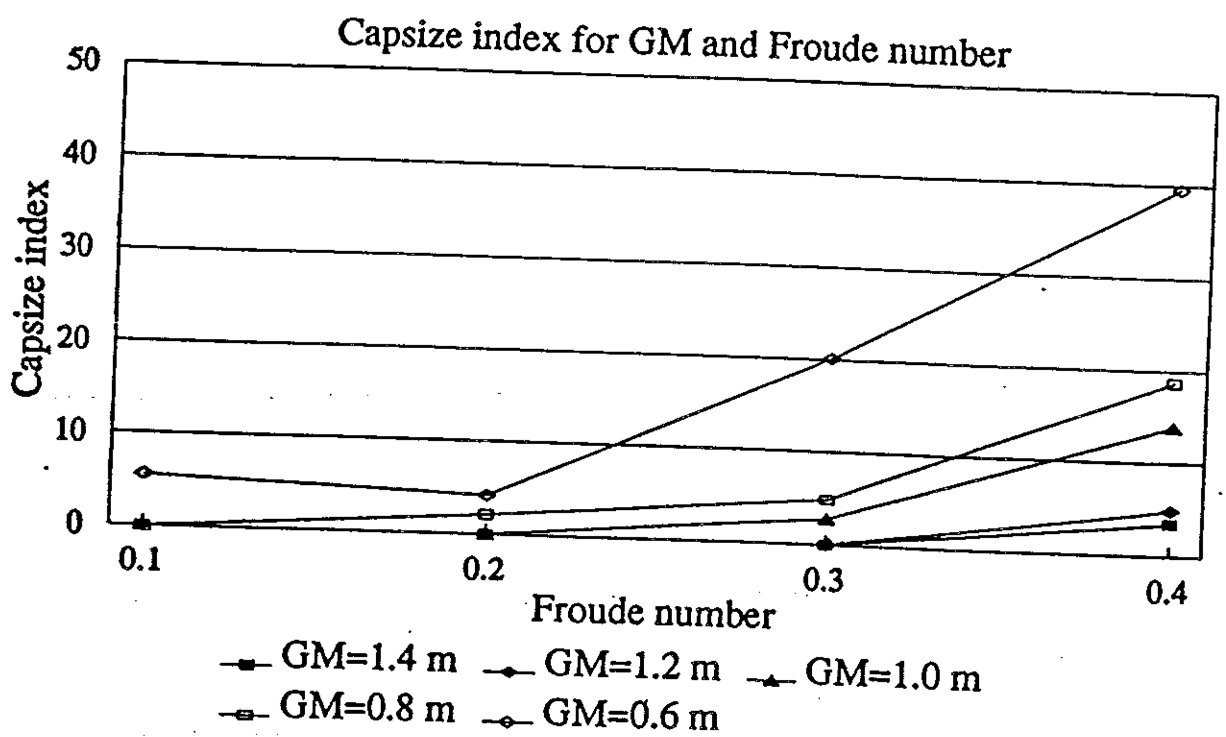
As discussed previously, the definition of ship speed is important; three different definitions were shown to affect the interpretation of the polar plots of the IMO guidance:

- speed and heading at the moment of wave impact at the stern
- speed and heading averaged over one wave encounter
- maximum speed and maximum heading angle during passage of high wave group

A dramatic increase in ship speed is possible after wave impact at the stern. A fundamental difference between capsizing of small ships versus big ships is the degree of severity of the waves for small ships. A small ship may encounter relatively high waves of large steepness (wavelengths 3 to 5 times the ship length, $H/\lambda \approx 0.1$), while it is unlikely that a large ship will encounter waves of the same relative length and steepness - as was mentioned by J. de Kat in his presentation on joint statistics of wavelength and steepness. Thus, a small ship faces a greater risk of being subjected to long and high waves (and hence a greater risk of broaching and capsizing). Therefore, caution is needed in the development of general guidelines, which may need refinement to account for ship size properly.

Due to lack of time, it was not possible to include a planned presentation by Dr. Renilson. This omission notwithstanding, the moderator thanked all the contributors and workshop attendants for their presentations and active participation.


Capsize index for GM and Heading angle
Capsize index
50
40
30
20
10
0
0
15
30
45
60
90
Heading angle [deg]
GM=1.4 m
GM=1.2 m
GM=1.0 m
GM=0.8 m
GM=0.6 m


Capsize index for GM and Froude number
Capsize index
50
40
30
20
10
0
0.1
0.2
0.3
0.4
Froude number
GM=1.4 m
GM=1.2 m
GM=1.0 m
GM=0.8 m
GM=0.6 m

Operation Diagram for the Master

Ship: Satisfaction of IMO Stability Criteria or equivalent

↓

Wave : Wave length > 0.5 × Ship length,
Estimate λ, T, and χ, where $T=0.8\sqrt{\lambda}$.

↓

Ship Course: Wave direction is 0~45 degree from the stern.

↓

Encounter Wave Period, T_E

↓

If ship's speed:
(1) in Surf-riding zone
Reduce to speed zone (2),
(2) in marginal zone
Reduce to speed zone (3),
when felt large surging.
(3) out of the zones

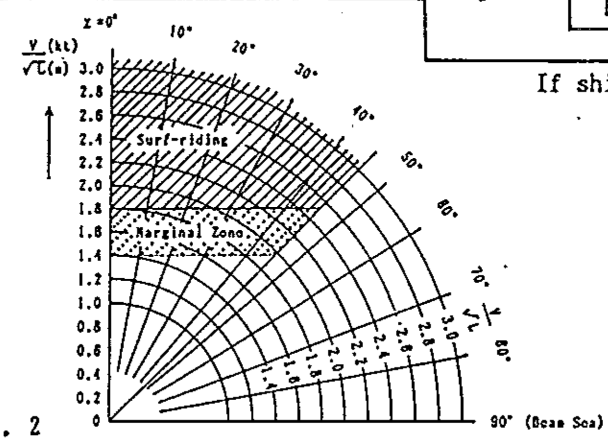


Fig. 2

↓

Next Step

↓

Plot V(knot)/T(sec) versus χ on Figure 3.

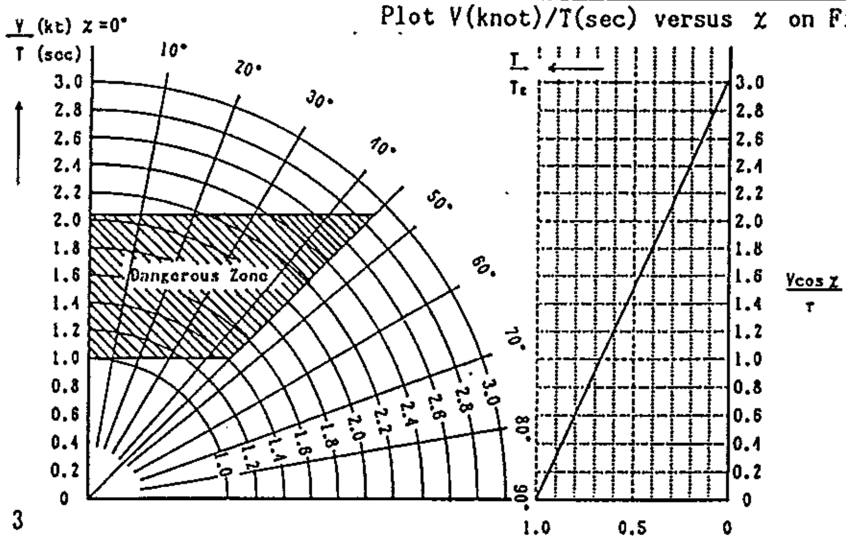


Fig. 3

↓

If V/T(χ) is in the dangerous zone, reduce the speed to come out the zone.

↓

If V/T(χ) is out of the dangerous zone, keep speed and course. → Judge T_E

↓

If T_E is nearly equal to T_R or $T_R/2$, reduce the speed further.*

* Keep in consideration the minimum speed for maintaining course control of ship.

HUMAN FACTORS IN STABILITY WORKSHOP

1330, THURSDAY, NOVEMBER 10, 1994

CENTRAL BAPTIST AUDITORIUM
FLORIDA INSTITUTE OF TECHNOLOGY

MODERATOR: DR. STEPHEN J. ALLEN

CO-MODERATOR: PROFESSOR CHENGI KUO

Reference (a): Human Factors Plan for Maritime Safety, Report CG-D-11-93, T. Sanquist, A. Lee, M. Mandler, A. Rothblum, U.S. Coast Guard Research and Development Center, Groton, CT, 1993

I. Introduction to Workshop

Dr. Allen welcomed workshop participants and briefly explained the purpose of the workshop. As part of the introduction, Dr. Allen discussed why naval architects should be interested in Human Factors (HF). The major reason is that human-related error has been identified as a cause of 65-80% of accidents in a wide variety of industries. This figure generally holds true for the maritime industries. The majority of marine accidents involving a loss of stability probably originates in some HF area.

Also from a regulatory perspective, the greatest improvements in marine safety may be effected through improvements in HF areas. This does not imply that naval architects should not strive to improve their designs; rather, we must view the entire "system." Technological improvements such as real-time computerized information to the Master or improved Ro-Ro designs must still be the subject of naval architecture research. But their impact on marine safety regulations must be coordinated with improvements in the HF area.

Dr. Allen provided some additional comments as part of the introduction. The role of HF within the marine environment, and specifically stability, has been only recently recognized. The IMO has devoted its attention to several issues during the last few sessions, and these will be discussed in a few moments.

Within the U.S. the Coast Guard has undertaken several studies to identify a plan to incorporate HF considerations in its marine safety mission. A recent report, Reference (a), was commissioned to identify needed HF research across the entire marine safety mission, not just stability.

At last year's Coast Guard Vessel Stability Symposium '93, one of the workshop panels undertook the discussion of HF. Dr. Jack Spencer from ABS Americas led this group. Their findings were focused on the following operational aspects:

1. Find out what major hazards are using casualty analysis - start with existing casualty reports.

2. Apply other industry HF research

3. Recognize that information to the Master is very important

4. Develop quality management systems

After briefly identifying recent Human Factors research he was aware of, Dr. Allen invited several participants to offer their views on what were some important human factors issues.

Dr. Chengi Kuo from the University of Strathclyde, presented several overhead slides explaining what the term "human factors" implied. He summarized by presenting the following definition of human factors: "Human Factors" is concerned with the interfacing of a set of personal capabilities and characteristics with a combination of hardware, software, working environment and operational culture in the effective performance of a task."

Next, Commander Randy Gilbert from the U.S. Coast Guard discussed his experience with various ship types and discussions of HF issues at recent IMO meetings.

Mr. Andrew Blyth from the United Kingdom next discussed the spectrum of human involvement in small craft, illustrating his point with a graphic showing the continuum between craft requiring 100% human involvement to those requiring no involvement. He concluded with the reading of excerpts from the IMO's high speed craft rules which involved several HF issues. His presentation is summarized below.

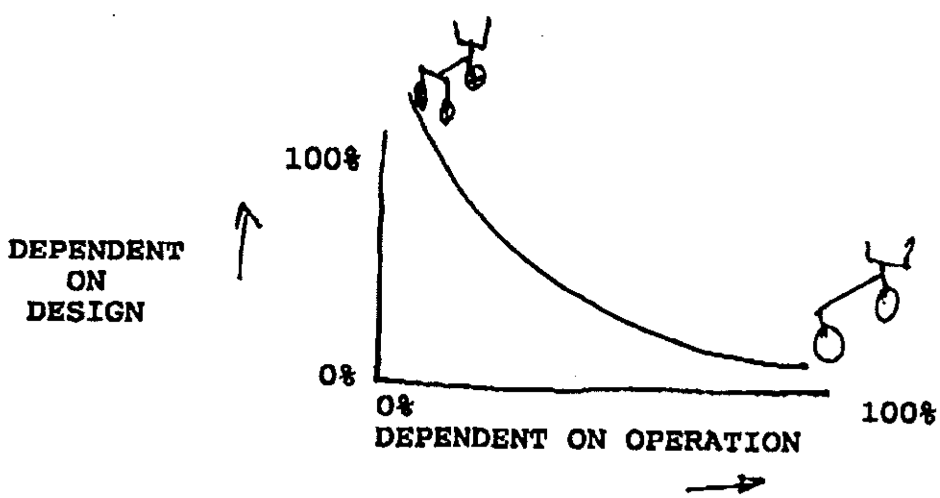
ASPECTS OF HUMAN FACTORS IN STABILITY

DESIGN

CONSTRUCTION

SHORESIDE (control/inspection)

SHIPBOARD OPERATION



<u>VESSELS WHICH ARE</u>
<u>100% DESIGN DEPENDENT</u>

RESCUE LIFEBOATS

DISPLACEMENT VESSELS

CONTAINER SHIPS

HIGH SPEED CRAFT

FISHING VESSELS

RACING POWERBOATS

SAILING DINGHIES

CANOES

SURFBOARDS

<u>VESSELS WHICH ARE</u>
<u>100% OPERATOR DEPENDENT</u>

<u>BUOYANCY</u>

<u>100% DESIGN DEPENDENT</u>

SURFBOARDS

SAILING DINGHIES

RESCUE LIFEBOATS

HIGH SPEED CRAFT

(CANOES)

DISPLACEMENT VESSELS

FISHING VESSELS

RO-RO SHIPS

OPEN NON-BUOYANT DINGHY

<u>100% OPERATOR DEPENDENT</u>

The last presentation was by Mr. William Cleary who has recently retired from the U.S. Coast Guard as Chief of the Naval Architecture Branch (G-MTH) in Washington, DC. Mr. Cleary made several points:

Human Factors in Marine Regulation

1. Regulations assume knowledgeable humans, but humans often assume that any marine craft that has been "approved" is so well protected that the operator can test it to the limit (Canada fishing boat).

2. The output of a naval architect is in a form which necessarily shows by detailed calculation how well the design meets (or exceeds) minimum rules (regulations). But that output is not intelligent information for operators so it gets "lip service" only (container T&S ignored).

3. The trend to avoid "stopping the ship" at any cost, affects operation (loading, offloading, maintenance) (all container ships). It affects ship systems safety (HERALD), and it affects ship's actual level of safety (MV OCEANUS).

4. The IMO trend to be driven by consensus. Plus the reluctance of nations to add their own regulations on top of IMO for very good regional reasons.

5. Solutions - Video training which includes the limits of safety. State the way SOLAS/load level support each other. Or undermine each other.

II. Workshop Objective

Dr. Allen then suggested that the workshop be divided into three or four groups to discuss specific HF issues. He proposed that the results of a recent study done for the U.S. Coast Guard might be useful in deciding how to break out. In this study, reference (a), HF in the maritime environment, may be conceptualized in terms of human and technological system domains as follows:

1. Vessel personnel/human resources

   Manning, licensing, training

2. Vessel design

   Inherent stability, "foolproof design"
   Economic considerations
   Ergonomically correct
   Automation, information systems

3. <u>Navigation and Vessel Routing</u>

Storm avoidance

4. <u>Organizational Factors</u>

Corporate "safety culture"
Willingness to allow master to exercise safe judgment

Discussion of the relevance of the above groups ensued. After several comments from the floor, it was agreed that number 3, "Navigation and Vessel Routing," and number 4, "Organization Factors" could be combined into "Operations." Thus the workshop participants were divided into three groups to investigate and study HF issues associated with:

A. Personnel
B. Design
C. Operations

Specifically, each group was charged to:

- Identify key HF issues within each category
- Prioritize importance of key issues
- Identify ongoing research in these areas
- Recommend what research or non-research action should be undertaken
- Decide how research findings should be implemented

The workshop format was now:

1330-1350 Introduction to Workshop

1350-1430 Short Presentations (10 min.) by participants

1430-1530 Break out into individual groups on:

Personnel
Design
Operations

(Break as appropriate)

1530-1600 Wrap-up/Discussion/Summary

At about 1430, participants began individual group discussions.

III. Results of Individual Groups

At about 1600 the individual groups were reassembled for summary presentations.

A. The findings of the Design Group were presented by Commander Gilbert who reported that his group had identified the following key issues affecting HF, in order of decreasing importance.

- A. Loading
- B. Ballasting
- C. Hull form
- D. Arrangements
- E. Designs are driven by economics
- F. Securing of cargo
- G. Securing of watertight envelope
- H. Methods of calculating stability - validating stability
- I. Conditions of environment in design
- J. Practical education of designers

Next in addressing what research or non-research was needed, the Design Group identified:

- H.1. Research on rolling or sallying a ship to determine GM
- G.2. Failure mode analysis on closing the envelope
- G.3. Research on loads on doors and hatches
- B.4. How long is acceptable to ballast ops
- G.5. Having double-check method for opening doors
- F.6. Linking sea state with vessel motion/tie-down requirements
- I.7. Design limitations on the vessel, especially environmental
- J.8. Identify areas that you can take human element out of

The numbers in the second column on the left denote the priority while the letter in the first column refers to the key issues from the preceding paragraph.

Thus "Research on rolling or sallying a ship to determine GM" was the highest priority research needed and it related to key issue H.

The Design Group summarized by recommending that HF improvement could be implemented by:

- Education, training and licensing of ship designers.
- Creating a master's check-off list which must be completed before getting underway.

B. The <u>Personnel</u> Group findings were then presented by Lieutenant Commander Alan Marsilio from U.S. Coast Guard Headquarters:

PRIORITIZED PERSONNEL ISSUES

1. Training -

   Developing of simulator
   Better use of STAB info
   Analysis of casualties
   Updated re-training
   Training of crew as well as officers
   Research and non-research improvements

2. Qualifications

   Improved licensing
   More stability required as part of licensing exam

3. Authority Invested in Master/Crew

   Analyze casualties
   Let Master decide

4. Feedback/Incentive Enforcement - Improved

   Reward safe operation
   Enforcement against violating stability requirements

5. Experience

   Pertinent to vessel type/operations

And the last presentation on <u>Operational</u> HF Issues from the Stability Viewport outlined:

1. Key Issues

   - Organizational operations
   - Shipboard Operations

2. A. Economically Driven (reason or why)

   B. Need to support from top down and suggestion upward flow (support).

   C. Provide "practical" teaching, training and experience (capability).

D. Responsibility structure (actualization)

-Now hierarchical
-Subvert Organizational structure to stability situations/issues

3. Research or Improvement Needed

-Non-Research
- Training Methods - Practical implementation
- TQL - Management

-Research
- Bridge/Cockpit Resource Management (leads to)
- Team Concepts

4. Improvements

-Video, interactive simulations

-Management needs to set example
- Company policy
- Responsibility to lowest levels

-Safety is economically feasible

IV. Summary

Several comments were offered from the workshop participants after each group's presentation. The major comment was that economics always drove companies which operate vessels. If there is no economic disincentive such as fines, companies will not promote safety. A discussion about insurance rates and safety ensued. The general consensus was that there will always need to be minimum stability requirements imposed by law on vessels, but these must be recognized as only minimum requirements. Vessel operations should be encouraged to exceed minimum safety.

Discussion at STAB94

To: the paper titled "Vessel's Heeling and Stability in the Regime of Manoeuvering and Broaching in Following Seas" by Ananiev & Loseva

From: N. UMEDA (National Research Institute of Fisheries Enginnering, Japan)

I would like to thank Prof. Ananiev for providing us an excellent paper for broaching. I would appreciate it if you would solve my questions.

(1) In my opinion, it is not appropriate to keep zero rudder angle during the time domain simulation. Because, broaching has been identified as a phenomenon that helmsman cannot maintain his ship course with any efforts of steering. It is rather common that a surf-ridded ship becomes directionally unstable with zero rudder angle. Thus, it is essential for the broaching study to consider a steering action up to the maximum rudder angle.

(2) In your simulation study, initial conditions are limited to the surf-riding condition with two kind of small disturbance. The discusser, in his paper for this conference[A1)], utilized eigenspace at the surf-riding equilibrium point to select more suitable initial conditions. However, when we use larger initial yaw rate, broaching can easier occur. Thus, the diagram like Fig. 6 in this paper should be regarded as only an output from a certain set of initial conditions.

Reference

A1) N.Umeda, Broaching of a Fishing Vessel in Following and Quartering Seas: Nonlinear Dynamical System Approach, Proc. STAB94.

STAB '94

Discussion to the Paper by B. Bandyopadhyay & C.C. Hsiung on Mechanism of Broaching-To of Ships from the Perspective of Nonlinear Dynamics

by Professor A. D. Papanikolaou, NTUA

The paper deals with the combined surge, sway, roll and yaw motions of a ship in oblique seas and addresses the "broaching-to" phenomenon. At the discusser's experience with second-order drift forces and motions calculations for several shiplike forms, it seems that in moderate to large amplitude seaways, certain second-order effects, e.g. the steady second-order, wave induced drift forces and moments, will be of importance for the prediction of a broaching situation, since they are leading to steady drift deviations (steady heel, pitch and heave) and to steady second-order forces and moments in surge, sway and yaw direction. These effects must be counterbalanced by the ship's propeller and rudder force couple. The drift effects seem significant for relatively short, steep waves and for wave frequencies close to the first-order motions' resonance. They might be introduced in the equations of motion as second-order corrections. Based on the experience and the previous work of the authors could they please comment on the importance of these effects on the broaching-to phenomenon of a ship in oblique seaways?

Ref. Papanikolaou, A., and Zaraphonitis, G., "On an Improved Method for the Evaluation of Second-Order Motions and Loads on 3D Floating Bodies in Waves", Journal Schiffstechnik, Vol. 34.,1987, pp. 170 - 211.

Discussion at STAB94

To: the paper titled "Piese-Wise Linear Methods for the Probabilistic Stability Assessment for Ship in a Seaway", by Belenky

From: N. UMEDA (National Research Institute of Fisheries Enginnering, Japan)

The author should be congratulated for his excellent contributions for probabilistic ship stability problems. I would appreciate it very much if you would solve my question about relationship between your work and current nonlinear dynamics.

As shown in Fig. 1-b), phase trajectories has heteroclinic orbits. If a time dependent external force is added to a system with such heteroclinic orbits, a chaos can be occurred. In other words, small perturbation near a saddle point may have a great influence for a global dynamical system.

On the other hand, you have stated that influence of excitation is very small at the range No.1, which involves a saddle point.

Therefore, your statement seems to be inconsistent with the fact mentioned above.

Discussion at STAB94

To: the paper titled "Ship's Stability Safety in Resonance Case" by Blocki

From: N. UMEDA (National Research Institute of Fisheries Engineering, Japan)

I fully agree with your suggestion for integrating probability density on the safe domain as a more practical measure than the area of the basin. In fact, I did present the same idea as a discussion for Prof. Thompson's paper at the IUTAM symposium in June 1990. Then I formulated a procedure to calculate the probability of capsizing due to pure loss of stability in quartering seas and showed some numerical results.[A1-A2] However, in my case, the effect of time dependent external moment on the basin was ignored on the basis of surging effect, while the correlation between the time dependent restoring moment, roll and roll rate is taken into account. So, for capsizing due to low cycle resonance, your numerical results are the most welcome for the following sea problem. Could you tell us your plan to show us your numerical results based on Eqs.(5.4-5.5) besides Figs. 10-11 that were based on your previous method?

References
A1) Umeda et al. "Probabilistic Study on Ship Capsizing due to Pure Loss of Stability in Irregular Quartering Seas". Proc. of STAB90, 1990 pp. 328-335.
A2) Umeda & Yamakoshi, "Probability of Ship Capsizing due to Pure Loss of Stability in Quartering Seas", Naval Architecture and Ocean Engineering, Vol.30. 1993, pp.73-85.

STAB '94

DISCUSSION

Paper Session 2
Author: Andrew G. Blyth
Title: The Development of an ISO Stability Standard for Small Craft

Discussor: Yoshifumi Takaishi, Nihon University, Japan

1. The discussor agrees with the author as to
a) the aspects being considered in the criteria under development which is described in the chapter 4, and
b) the importance of validation as proposed in the chapter 8.

In Japan also a project is just set up to examine the applicability of the draft standard to existing small crafts.

2. Could the author explain somewhat details of the basic idea of the the Method C for Non-sailing craft, i.e. which phenomenon is taken into account to determine the minimum "freeboard" requirement in waves?

3. As to the Additional Requirement for Non-sailing craft, the weather criterion is derived by modification of the style after Sarchin and Goldberg "Stability and Buoyancy Criteria for U.S. Naval Surface Ship". The weather criteria of IMO stability criteria, named A.562, becomes now common for dynamic stability assessment of ships. The discussor would like to recommend that applicability of the weather criteria A.562 to small crafts should be examined in the validation work of the present draft text.

Discussion to the Paper by J. M. Falzarano
on
Complete Six-degrees of Freedom Nonlinear Ship Rolling
by
Professor A. D. Papanikolaou, NTUA

The author presents a numerical, time domain procedure for assessing the transverse stability and survivability of ships in extreme weather conditions. According to the title of the paper the method aims to be a complete, six-degrees of freedom nonlinear solution, at least for the rolling motion. However, as explained in the text and in the given numerical examples, the method is currently working only as a nonlinear, single degree of freedom solution (SDOF) or at best three degrees of freedom procedure (3DOF) for the coupled sway, roll and yaw motions with linear couplings in the hydrodynamic terms. No couplings between the asymmetric and symmetric modes of motion, e.g. between roll and heave or pitch motion are considered. Although the consideration of the nonlinear restoring moment in roll is of primary importance for assessing the transverse stability of a ship hydrodynamic nonlinearities and couplings are of great importance too, especially for extreme weather excitations and ship motions.

The discusser understands that the addressed problem cannot be solved easily and needs further research in various areas of ship hydrodynamics.

Concerning the given examples for the SWATH ship T-AGOS (Fig. 7 to 12) I am wondering whether the author compared the theoretical predictions with any available experimental data. Although the dimensions of the various depicted quantities are not given in the graphs (the RAOs should be actually dimensionless in order to compare between linear and nonlinear calculations) there are some points to be clarified:

1. The results of nonlinear analysis (SDOF and 3-DOF) depicted in Fig. 7 are not realistic due to the omission of important hydrodynamic terms, especially in the SDOF model experiments. The conclusion of the author that the damping coupling is less important than the added mass coupling is not supported by the necessary experimental evidence.
2. The results of Fig. 10 and 12 for the roll amplitudes (given in [rad]?!) suggest that the influence of the above water hull form for the studied SWATH vessel in the restoring moment. A depiction for the RAOs in dimensionless form should show a decreasing resonance peak with increasing incident wave steepness, at least for moderate seaways for which a modelling is herewith possible. However, the equally important influence of the nonlinearities on the roll damping is not included, thus both the position and the height of the amplitudes at resonance are most probably not realistic. This might be concluded from the fact, that at my knowledge the studied T-AGOS disposes a displacement of abt 3500 tons, thus **it seems impossible to exhibit, even at resonance, for a 7 ft (2.1 m) wave amplitude excitation a roll amplitude of abt 23 deg ! (0.4 rad acc. to the figures).**

I would appreciate the comments of the author to the above.

STAB '94

Discussion to the Paper by J. M. Falzarano & F. Zhang
on
Nonlinear Dynamics of Floating Offshore Platforms
by
Professor A. D. Papanikolaou, NTUA

The authors present a numerical, time domain procedure for assessing the stability and survivability of Mobile Offshore Drilling Units (MODUs) in extreme wave conditions. According to the title of the paper the method aims to deliver a nonlinear dynamic solution to the stability problem of offshore structures in waves. The authors simplify the present problem by addressing the pitch motion of the structure in head waves as a single degree of freedom oscillator, so they neglect couplings with other modes of motion and wave headings, and claim that this is the most critical situation for the capsizing of an offshore structure or at least as critical as capsizing by rolling. In view of the simplifications made for the modelling of the present problem (neglect of couplings with other modes, no consideration of drift forces and constant drift deviations due to the action of waves and possibly winds and currents, no consideration of the action of moorings or DPS) I am wondering about the reasoning of the authors to consider the isolated pitch motion only. I am puzzled also with the restoring characteristics of the studied platform, that is not described closer in the paper, because it is in all thinkable practical cases impossible to obtain a stiffer platform in roll direction, compared to the pitch direction, due to the obvious relative magnitude of the relevant moments of inertia of the waterplane area. Later in the paper (discussion of Fig. 4) the authors admit that the weakest restoring capability of the particular platform is for a tilt of the orientation axis of abt 45 deg against the incident wave (oblique seas case). Thus the dynamics of the platform in oblique seas must be studied more carefully before concluding on the stability of an offshore platform. However, the hydrodynamic modelling for the oblique seas case is not addressed in the paper. The opinion of the authors to the above is appreciated.

Discussion at STAB '94

To: the paper titled "Operational Factors in Stability Safety of Ships in Heavy Seas" by Grochowalski, Archibald, Connolly and Lee

From: N. UMEDA (National Research Institute of Fisheries Engineering, Japan)

I agree with your opinion that "riding on a wave crest" is important for capsizing and completely different from a true surf-riding. But, this phenomenon have been theoretically explained as a part of large amplitude surging motion. Since an unstable equilibrium of force in surge exists near a wave crest, the ship situates on the wave crest for longer duration as a "riding on a crest" and situates on a wave trough for shorter duration. This is a common behaviour of a nonlinear oscillator. On the other hand, in a true surf-riding, the ship captured near a wave trough, because a stable equilibrium exists near wave trough.

I do not agree with your definition of the surf-riding (or riding on a crest.) That is, the surf-riding means that the duration of running with a wave is more than 30% of the natural roll period. Because, whether capsizing on a wave crest occurs or not cannot be determined only by the duration of staying on the crest. Initial roll angle and roll rate when the ship meets a wave crest arc as important as the duration. If a ship meets a wave crest with large roll angle, the ship may capsize within a duration of less than 30% of the natural roll period. The final conclusion will be obtained as a result of dynamic analysis of a surge-sway-yaw-roll motion.

STAB '94

Discussion to the Paper by M. Hamamoto, M. Fujino & Y.S. Kim
on
Dynamic Stability of a Ship in Quartering Seas
by
Professor A. D. Papanikolaou, NTUA

The paper deals with the combined sway, roll and yaw motions of a ship in quartering seas and addresses various phenomena leading to a possible capsizing of the ship in following and quartering seas. In studying these admittedly complicate phenomena, especially in moderate to large amplitude seaways, certain second-order effects might be of importance, e.g. the steady second-order, wave induced drift forces and moments, leading to steady drift deviations (steady heel, pitch and heave) and to steady second-order forces and moments in surge, sway and yaw direction, to be counterbalanced by the ship's propeller and rudder force. In fact at least one aspect of the broaching phenomenon can be attributed to the excited drift yaw moment on the ship by quartering or oblique seaways (see [1]). These effects seem significant for relatively short, steep waves and for wave frequencies close to the first-order motions' resonance. They might be introduced in the equations of motion as second-order corrections. Based on the experience and the previous work of the authors could they please comment on the importance of these effects on the dynamic stability of a ship in quartering seas?

[1] Papanikolaou, A., and Zaraphonitis, G., "On an Improved Method for the Evaluation of Second-Order Motions and Loads on 3D Floating Bodies in Waves", Journal Schiffstechnik, Vol 34., 1987, pp. 170 - 211.

Discussion at STAB94

To: the paper titled "Mechanism of Broaching-to of Ships from the Perspective of Nonlinear Dynamics" by Bandyopadhyay & Hsiung

From: N. UMEDA (National Research Institute of Fisheries Enginnering, Japan)

First of all, the discusser respects the authors' bold attempt for dealing with a complex multi-degree-freedom system. He would like to ask the following questions:
(1) It is not acceptable that the phase trajectories shown in Figs. 2-3 directly prove the existence of a chaotic attractor. Because, the system focused here is not a single-degree-freedom system, but a multi-degree-freedom system. In the latter system, non-repeated phase trajectories or Poincare map are not suitable indices of a chaotic attractor as the system may have more than two oscillation periods. In the case of Figs. 2-13, the behaviour can be explained as a sum of a short-period roll motion, long-period decaying yaw motion and other usual motions. At least, more advanced index, such as the Lyapunov exponent, should be used to identify a chaotic attractor.
(2) It is also not acceptable that the inception of broaching-to is attributed to the bifurcation in Figs. 3-4. Because, there is no qualitative difference between two figures. Only quantitative difference exists. That is, whether the yaw angle exceeds 45 degrees or not. In the nonlinear dynamics the bifurcation means a qualitative change of a system.
(3) The broaching-to defined in this paper is not relevant to the broaching-to identified in the previous researches or mariner's experience. The reason why broaching is danger is that the helmsman cannot maintain his ship course with any steering efforts. However, the helmsman modeled in this paper only keeps small rudder angle.

Discussion at STAB94

To: the paper titled "Nonlinear Dynamics and Capsizing of Small Fishing Vessels" by Jiang, Troesch and Shaw

From: N. UMEDA (National Research Institute of Fisheries Enginnering, Japan)

Could you tell me the particular reason why you did not focus on zero points of the Melnikov function as a conventional index of capsizing? Except for an empirical relationship with the capsizing probability from numerical experiments, do you find any certain physical background for a relationship between capsizing and the time average of the positive part of the Melnikov function?

STAB '94

Discussion to the paper:

"Intact Ship Survivability in Extreme Waves: New criteria from a Research and Navy Perspective".

Authors: J.O. de Kat, R. Brouwer, K.A.McTaggart, W.L.Thomas.

I would like to congratulate the authors the comprehensive, state of the art, and well designed study, which combines analyses of sea waves data, physics of capsizing, experimental results and numerical time-domain simulations. In general, the philosophy of this approach is very similar to the study on stability safety of smaller ships and fishing vessels, currently being performed at the National Research Council of Canada.

A combination of model experiments with time-domain simulation provides possibility to enlarge the range of studied situations and conditions, and also allows to investigate the influence of characteristics. Such a combination is fundamental to the development of stability criteria for ships operating in extreme conditions. This paper constitutes a good illustration of a successful use of the methodology.

The paper also shows how the detailed scientific analysis can yield practical effects in the form of design tools or operational guidelines. This is always the ultimate goal for all researchers. The authors should be commended for this achievement.

Some of the elements and results of the presented study require some discussion and further considerations. the following are some comments and questions which arise from this very interesting paper.

1) A joint distribution of wave length and wave steepness is considered in establishing the environmental conditions as the input data for the simulations. This is an important element in the study, as the wave steepness is one of the most important factors in ship capsizing.
However, the "maximum steepness" discussed in the paper is the steepness related to the significant wave height and to spectral peak period for high sea states. Some averaging procedures are involved in calculation of these values and, therefore, they in fact represent significant wave heights and significant steepness corresponding to the maximum sea states, and not the true maximum values. In the same conditions, the maximum steepness and height would be much larger. In the high sea states, breaking waves are formed frequently, and their steepness is in the range 0.10 - 0.14. Obviously, if such conditions were taken as the input data for the numerical simulations, the results and the criteria proposed would be different, and much more stringent.

If, in the simulation procedures, regular wave with the height and steepness equal to the significant wave height and significant steepness in the irregular waves is used, then all higher and steeper waves which certainly occur at the considered sea state, will be eliminated. Yet, those eliminated waves constitute the largest danger from capsizing point of view. Thus, the criteria based on the "significant" steepness will be misleading and will not provide the safety level as it is claimed.

2) I am pleased to see that the authors consider combinations of various dangerous physical phenomena acting together or in a sequence. This is a significant departure from traditional approaches, where only individual phenomena are considered and modelled numerically. Application of the time-domain simulation techniques provide possibility of modelling of such complex situations during ship motion in extreme waves. The same approach is taken in our capsizing study.

A good illustration of various combination of dangerous phenomena generated when a ship operates in extreme conditions, can be found in the film produced at the National Research Council of Canada (see: additional reference). the film presents some analyses of various types of capsizing, recorded during comprehensive model tests carried out as a part of the capsizing studies,

3) The authors stated that the analyses of physics of ship capsizing and the validation of the time-domain software were based on results of various model tests. No reference is given to those model tests. Could the authors give some information about the tests?

The paper would also gain a lot, if the comparisons of the simulation results against experimental results were given.

4) The influence of the wave length/ship length ratio and the spatial wave steepness for The wave lengths between 1 L - 2.5 L on ship propensity to capsizing, is emphasized in the paper. This is in agreement with our capsizing study. Indeed, it is the instantaneous configuration of the immersed hull in the wave profile which causes the generation of the hydrodynamic forces acting on the ship, and subsequently its behaviour.

5) At one point, the authors mentioned the influence of phenomena generated by bulwark submergence, and of water on deck on ship capsizing. Are these phenomena included in the time-domain simulations carried out in the study?

6) The influence of hull shape on stability safety is investigated by large number of simulations for the systematic variations of the selected hull form parameters.

I would like to point out, that there are some traps in such a procedure. For the same hull, some form parameters are correlated, and variation of one selected parameter usually affects some others, although they are to be kept constant. This affects the results of analyses, and sometimes the conclussions may be misleading if they are attributed to changes of one parameter only, while in fact some others are changed as well.

The statement: "Ships with high value of B/T tend to show a higher capsize index than ships with a low B/T at constant GM" leads to surprising conclusion that increase of B/T reduces stability safety. In fact, increase of B/T usually enlarges stability on calm water (GZ curve), which should reduce the risk of capsizing.

If GM was kept constant in variations of B/T, the KG had to be changed, i.e. increased, and this may have a strong detrimental effect - but this is not the negative influence of the increase of B/T. In such an exercise, it is rather KG/D which should be kept constant in order to find the real influence of B/T.

Could the authors explain this aspect, and also provide some details on the generation of the "derivative forms" (i.e. what happened to form and mass distribution parameters when one factor was systematically varied)?

6) Similarly confusing statements are made on the influence of the freeboard height:

"concerning freeboard, below a critical value of D/T the safety against capsizing deteriorates quickly" -

and:

"Hull forms with a large freeboard (D/T = 2.4) may be vulnerable to capsizing even when the range of positive stability exceeds 90 degrees. In other words, a large freeboard will contribute to a low capsize index, but only when the initial stability (GM) is sufficient".

Is the positive influence of the freeboard limited only to a certain range of freeboard height? Could the authors explain it in more details?

7) There are some unclear statements regarding the capsize index CI for existing ships:

"The current regulations seem to result in a maximum value of CI^{crit} between 15 and 25". (also Table 3).

"... for most ships the maximum allowable KG according to present Sarchin and Goldberg criteria results in a safety level that lies close to a capsize index CI = 5".

"... in no other loading condition should the capsize index exceed 25 (the level dictated by the weather criterion of Sarchin and Goldberg)".

Could the authors explain these different statements?

The CI = 20 or 25 seems to me to be too high as an allowable limit for stability safety.

Additional Reference:

S. Grochowalski, C. Wallace - "Ship Capsizing in Quartering Seas". Video tape, National Research Council & Canadian Coast Guard, Canada 1990.

Discussion at STAB94

To: the paper titled "Broaching-to: Thirty Years on" by Vassalos & Maimun

From: N. UMEDA (National Research Institute of Fisheries Enginnering, Japan)

I have read this paper of numerical study with great interests. I would like to ask the following two questions:

(1) I disagree one of your conclusions that ignoring the effect of diffraction could be regarded as a safeguarding measure in assessing broaching. The opposite conclusion have been obtained in the previous researches by Ohkusu[A1)], Yoshino[A2)] and the discusser[A3)]. By using a slender body theory for low encounter frequency and model experiments, their papers show that the diffraction effect significantly increases magnitude of wave induced yaw moment. I presume that the theory used in your paper does not suit hydrodynamic phenomena with low frequency.

(2) In my opinion, Figs. 7-8 are not examples of *one wave broach*, but examples of capsize due to *pure loss of stability*. Because, as you pointed out, the main cause of capsizing is the reduction of GZ curve due to wave crest. In addition, no centrifugal force effect from yaw to roll causes capsizing and no surf-riding were observed in the time series of this paper.

Reference

A1) M. Ohkusu, J. Soc.Nav.Arch. Japan, vol.159, 1986, pp.129-138.

A2) I Yoshino, M. Fujino and T. Fukasawa, J. Soc. Nav. Arch. Japan, vol 163, 1988, pp.160-172, in Japanese.

A3) N. Umeda, M.R. Renilson, Pro. 11th Australian Fluid Mechanics Conf., 1992, pp.363-366.

Reply to questions by Dr. S. Grochowalski

Intact ship survivability in extreme waves: new criteria from a research and navy perspective

Authors: J.O. de Kat, R. Brouwer, K.A. McTaggart, W.L. Thomas

As regards the concept of wave steepness, a clear distinction must indeed be made between the characteristic or "significant" steepness and the instantaneous "spatial" steepness. The maximum significant steepness of any seaway will not exceed 0.05 (which seems to be the natural boundary of limiting steepness). The design guidelines were developed on the basis of simulations in regular waves with a spatial steepness of $H/\lambda = 0.08$, which was coined the "expected maximum steepness". The term "expected" is used here in the statistical sense, i.e., it represents a mean maximum value. Steeper waves will occur in a random seaway, but the probability of occurrence will be small, especially when this concerns waves that are long. As we are looking at frigates, a typical ship length is $L = 120$ m. A wave with a length of 1.25L would have a height of 12 m for a steepness of 0.08; a longer wave would be even higher. This suggests that the steepness of 0.08 can be considered as a realistic maximum value. It should be noted that if we were to develop similar guidelines for small ships, steeper waves might have to be considered, and the range of wavelengths should be increased (up to $\lambda = 6L$, for example).

We agree with the importance of combined events in capsizing - it is often not possible to single out one cause of capsizing. The capsize video referred to by Dr. Grochowalski is highly recommendable, the insights that one gets from viewing the various capsize events is most excellent.

Validation of the time domain code FREDYN has been and still is considered as a most important issue. Data are not included in the paper for two reasons: paper length (this paper well exceeds the officially allowed number of pages) and confidentiality (most data used were supplied by member navies for frigate type ships). In past years, we used mostly model test data that were available from different projects. We have now reached the stage where a formal and structured approach is being set up for validation procedures. This covers theory and code verification, comparison between simulations, model tests and full scale measurements for seakeeping and maneuvering in moderate sea states, and between simulations and model tests for seakeeping/survivability in extreme conditions. In view of its intended future use, it is critical to know the program's capabilities, confidence bands and practical limitations.

Bulwark submergence and water on deck have so far not been included in the model. A reason for this omission in the model is that naval frigates do not have a bulwark and that water on deck is not considered a serious problem because of the relatively high freeboard. With the interest turning also to other ship types, however, these aspects will be addressed in the future.

In the derivation of the systematic hull forms, use was made of procedures that were applied in the systematic "Fast Displacement Ship" seakeeping model tests, reported in [1]. Four transformation methods were used in the present study; each method has its own set of parameters that are independent, remain unchanged, or will change as a consequence of a transformation. Linear transformation is used for L/B and B/T, a different method is applied for changing the block coefficient and vertical prismatic coefficient. The latter method uses a predefined transformation of the section area curve, while retaining the characteristic form of cross sections of the parent hull. The weight distribution was such that the pitch and yaw gyradii equalled 0.25L and the roll gyradius was equal to 0.38B.

Influence of B/T: a ship (1) with a high B/T value will typically have a high initial GM for the same KG, when compared with a low B/T ship (2). However, if these two ships have the same freeboard, the deck edge of ship (1) will be submerged at a smaller roll angle than for ship (2). It may happen then that ship (1) has a smaller range of positive stability than ship (2); in such circumstances, ship (2) may be less prone to capsizing than ship (1). This was also observed in the HSVA capsize tests with container ships. Beside the aspect of angle of vanishing stability, a ship with high B/T may be subjected to larger waterplane area and hence larger stability fluctuations in astern seas. These comments are not meant to imply that ships with high B/T are unsafe - usually their GM and range of stability are sufficiently large, while even allowing for a relatively high KG. Caution is needed, however, for ships with high B/T and wide transom stern in loading conditions with low GM or low range of stability.

Influence of D/T: below a critical value of D/T (approximately 1.9 for ships with high C_w), the ship would have a high capsize index, regardless of decreasing KG (within a realistic range). The other statement is merely meant as a warning that a high D/T is not necessarily a sufficient safeguard against capsizing (although in general freeboard certainly reduces the capsize index).

We agree with the assertion about some unclear statements on critical capsize index values, see errata to the paper. CI = 25 would be too high as an allowable capsize index for normal operating and loading conditions. However, when a ship is e.g. in a minimum operating condition (low fuel, low ballast, high KG), a high value of CI = 25 would be allowable, provided the ship adheres to operational restrictions regarding speed, heading and sea state - the risk of being in a storm while in a critical loading condition will be small; if necessary, ballasting would be required.

References

[1] Blok, J.J., and Beukelman, W., "The High-Speed Displacement Ship Systematic Series Hull Forms - Seakeeping Characteristics," *Trans. SNAME*, Vol. 92, 1984

S T A B 1994

Discussion to the paper "Operational Factors in Stability Safety of Ships in Heavy Seas."

by: S. Grochowalski, J.B. Archibald, F.J. Connolly, C.K. Lee

Authors' reply to the comments by Prof. N. Umeda

Non-symmetric surging motion can be described and analyzed by use of a nonlinear oscillator theory as Prof. Umeda suggests. However, "riding on a wave crest" in high, steep and breaking waves is more then the non-symmetric surging with longer duration of sitting on the crest than in the trough. The energy of wave impact contributes significantly to accelerating the ship, and the form of the longitudinal motion may be not oscillatory in the classic sense. "Riding on a wave crest" in extreme waves requires further studies.

The paper does not propose a definition of surf-riding. It has been emphasized that theoretical surf-riding which lasts "forever" occurs rarely in practical operation, and the riding which lasts shorter time can be as dangerous as the theoretical one. The analysis of the experimental results showed that the visibly distinct and dangerous riding is the one that lasts longer than 30% of the roll period. As in the analysis of the experimental results a clear distinction between the runs "with" and "without" riding had to be made, the limit 30% of roll period was assumed as the criterion for selection of the events. It is not a criterion for a degree of danger. The purpose of the analysis was to find the correlation between the selected operational factors and the occurrence of the riding.

However, relating the time of riding to the natural roll period is essential and logic. This relation indicates what is the probability that the large heel angle occurs while a ship remains on a wave crest. This has a direct influence on stability safety margin, and this is exactly what Prof. Umeda indicates in his comments. The critical (or criterial) value of riding time related to roll period should be found through further detailed studies, obviously taking into consideration all components of ship motion and all dangerous physical phenomena that may occur in such a situation. As it has been indicated in the paper, the time of riding equal 50% of the roll period can be assumed as such a critical value. This time assures that the maximum roll angle will always be reached while the ship still remains on the wave crest.

STAB '94
INTERNATIONAL CHAIRMAN's SUMMARY

Wm. A Cleary Jr - Adjunct Professor Ocean Engineering
International Chairman - STAB ' 94

General

In all, 60 papers & presentations were made at STAB 94, all on either INTACT STABILITY or DAMAGED STABILITY.

Just as important were the 7 scheduled WORKSHOPS with an International Chairman's Group.

Finally the special WORKSHOP ON RoRo SAFETY requested by the entire STAB '94 conference at the opening session added new thoughts from the group of world experts at the conference.

Volumes 1-5 contain the 58 papers prescheduled and received in time for the agenda. Volume 6 contains 2 additional papers - 8 Executive Summaries of the discussions in the Workshops, including the special Workshop. - plus Errata for 2 papers, plus the formal discussions received on the scheduled papers.

Quantitative Review

One of the attending delegates, Mr A. Blyth made an excellent summary of the conference as a report to the Ship Safety Committee of The Royal Institution of Naval Architects. As he noted, the subject matter of the papers can be summarized (re stability of ships and ocean vehicles) as follows:

Regulation/Standards	5	RoRo Ships	3
Broaching/Following Seas	10	Fishing Vessels	6
Extreme Waves	2	Rolling in Waves	8
Semi-Submersibles	3	SWATH	1
Probability & Risk	6	Wind Effects	2
Experimental Techniques	1	Damage	2
Mathematical Techniques	4		

Qualitative Review

I wish to emphasize some of the more frequently repeated opinions of the participants in the Stability Workshops - in order to present a qualitative overview of the present state-of-the-art with regard to the twin safety functions; Intact and Damaged Stability.

Probability in Stability

It was pointed out and accepted that -although the IMO original stability standard was based on the collating of experience of several decades of casualties - it is now impossible to wait for years of casualty data before fixing on new standards for the many types of ships and different types of ship operation currently in service. Therefore various analysis methods such as probability will be fully necessary in order to decide stability standards in the foreseeable future.

It was pointed out that actual stability hazards must be identifed for each new ship type and then standards proposed which directly reflect the dominant hazard - for example - it is evident that the damping coefficient is an important parameter in rolling but not in quartering seas.

High Speed Ship Stability

It was recognized that some high speed monohulls should be evaluated at speed in following and quartering seas and other types in beam seas. The standard calm water stability evaluation is not the dominant stability evaluation needed..

It was recognized that there is no physically correct applicable standard for SWATH ship stability (and yet many SWATHS are successfull, so far, in service without an applicable standard)

Some basic hydrodynamic areas are still poorly understood. Wave impact forces, which directly affect both stability and structural safety, are not solved in most applications; certainly not enough to make general standards.

The high speed damage stability discussers agreed that current damage scenarios are not realistic and may not be the dominant risk of damage. This group recommended IMO -SLF subcommittee should state that high speed damage scenarios urgently need further examination.

Capsize Thresholds

In the discussion on **intact capsize thresholds,** it was agreed that the actual threshold of capsize varies too much for a single standard even on normal monohull ships in different wave & seaway situations and/or when the mass distribution is unique (such as in a containership with high vertical stacking of the cargo).

It was concluded that much more examination of the physical phenomenon is needed.

It was stated several times by different delegates that the present GZ curve evaluation standard should retained until new standards are agreed ; but it was stated that it has already been shown to be inadequate to use this standard for many ordinary monohulls when they have unique loadings; and for most unique new ships (example SES ships where the Range of Stability may be doubled for some ships (or halved) even though they are similar -- just because of loading differences)..

The discussion on **damage capsize thresholds** was changed to a specific discussion on the relative merits of adding bulkheads on the car deck of RoRo ships - a direct result of the ESTONIA casualty.

RoRo Safety

Perhaps the most important idea offered was the suggestion that the entire maritime community needs to be served by the *'lessons learned'* from the many near accidents which, fortunately do not become headlines but which nevertheless precede a severe accident in which lives are lost needlessly.

Information for the Master

The prime conclusion of this discussion group was the recognition that "stability information" has become so voluminous that it can only be properly presented by computer directly, and not by pages of computer printout. The data must be compressed, succintly organized, and professionally presented.

The group also recommended that mandatory periodic training and certification be increased.

Survival in Storm Seas

This workshop consisted of several presentations - all of which were replete with information. In particular, two shipping industry representatives gave first hand overviews of the importance of operational design review, continuous maintenance, and immediate repair after storm voyages.

The containership presenter recommended many items for renewed effort among which were the need for more accurate knowledge of hull distortions in storm seaways, better lashing guidelines, development of better hull motions prediction schemes coupled with proper weather routing, and greater use of on-board monitoring.

The tankship presenter showed the direct benefits of continuous on-board monitoring

Other speakers showed again the need for research which will identify the many different dominant capsize parameters in many different situations at sea.

Human Factors

The summary is worth repeating.---

If there is no economic disincentive (eg fines) , companies will not (actively) promote safety.

Minimum stability requirements will always need to be imposed by law

Vessel operators should (somehow?) be encouraged to exceed minimum safety.

International Chairman's Opinion

In spite of the many needs for immediate developmental research made public at this conference, the greatest need is to immediately inform the traveling public and operating crews of ships worldwide , whose lives are often at direct or continuous risk due to lack of agreed standards and the probable 'no standard conciousness', that <u>traveling faster on the oceans is not safer than slower travel</u> and will not be safer until realistic minimum standards based on correct dominant capsize parameters are accomplished.

W A Cleary Jr

SECRETARIAT STAB 94

GENERAL CHAIRMAN	W. A. Cleary, Jr - Adjunct Professor O/E
OCEAN ENGINEERING PROGRAM CHAIRMAN	Professor A. Zborowski, Ph.D.
CENTRAL BAPTIST CHURCH - AUDITORIUM	Dr. Gary Fagan, Pastor
SPECIAL EVENTS - AUXILIARY SERVICES	Ms. Barbara Towers
OFFICE SERVICES - DIRECTOR	Mr. William Hamilton
OFFICE SERVICES - PUBLISHING	Ms. Rosary M. Pedreira
GLEASON AUDITORIUM COORDINATOR	Mr. Gary Allen
OCEAN ENGINEERING STAFF	Ms. Janet Carey Ms. Ann Bergonzoni Ms. Juanita Fennimore Mr. Daryl Slocum
OCEAN ENGINEERING STUDENTS	Ms. Jennifer Clark Mr. Michael Callahan Mr. Damian Hite Mr. Joe Blodgett Mr. Alejandro Gutierrez Mr. Mathew Craven
SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS FLORIDA TECH STUDENT SECTION	Ms. Allison Link

AND

THE FLORIDA TECH STUDENT SUPPORTING TEAM

STAB 94 COMMITTEES

INTERNATIONAL PROGRAMME

Prof. C. Kuo, University of Strathclyde, Glasgow
Prof. M. Fujino, University of Tokyo
Prof. L. Kobylinski, Tech. Univeristy of Gdansk, Poland
Prof. P. Cassella, University of Naples, Italy
Prof. P. Bogdanov, Ship Hydrodynamics Center, Varna, Bulgaria
Dr. S. Grochowalski, National Research Council, Ottawa, Canada
Prof. P. Blume, Hamburg Ship Model Basin, Germany
Prof. D. Huang, Dalien University, Dalien, China
H. Hormann, Head Marine Safety Germanischer Lloyd
H. Vermeer, Netherlands Shipping Directorate
I. Manum, Norwegian Maritime Directorate
Prof. C. Guedes Soares, Instituto Superior Tech Libson, Portugal
Dr. I. Boroday, Krilov Ship Research Inst., St. Petersburg, Russia
Dr. N. Rachmanin, Krilov Ship Research Institute, Russia
Dr. R. Ozkan, Instanbul, Turkey
Chairman - W. A. Cleary Jr., Florida Institute of Technology

COMMITTEE of the AMERICAS

Prof. B. Adee, University of Washington, Seattle, WA USA
Prof. R. Battacharyya, Annapolis, MD USA
H. P. Cojeen, USCG Headquarters, Washington, DC USA
Prof. R. G. La torre, University of New Orleans, LA USA
Dr. M. A. S. Neves, COOPE/UFRJ, Rio de Janiero, Brazil
Prof. J. R. Paulling Jr., Richmond, CA USA
Prof. N. Perez, University of Chile, Valdiva, Chile
Prof. G. L. Petrie, Webb Institute, New York, NY USA
Prof. C. Sanguinetti, University of Chile, Valdiva, Chile
R. J. Sonnenschein, MARAD, Washington, DC USA
Dr. C. Spadavecchia, Prefectura Navale, Burnos Aires, Argentina
Prof. M. Santarelli, Buenos Aires, Argenina
Dr. J. S. Spencer, ABS AMERICAS, Huston, Texas USA
Prof. R. Yagle, University of Michigan, Ann Arbor, Michigan USA