MCA Research Project 583

Evaluation of New

Intact and Damaged Stability Criterion

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Version 1

BVT Surface Fleet

BVT Surface Fleet, South Street, Scotstoun, Glasgow, G14 0XN, United Kingdom

Telephone: +44 (0) 141 957 2400 Fax: +44 (0) 141 957 2328

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Executive Summary

This report describes research undertaken by BVT Surface Fleet under MCA Research Project 583 to test a new ship stability criterion proposed by the Wolfson Unit under Research Project 509. The new Wolfson Criterion defines maximum safe wave height to avoid capsize as a function of basic ship residual stability parameters. It was derived from a series of model tests on small high speed craft, marginally satisfying the stability requirements of the HSC Code.

In this study the Wolfson Criterion has been evaluated against real ship incident data to establish applicability across a variety of vessel types. The principal source of data was a listing customised for this project from the Lloyd's Register Fairplay marine casualty database over the last 10 years. This involved vessels of many different Flag State Marine Administrations, all being members of IMO.

Obtaining stability information for input to the Wolfson Criterion from these authorities proved difficult, even for those ships registered in the UK, under MCA jurisdiction. Issues of confidentiality and reluctance of owners to release information limited the number of cases that could be used as test data. Those obtained were on the understanding that names of individual ships, operators or anything enabling these to be traced must remain confidential.

The results have therefore been presented in this report as plots with points and basic identifiers only. They are plotted to the same base as used in the Wolfson Unit report for RP509, for ease of comparison. Other sources of data included the Marine Accident Investigation Branch and similar organisations overseas. Direct approaches were made to ship operators, academic and research institutions and there was a general literature search for published papers and information online, which provided some alternative model test results.

Despite a poor level of response it was established that capsize incidents caused primarily by heavy seas are relatively rare. There were usually other significant factors, such as substandard stability or watertight integrity, the snagging of a fishing boat's net or severe damage. The Wolfson Criterion can theoretically be applied to a ship with any degree of damage. In general however, the study focussed on intact stability because of the great variety of possible damage cases and these are difficult to generalise across all ship types.

The small number of real ship incidents (11 cases plotted on Figure 7.1) were broadly, but not exactly consistent with the Wolfson Criterion. They covered a much broader range of residual stability than the original Wolfson model tests. A greater number of independent model tests for large ocean going vessels were available, mainly from the HARDER project (38 cases plotted

on Figure 7.2). These however did not follow the trend indicated by the Wolfson Criterion, though only a few of the results actually contradicted the rule.

Overall however it was concluded there is insufficient compelling evidence to justify further consideration of the Wolfson Criterion across all types of vessel.

The findings of the earlier RP509 report by the Wolfson Unit in respect of the HSC Code remain valid. No actual wave induced capsize incidents have been identified for such vessels, but it remains a theoretical possibility that vessels designed to the minimum stability requirements of the code could be vulnerable.

A further point emerging from discussion with operators of conventional ferries was that services are limited by conditions for berthing and manoeuvring in and out of port, before conditions on passage become an issue. Based on calculations of wave height to capsize when intact, using the Wolfson Criterion, it was judged that services would already have been cancelled in such conditions.

For larger ocean going ships in general, the Wolfson Criterion would only become limiting when damage is sufficient to lower the residual stability parameter to levels similar to those of the tested HSC models. There is a variety of stability requirements for different ship types. To simply add the Wolfson Criterion could unfairly penalise those ships designed to higher damage stability standards. It would probably require a more integrated approach considering probabilistic damage. The additional research and analysis required to establish this is unlikely to be justified. There is a lack of real ship incidents of this kind, for ships meeting current standards.

Approvals

Signature

Author/Authors	Tom Carreyette	February 2009

Signature

Approver	Jamie Fyfe	February 2009

Signature

Authoriser	Martin Greaves	February 2009

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1 Introduction

1.1 Background

MCA Research Project 583 was awarded to BAE Systems, Glasgow at the end of 2007, as a follow on from work undertaken by the Wolfson Unit of Southampton University under MCA Research Project 509, reported in March 2005 [Ref 1].

In essence, the foregoing report described a series of model tests conducted by the Wolfson Unit using a tank testing facility to ascertain minimum stability characteristics required in order to avoid capsize in waves. The tests were based on high speed craft, using models for 2 monohulls, 3 catamarans and a trimaran in over 50 configurations, intact and damaged. They were subjected to waves of varying frequency and direction until they capsized.

The conclusion of MCA Research Project 509 [Ref 1] was that for marginally compliant vessels the HSC Code [Ref 2] may not ensure an adequate level of safety, when used in conjunction with the sea state limiting permit to operate, applied by MCA. However, a simple rule could be applied to estimate the wave height to cause capsize in the most onerous combination of wave frequency and direction. This rule could be expressed as a function of vessel dimensions and statical stability properties and is referred to throughout this study as the ‘Wolfson Criterion’.

It was suggested that this formula could be applied to a variety of ship types and sizes, since it had been demonstrated across such diverse hull forms, both intact and damaged and the model test results could theoretically be scaled up to larger ships.

MCA wished to test the Wolfson Criterion against real ship data and compare these with findings of other studies. BAE Systems was contracted to undertake this validation at the end of 2007, under MCA Research Project 583, to be completed within one year. This report describes the process and findings of the research.

Since award of this contract BAE Systems Surface Fleet Solutions has entered into a joint venture with VT Group (formerly Vosper Thornycroft) to form the new company BVT Surface Fleet. It is under this company name that the project is being completed. The new company name BVT is used throughout the remainder of this report.

1.2 Objectives and Scope of Study

The original MCA Specification for Research Project 583 stated that objectives of the study were to:

- Compare the minimum wave height required to cause capsize as estimated from the Wolfson Criterion with in service and/or accident experience, in order to determine what correlation there may be.
- Make similar comparisons between the Wolfson Criterion and any available trials or model experiment data.
- Make such comparisons for a range of vessel types in order to obtain an initial indication as to whether the method is in fact applicable to a variety of ship types including non high speed craft.

The specification stated that the scope of the study was to encompass the following:

- Full scale and model test data
- Both intact and damaged conditions
- A wide range of vessel shapes, including if possible passenger, cargo, offshore support and fishing vessels
- Vessels that have survived severe conditions
- Vessels that have capsized

These considerations are taken together and discussed further below, in the light of the BVT proposal and subsequent agreements at the project start up and progress meetings. The discussions helped to prioritise the work and rank the various aspects by relative importance.

The main emphasis of the research was to seek out full scale data for a variety of ship types surviving or capsizing in heavy seas. The availability and quality of such information is limited as casualty reports in the marine industry often lack reliable numerical data, which cannot be easily measured and recorded in the heat of an incident. Even when this is available there can be reluctance to release proprietary or sensitive information. Reassurances about protecting data and not identifying specific ship casualties were given to ship owners and operators, where needed.

It was agreed with MCA early in the project that intact conditions would be more likely to conform to generic trends, as given by the Wolfson Criterion, than damage (i.e. flooded) conditions. The survivability of damaged ships is very sensitive to damage extent and location as well as the subdivision arrangement of each vessel. The information required to validate the Wolfson Criterion for damaged vessels is not usually available from casualty reports, also damage cases are often not covered by ships’ stability booklets. For these reasons the research has concentrated on intact conditions, but documented cases of damage are not discounted.

The range of vessel types studied reflects the diversity intended, with passenger, cargo, offshore supply, fishing and naval vessels all considered.

Model test data is considered of secondary importance in this study, since the Wolfson Criterion was itself developed on a basis of model tests. Full scale data is therefore more valuable for validation purposes, whenever available. However, because of the difficulties of obtaining reliable data from real ships, as outlined above, comparison with other model test results was made for certain cases. Model test data does have the advantage of a controlled environment and ability to measure more results than usually available from ships at sea.

Under the present study, the accuracy of comparison with the Wolfson Criterion is dependent on the quality of information received. So where supporting data was limited it was necessary to draw from general experience and engineering judgement to evaluate the Wolfson Criterion.

Where the required statical stability information is not available this could be generated by building a computer model, if a body plan or hull offsets and a drawing of internal tanks and subdivision for any damage cases can be provided. The current scope of work does not include this activity.

1.3 Definition of Capsize

Another early discussion with MCA was to agree what is meant by capsize, for the purposes of this study. Since this work follows on from Research Project 509 undertaken by the Wolfson Unit it is important to be consistent with that. In the model tests, capsize was considered to be heeling or rolling beyond 90 degrees without righting. Thereafter the vessel may continue from being on ‘beam ends’ to ‘bottom up’ or may bodily sink due to flooding of internal spaces.

In a capsize event it is necessary to abandon ship before sinking, though some persons may already be trapped. It is therefore better to anticipate the likelihood of capsize and give the order to start evacuating before capsize occurs. The heel angles, ship motions and sea conditions in which it is practicable to evacuate are not part of this study. So capsize is not considered to have occurred until the ship has bodily reached the condition described above.

1.4 Methodology

This section gives a broad overview of the methodology and strategy applied in this research project. The specific processes employed are detailed in subsequent sections of the report as referenced in the following paragraphs.

The primary source of worldwide marine casualty data used in this project was Lloyd’s Register Fairplay (LRF) who maintain a comprehensive database. It is based on the Marine Casualty Reports printed in the daily newspaper Lloyd’s List. This organisation offers a service to provide customised casualty listings filtered by specific criteria in selected data fields.

LRF were tasked by BVT for this study to produce a listing of reported casualties over the last ten years involving ships in heavy seas. The detailed process of down selecting from this listing to a short list of incidents relevant to and sufficiently well documented for this study is described in Section 2.

The resultant short list was for a range of vessel types operating worldwide under many different Flag States. The appropriate Marine Administrations and/or casualty investigation authorities were then approached requesting specific stability information for these vessels. This aspect is described in more detail in Section 5, which also applies to ship casualties identified from other sources.

Another source of information was the website of the Marine Accident Investigation Branch (MAIB) which contains downloadable casualty reports for mostly UK registered vessels. This is further described in Section 3, which also includes some other similar organisations outside of the UK administration, providing this service. Some of these reports are complete with the required stability information for input to the Wolfson Criterion.

Various ship owners and/or operators were separately approached requesting information relating to casualties or incidents in heavy seas. Many of these were contacts from records of companies dealt with before, in years past, when part of the current BVT organisation operated as an independent marine consultancy. This process is further described in Section 4 and the stability analysis in Section 5.

In some cases this line of enquiry resulted in ship data being provided for members of the fleet not involved in casualties, but useful to assess the impact that the Wolfson Criterion would have, if applied as a limiting wave height for permissible operation. This aspect is also covered in Section 4.

The final stage was to search for relevant data from published literature not already covered above, to be used as a further check on the validity of the Wolfson Criterion. This covered model tests, computer simulation and any further full scale ship results which may be available. This is described in Section 6 of the report.

From all the above collated data it was then possible to calculate various real ship cases by the Wolfson Criterion as a check on the method. Comparison could be made between the theoretical estimates and actual incidents, whether they capsized or not, as well as assessing the impact of applying the criterion as an operational standard. Also the findings of alternative studies (mostly model tests) identified from the literature search could be included in the comparison. All these scenarios are covered under Section 7.

1.5 Confidentiality

The information relating to ships involved in casualties and the stability characteristics in general of ships currently in service needs to be treated with confidence. In order to maximise the information obtained it was necessary to give an undertaking to ship owners and operators not to identify individual ships and company names. This should not be a problem in pure research, when results can be presented as data points only, with basic identifiers to indicate the general type and size of ship and nature of incident. Hence the results of this research are presented in this way within this report. An MCA Letter of Authorisation committing to the strictest confidence in this regard accompanied every request for information which was sent out to ship operators, Marine Administrations or other parties providing input to the study. The text of this letter is included as Annex A to this report.

In the case of the Lloyd's Register Fairplay (LRF) database extract commissioned for this study, there was a separate agreement to protect the LRF proprietary information it contains. The whole data set would not be reproduced, but selected data extracted with acknowledgement to LRF.

1.6 Acknowledgements

The main sources contracted to provide information commissioned for this study were:

- Lloyd's Register Fairplay (see Section 2) and
- The Meteorological Office (see Section 2.6).

Because of the confidentiality issues referred to in the previous section most companies who provided information for this project chose to remain anonymous. These sources included over 20 UK based ship owners and operators, as described in Section 4. Those who did not express a view on confidentiality would then stand out if named, so these have not been specifically listed either.

The author thanks all those who provided input, whether numerical for use with the Wolfson Criterion or more qualitative feedback and experience of seagoing personnel, included in the discussion in this report.

Special thanks to Professor Papanikolaou at the National Technical University of Athens (NTUA) who freely provided full data for one of the casualty cases studied.

Thanks also to Professor Vassalos of the Ship Stability Research Centre at the University of Strathclyde, who drew attention to the International Tank Towing Conference (ITTC) Specialist Committee on Stability in Waves, as a further source of information (see Section 6.2.2).

The Marine Administrations approached are separately listed in Section 5, Table 5.1, which indicates those who provided feedback.

Other information was obtained from online sources including websites for:

- The UK Marine Accident Investigation Branch (MAIB) (Sect 3)
- Marine Casualty Investigation Board (Ireland) (Sect 3)
- Isle of Man Ship Registry (Sect 3)

- Transportation Safety Board of Canada (Sect 3)
- HARDER project (Sect 6)
- The Royal Society (Sect 6)
- UK Society for Modelling and Simulation (Sect 6)

These are referred to in succeeding sections of the report as noted in brackets, with hyperlinks where applicable. Other input for the study was obtained from various sources, online, in house, from MCA or in general conversation with people associated with the marine industry. Reference was also made to several other sources which did not yield information specifically of value to this study.

2 Lloyd’s Fairplay Casualty Data

2.1 Introduction

Lloyds Register Fairplay (LRF) was commissioned by BVT to perform a search of their marine casualty database using the required search criteria. The principal filters applied in the search were

- in the ‘weather’ field, where only cases of heavy weather or rough seas were extracted and
- in the ‘casualty type’ field where entries were selected only if described as ‘foundered’ or ‘hull/machinery damage’.

The LRF database does not include a casualty type for ‘capsize’ as such, so the description ‘foundered’ had to be selected as a first cut. The reason for including ‘hull/machinery damage’ was to capture any cases where ships were subjected to heavy seas and there may have been danger of capsize, even if it didn’t actually happen. This is still of interest for comparison with the evaluation according to the Wolfson Criterion.

This filtering of the database resulted in an initial listing provided by LRF of 831 casualty incidents over a ten year period to February 2008. An update was provided in June 2008, by then comprising 855 entries eligible for further examination. This was the final version used as the basis for this study.

2.2 Casualty Listings

Scrutiny of all cases generated from this filtered listing was then required, to choose which incidents were suitable for testing the Wolfson Criterion. The first consideration was whether ‘capsize’ was stated in the ‘Précis Text’ or ‘Complementary Text’ field. These are standard fields in the LRF database which were requested for inclusion in the extract. They contain the descriptive text of the casualty report. There were 47 of these mentioning ‘capsize’ out of the full listing of 855, though not all could be linked to wave action as the primary cause. The listing has a field distinguishing incidents on voyage from those in port. Only 33 of them were on voyage and it was felt the remainder were not of interest to this study. Ships berthed or anchored would not be expected to react to wave action in the same way as in the model tests, which were untethered.

A second and independent search of the set of 855 records was made to determine how many of the reports stated an actual wave height. There were in fact 57 of these, only 3 of which were noted as capsize incidents. The study was not limited to just these 3 since non-capsize incidents are of interest. Also capsize cases without wave heights, from the first selection were not discounted. An indication of wave height can be inferred from the sea state. Meteorological Office (Met Office) records of wave height could also be obtained retrospectively for a given sea position, as described in Section 2.6.

2.3 Selection of Cases

The down selection of cases for which to seek further information was made on a basis of quality of information describing sea conditions and threat of capsize. There were examples where capsize was not specifically mentioned, but seems likely to have occurred based on the description. In other cases capsize clearly did not occur. The selection was also intended to encompass a variety of ship types and sizes, encountering large waves at sea, in locations worldwide. The basis of choice was to find the best combinations of these aspects.

This process resulted in an initial shortlist of 30 selected cases, 16 of which were capsize incidents, the remainder were not. Examples of ships that survived waves were important to test out the Wolfson Formula, so as not to preclude any cases where it might predict capsize, when this didn't occur. These were all noted by LRF as serious casualties and many of them reported wave heights that were experienced. Some involved damage or shifting cargo. In the database listing, damage does not always imply flooded compartments, but often refers to more superficial damage to superstructure, deck fittings, equipment or cargo. Not every case of capsize was selected - only those where sea conditions were a significant factor contributing to the capsize. This was judged as far as could be ascertained from the description.

The LRF listing did not include the vessel flag or nation of registry. The next step was to seek further information, initially by looking up the ships in sources such as Lloyd's Register of Ships and the online ship search facilities Equasis and Miramar, which can be useful for ships now deleted from the register. The individual Marine Administrations could then be approached to request stability information for the ships in question. Some of the ships had changed name and or flag within some months of the time of incident. In these instances it was decided to approach more than one administration for a single ship.

Hence it was determined, for the shortlist of 30 ships, no fewer than 29 Marine Administrations had to be approached. All were listed as official IMO members in the IMO website, from which the contact addresses and Emails were obtained, if applicable. All were initially contacted by formal letter, enclosing the MCA Letter of Authorisation (text included as Annex A to this report). This was followed up by Emails and in some cases telephone calls, when a suitable contact could be found. The response to these enquiries was very poor and is fully reported in Section 5, which includes a full listing of the Marine Administrations approached in Table 5.1.

2.4 UK Registered Vessels

The above procedure for initial selection was followed before considering the flags under which ships were registered and it resulted in only one UK example. The Marine Administration for UK flagged ships is the MCA. So it was decided to produce a more extensive list of UK registered ships for which to request stability data. It was believed this might produce a better response.

Hence a further pass was made of the original LRF database listing of 855 casualties in heavy seas for UK flag vessel reports, even if they were not in danger of capsize and wave information was missing. This resulted in a list of 14 ships, registered under the UK flag at or near the time of the incident. Stability information for these ships was requested from MCA. However this could not be disclosed because of MCA confidentiality agreements, so approaches to individual operators were necessary. Response was again poor, as described in Sections 4.4 and 5.4.

2.5 Wave Definitions and Assumptions

In general marine casualty reports can describe sea conditions in a variety of ways. The initial LRF database filter used to select the reports provided was for ‘heavy weather’ cases only, or similar phrase. The individual Précis and Complementary Text fields might then state a wave height, swell height, sea state, Beaufort wind force, wind speed, descriptive term like storm or gale, or perhaps a named Hurricane or Typhoon. In cases where both a wave height and wind speed or Beaufort force is given, a plot was produced to see if there was a reasonable correlation. This could be useful to infer an unknown wave height from other information. All the LRF data was included in this plot, corresponding to the 57 cases of stated wave height referred to in the second paragraph of Section 2.2.

The plot is reproduced here as Figure 2.1. The lower line is the Beaufort wind force related to wave height according to the Met Office guidelines. The points around it are reported data. The upper line is the maximum wind speed related to wave height, according to the Met Office Beaufort table (see Annex C to this report). Again points around it are reported data. These are so scattered as to indicate that only limited confidence can be placed on such reports. The wave height from Met Office guidelines is the ‘probable maximum waveheight’ for a fully developed sea, corresponding to the particular Beaufort wind force. Actual seas encountered may not be fully developed in association with a steady wind speed.

Wave height reported at sea is generally assumed to correspond to the significant wave height (average height of highest third of the population of waves in the total spectrum). This is the height of waves as they appear to an observer at sea. If however a particular exceptional wave is singled out the reported wave height is most likely to be the maximum wave height.

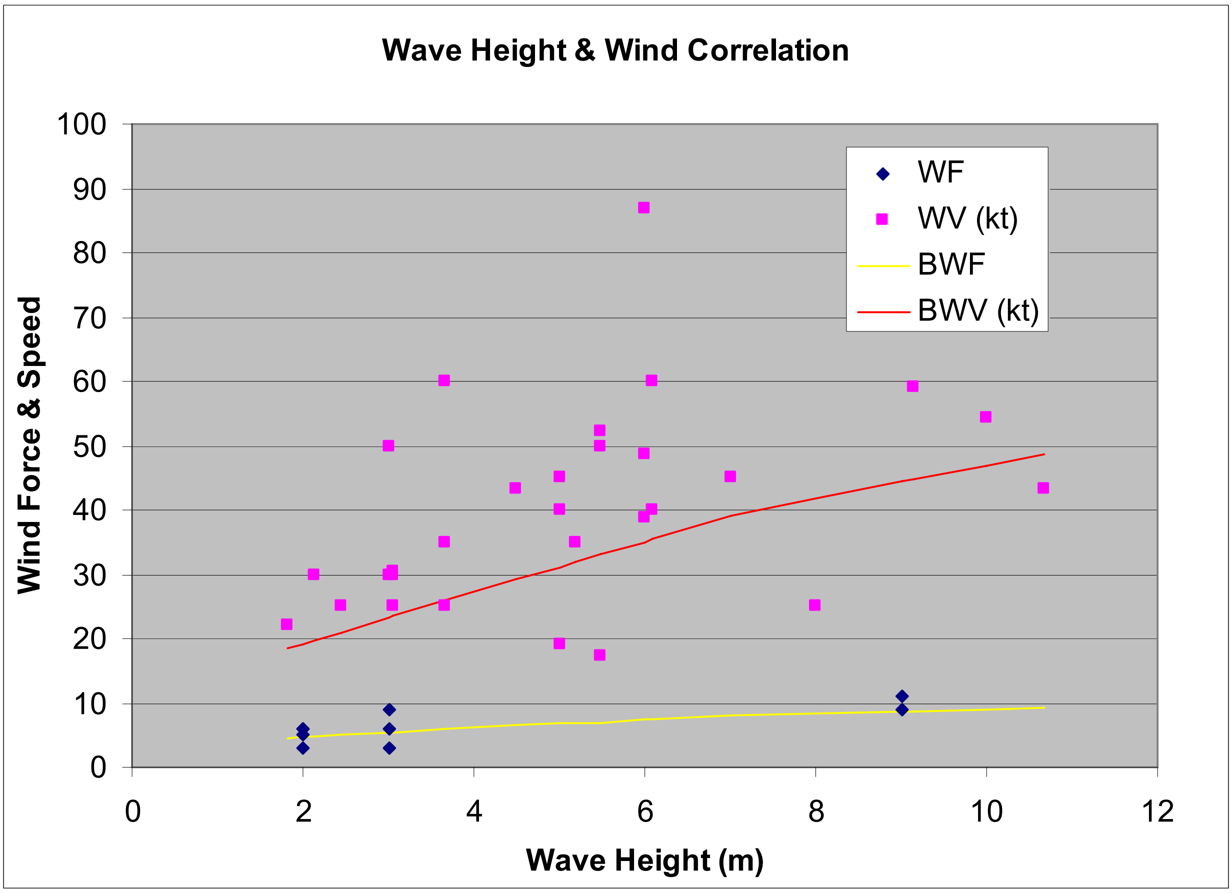

Figure 2-1 Wave Height and Wind Speed/Force

2.6 Meteorological Office Data

The Meteorological Office (now officially branded as the Met Office) has a section, Marine – Past Data Consultancy, which holds a global wave model and regional wave models. This organisation can supply wave heights and direction (also wind data) within a 3 to 6 hour window at a given position. This service was used for some of the marine casualty incidents where this information was missing or unclear. The number of data extractions had to be limited because of cost, so this service was used mainly for cases where it was already established that the ship's stability information was available for input to the Wolfson Criterion.

This amounted to 13 events for which a position and time was specified corresponding to the casualty incident. The Met Office then provided significant wave heights for these locations and times together with supplementary wind and wave data. Results were taken from the UK, Europe or Global Model, depending on position.

The data is Crown Copyright but agreement was given to use the wave heights as input to the analysis of ship casualties for the purposes of validating or testing the Wolfson Criterion method of assessing susceptibility to capsize. This was done in the analysis described in Section 7 to produce the points plotted on Figure 7.1, where wave height was not clear from the casualty report or other source.

The Met Office report provides Significant Wave Heights (crest to trough) which are formed by the resultant of wind wave and swell wave components. Wind waves are defined as waves generated by the local wind conditions, blowing over the surface of the sea or ocean. Swell waves are wind waves which have travelled from outside the area considered, and are no longer sustained by local conditions. It is quite possible to have a combination of swell waves from different directions, interacting with the local wind waves. In the modelling, wave heights add together according to the square root of the sum of the squares of the heights of the separate wave trains. This is because the wave energy is proportional to the square of the wave height and it is the energy which is additive. The Met Office guidance advises that the maximum wave height is 1.86 times the significant wave height, for the wave spectrum type used in the modelling. This can be approximated to twice the significant wave height for actual sea conditions, as assumed in the Wolfson Criterion.

Figure 2.2 is similar to Figure 2.1 explained in Section 2.5, but uses only the data obtained from the Met Office records. Generally the grouping of points around the Met Office guidelines is closer because all data comes from their records. The rogue point for 115 knot wind is probably a gust not having time for waves to develop and the 36 knot wind with only 1.5 metre waves is believed to be within an area protected by a breakwater. Figure 2.2 shows that wave heights obtained from the Met Office are more reliable than trying to estimate from Figure 2.1.

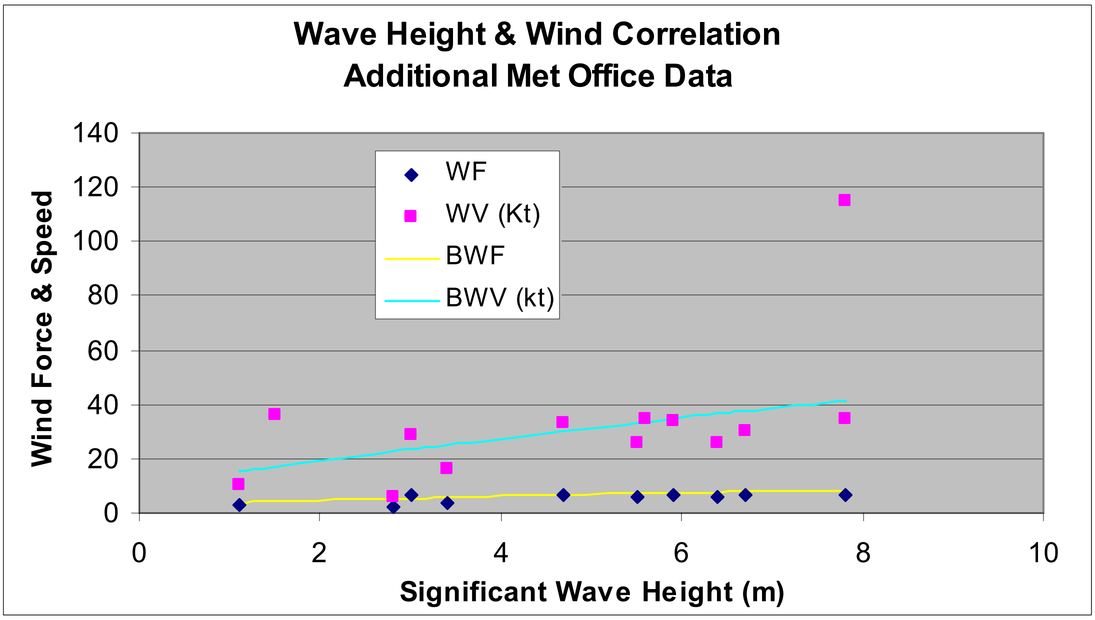

Figure 2-2 Wave Height and Wind Data from Met Office

2.7 Frequency of Capsize Incidents

The figures referred to in Section 2.2 indicate a scarcity of capsize data, but is nevertheless useful as a measure of frequency of this type of incident. So before setting aside the original LRF listing of 855 casualties, most of which were not investigated further, it is useful to consider the data on a statistical basis. The 33 cases of capsize on voyage represent 3.9% of all LRF reported casualties in heavy seas. A simple plot shows how these break down in terms of Gross Tonnage, with the majority of cases (18 of the 33) being vessels under 1000 GT. This is shown in Figure 2.3.

Also, when the individual vessel incidents are examined there is an issue as to whether they were compliant with existing standards. The capsize incidents which do occur are, in many cases either:

- damaged beyond statutory requirements for stability assessment, or
- not operated or maintained in accordance with existing standards (e.g. overloaded or with inadequate watertight integrity)

This probably applies to some of the larger vessels and if discounted the incidents would be even fewer, with predominantly smaller ships. Due to shortage of stability information this cannot be quantified precisely.

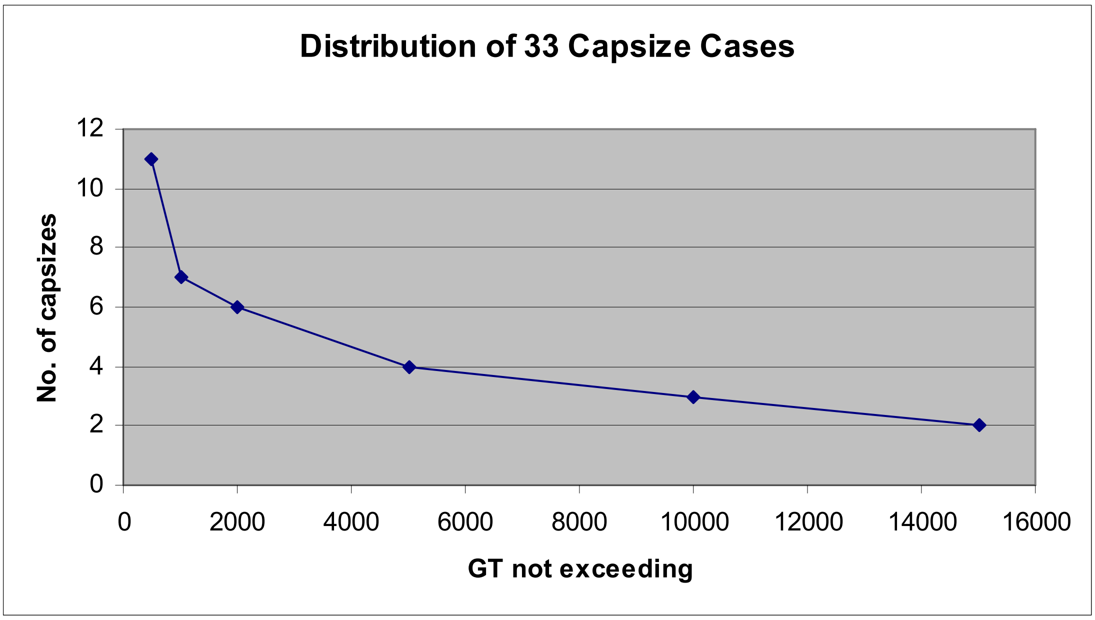

Figure 2-3 Incidents of Capsize

2.8 Conclusion

The initial approach using LRF casualty data for worldwide incidents over the last 10 years was comprehensive and has resulted in a shortlist of 30 suitable incidents, only 16 of which were capsize cases. There is a scarcity of such events linked directly to wave action and some of these involve damage or possibly substandard stability. Other sections of the report are concerned with how many of these cases and those from other sources can be brought forward with the required stability information in order to test the Wolfson Criterion.

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3 Accident Investigation Data

3.1 MAIB

After producing the shortlist of suitable casualty records from LRF, as described in Section 2, further information about these casualties was sought in the form of official reports.

The Marine Accident Investigation Branch (MAIB) is a UK government organisation primarily concerned with investigating serious casualties involving UK flagged vessels. Some overseas flag cases are investigated when specially requested by the nations in question. Their reports are available for download from their website

http://www.maib.gov.uk

Since none of the vessels on our LRF shortlist was included in the online MAIB reports (not even the single UK registered case) it was decided to search the entire MAIB listing as a separate exercise. The keyword 'capsize' was used in this search and generated 346 results, spanning more than ten years. Many of these are for very small leisure and recreational fishing craft and some casualties have more than one report. They were all reviewed and only a very small number were found to contain the required stability and other information for input into the Wolfson Criterion, as summarised in Section 3.3 Results.

3.2 Overseas Investigation Bodies

Some of the overseas Flag States have similar websites for marine casualty reports. Many do not, but were approached as part of our enquiry to Marine Administrations as described in Section 5. Those that were found online with downloadable reports that could be checked for capsize incidents comprised the following:

- Marine Casualty Investigation Board (Ireland) http://www.mcib.ie/
- Isle of Man Ship Registry http://www.gov.im/dti/shipregistry/reports/vessel_reports.xml
- Transportation Safety Board of Canada – Marine Reports http://www.tsb.gc.ca/en/reports/marine/index.asp?section=ALL

Similar to the MIAB reports, these covered approximately the last ten years, but there were far fewer reports. Not every Flag State/administration was searched, but those nations included in the initial LRF shortlist of 30 casualties described in Section 2.3, plus Ireland, because there was some administrative overlap with UK registered vessels considered under Section 2.4.

3.3 Results

From this review of UK (MAIB), Irish, Isle of Man and Canadian administration casualty reports, only 4 sizeable commercial fishing boat capsize incidents (upwards of 20 metre length) were found relevant to this study, plus one case of a small cargo vessel (2500 gross tons) capsizing in a storm. These are the only reports which provide suitable information for capsize cases and they are summarised as cases C1 – C5 along with the data from other sources in Section 7.

Even these few cases are not clear cut incidents of well found vessels capsizing due to wave action. Some of the reports describe shortcomings in the standard of watertight integrity or the method of operation, with regard to maintaining adequate stability. Where stability requirements were complied with, at least one case of capsize was believed to have occurred due to the mechanism of synchronous roll (case C5, Section 7.2).

3.4 Conclusion

The search of marine accident investigation reports available online has resulted in 5 examples of good quality data, including full stability information, suitable for input as case studies to the Wolfson Criterion to validate the method for real capsize incidents.

4 Operator's Data

4.1 Requests for Information

Early in the project, prior to obtaining the casualty database listing from LRF, formal letters were written to a number of mostly UK based ship owners and operators. These were companies on file with which there had been contact in the past. In some cases consultancy services had been provided or there was involvement in new build or design projects under YARD Ltd or other parts of the organisation which have since been absorbed into BAE Systems and latterly BVT Surface Fleet. A total of 22 such companies were approached and in many cases new contacts had to be established.

These letters were general enquiries asking if the ship operators could provide any useful information relating to ships encountering heavy seas. The data sought was clearly defined in the form of a table to be completed for each incident if possible, designed to be suitable for input to the Wolfson Criterion. This enquiry did not name specific ships or incidents for which data was wanted. The hope was it might result in some cases being identified, which would provide the required data for them. In order to encourage release of data there was an undertaking to treat the information in strict confidence, and only publish results in a form that does not divulge individual ship or operator names. See Section 1.5, Confidentiality. Each enquiry was accompanied by an MCA letter of authorisation on headed paper, the text of which is included as Annex A to this report. Annex B is the basic standard letter which was sent out, though these were slightly customised to suit each addressee. The letter itself has an annex, containing a table to be completed with the data requested.

Following up these enquiries with Emails and telephone calls continued in parallel with other tasks for many weeks of the project.

4.2 Responses

The response was varied but generally rather poor. Several companies responded that they had no records of such incidents or they did not have the resources to search for them. One or two suggested they may be able to help if there were enquiries about specific incidents (see Section 4.4). Others provided qualitative feedback and offered the views of experienced mariners, including masters, some of whom had served previously in other companies and vessels. These views are recorded in Section 4.5, where considered relevant to this study.

No further actual cases of ship capsize emerged from this particular line of enquiry and only a single heavy weather incident, suitably documented for comparison with the Wolfson Criterion. This was for a small cargo ship weathering a storm, when the master decided it was not safe to turn and head for shelter. The heavy seas were survived without serious damage. This is summarised as case S1 in Section 7.2.

Some companies did not have data to pass on relating to the behaviour of their ships in heavy seas, but were prepared to make stability information available to assess the impact of the Wolfson Criterion on their operation of ships, if it were to be adopted by MCA as a requirement. These cases are further described in Section 4.6.

4.3 Further Sources

Some further case studies may be held by various universities and research organisations. Most of these however cannot release information due to confidentiality or propriety issues, unless specifically contracted to undertake research. Some have published papers in the public domain, which form part of the literature survey described in Section 6. So in general the academic institutions were not approached directly for information. Where BVT/BAE Systems had worked recently in partnership with them, however, this was done.

This resulted in one more documented case of a real ship capsize incident. Professor Apostolos Papanikolaou of the National Technical University of Athens kindly provided all relevant data for the case of a 4400 gross ton passenger ro-ro ferry which capsized. However this was after the ship had run into rocks and sustained damage more onerous than in the applicable stability standard. It could be argued this is not a fair test case on which to base proposals for a modified standard. It is however valid as a test of the Wolfson Criterion method, even if it is beyond the range it would be applied. It is therefore included as case C6 in Section 7.2. This casualty did not appear in the original LRF listing, because ‘Grounding’ incidents were not included in the original request.

Another source of information that was tried, at the suggestion of MCA was the Domestic Passenger Shipping Steering Group (DPSSG). This is a group representing UK passenger ship operators (mostly ferry companies) who meet with MCA on a regular basis to discuss matters of marine regulation. The same general enquiry letter (see Annex B) as sent out to 22 ship operators, per Section 4.1 was Emailed to the DPSSG members, through MCA. Some of these probably repeated requests already sent and none of them resulted in any new information being received, which was not obtained from an alternative approach.

4.4 Requests for Specific Incident Data

Some of the ship operators approached as described in Section 4.1 were approached a second time, requesting information for specific incidents, following the identification of 14 more incidents involving UK registered vessels, as described in Section 2.4. This was generally for ship stability data, which MCA may have held, but were not authorised to release due to confidentiality agreements. The response was once again poor. Operators still did not provide any information, with the exception of one, who wished to remain anonymous.

4.5 Qualitative Feedback

Where operators could not provide documented incidents, even qualitative feedback from the industry was welcomed. Comments from experienced mariners and discussions in general with ship owners, managers and operating companies were encouraged, even when of an anecdotal nature.

Some of the UK ferry operators spoken to are busy looking into compliance of their vessels with new SOLAS requirements prior to their coming into force. In particular the Severe Wind and Rolling Criterion required by European Directive 98/18/EC (and part of IMO Resolution A749E) is going to be quite onerous for some ferries.

When considering wave height to cause capsize, which is quantified by the Wolfson Criterion, a case for exemption could be made. Operations are limited by conditions in port, more than on the passage. This aspect is covered in Section 7.5.2.

Contacts were approached who had served in various types of vessel. From this experience there was no known case where a merchant ship had simply rolled over due to a wave. It was agreed fishing boats and small craft might be the exception to this. The marine accident searches described in Section 3 cover fishing boat capsizes, but even these were not solely due to wave action.

On long haul routes or deep sea passage it is quite possible to be caught in severe seas and have to ride out a storm. The procedure is to run slowly into the direction of oncoming waves. Of course other circumstances such as machinery or steering gear failure, or just poor seamanship may preclude this action. The Wolfson model tests determined wave height to capsize by trying all directions until the most critical was found (usually quartering seas) so makes no allowance for good seamanship. This may partly account for the lack of real ship data leading to capsize. Most potential capsizes were averted. Even so, capsizes which did occur mostly involved other factors such as shifting cargo or flooding. In the case of fishing boats, snagging of nets is a significant factor in many losses.

4.6 Ship Data to Assess Impact of Criterion

One aspect of this study declared in the original proposal was to determine the impact of the Wolfson Criterion on a range of actual ships and consider the questions; What limiting wave height does it indicate? Would that be likely to impose operational constraints compared to current practice? This aspect is separate from the validation of the method against real ship data, but it is also important to address when considering the Wolfson Criterion approach as a method of assessment.

Some stability data for this purpose was collated from our own in house records, though these were for military ships and auxiliary vessels. This helps to understand the implications of applying the criterion to different types of ships. Other data was for commercial vessels, predominantly ferries, where operators provided access to stability information from which it was possible to calculate limiting safe wave heights for operation and feedback was provided on the operational implications. These results are presented in Section 7.5.

4.7 Conclusion

Input to the study from operators approached directly is limited to some general qualitative commentary, which has been included as points in discussion within the report, plus a very few documented quantitative cases used in Section 7 for input to the Wolfson Criterion.

5 Stability Data

5.1 Introduction

The short list of 30 cases from the LRF casualty database was produced and the corresponding 29 Flag States identified, as described in Section 2.3. The Marine Administrations for each of these were approached as described below.

The accident investigation reports by MAIB and other bodies, selected as described in Section 3 already contained the relevant stability data. This section describes how the stability information for the remaining vessels was sought. It also discusses the specifics of what stability data is required and how this was interpreted in the application of the Wolfson Criterion. There is further discussion of the impact and implications of the Wolfson Criterion in Section 7.

5.2 Data required

The data required for input to the Wolfson Criterion is primarily the displacement, maximum righting lever and range of stability, for a condition close to that which applied at the time of the incident. The correct values for input to the Wolfson Criterion should be residual values. That is after damage or deduction for any heeling levers, such as wind, crowding of personnel, lifting of weights or high speed turn as defined in Section 5.6.2 and Figure 5.2.

In the majority of cases this has proved difficult to obtain. As discussed in Section 2.7, capsize cases are relatively few. Stability information could then only be obtained for a few of the shortlist of vessels capsizing or surviving storms. This has limited the number of cases that can be used to test the Wolfson Criterion. More cases were sought beyond the original LRF search, using MAIB and other sources described in Section 3.

The cases carried forward are those for which the righting lever (GZ) curve was available, enabling evaluation of the above. The Wolfson Criterion can assess the vulnerability to capsize for vessels intact or damaged with or without heeling agents. The difference is reflected in the residual GZ_{max} and range values, resulting in different critical wave heights according to circumstances.

5.3 Marine Administrations Approached

As described in Section 2.3, a total of 29 Marine Administrations were approached requesting stability information for specific ships involved in casualties that were reported on the LRF database. Table 5.1 lists these, indicating the low level of response received after the initial formal letters were followed up by Emails and in some cases telephone calls, where a contact could be found. Where the response column indicates 'Provided 1 SIB' the administration in question supplied a Stability Information Booklet (or extract) for a particular ship requested.

In the case of UK flag ships, for which the MCA is the Marine Administration it was decided to revisit the original LRF casualty listing to select more vessels, rather than the single case noted below. This is described in Sections 2.4 and 5.4.

Table 5-1 Marine Administrations

Flag State	**No. of ship casualties for which info requested (+ those changing from another flag within 1 year of incident)**	**Response**
Panama	5 (+1)	
Belize	1 (+2)	
Ukraine	2	
Indonesia	2	
Bahamas	2	Provided 1 SIB
Greece	1 (+1)	
Rep Korea	2	
DPR Korea	1	
DPR Korea	1	
Mongolia	1	
Russia	1	
Honduras	1	
Cambodia	0 (+1)	
Philippines	1	
St Vincent & Grenadines	1	
Comoros Is	1	
United Kingdom	1	(+14 more, See Sect 5.4)

Finland	1	Provided 1 SIB
Malta	0 (+1)	
Canada	0 (+1)	
Barbados	0 (+1)	
Azerbaijan	1	
Japan	0 (+1)	
Senegal	1	
Australia	1	Provided 1 SIB
Antigua & Barbuda	1	
Isle of Man	0 (+1)	
Italy	1	
Marshall Is	0 (+1)	
Spain	1	
Total	30 ships (+11 extra ids)	3 SIBs

The number of ships for which stability information was requested from each Marine Administration amounted to the number above plus the additions in brackets. The numbers in brackets represent ships already counted but under an earlier or later identity (name/flag), where more than one Marine Administration was approached for the same ship.

5.4 Response

The last column of Table 5.1 indicates that only 3 out of the 29 Marine Administrations provided a Stability Information Booklet (SIB) for one of the ships on the short list of 30 cases selected from the LRF casualty database. These three examples are all ships which survived storms.

The single UK registered vessel listed in Table 5.1 was supplemented by 14 more cases chosen after revisiting the original LRF casualty listing provided for this study, as described in Section 2.4. Only one more documented case emerged, from a company who wished to remain anonymous. This company had been approached earlier with the general request per Section 4.1, but now responded to the specific request. The full set of data required for input to the Wolfson Criterion was provided for the case of a vessel that sustained minor damage in stormy conditions. Although there was never any risk of capsize, it does provide a point on the 'safe' side of the Wolfson line as a further check.

These points are included as cases S2 - S5 in Section 7.2 of this report.

5.5 The Wolfson Criterion

The formula proposed by the Wolfson Unit for assessing the susceptibility of ships to capsize is presented in four different forms within Section 27 of the Wolfson Report [Ref 1]. The basic formula is:

Wave Height = [Range x $(RM_{max})^{0.5}$] / 10B   Formula 1

Where:

Wave Height is the minimum wave height that might result in capsize (metres)

Range is the residual range of positive stability (degrees)

RM_{max} is the maximum residual righting moment (tonne-metres)

B is the overall beam of the vessel

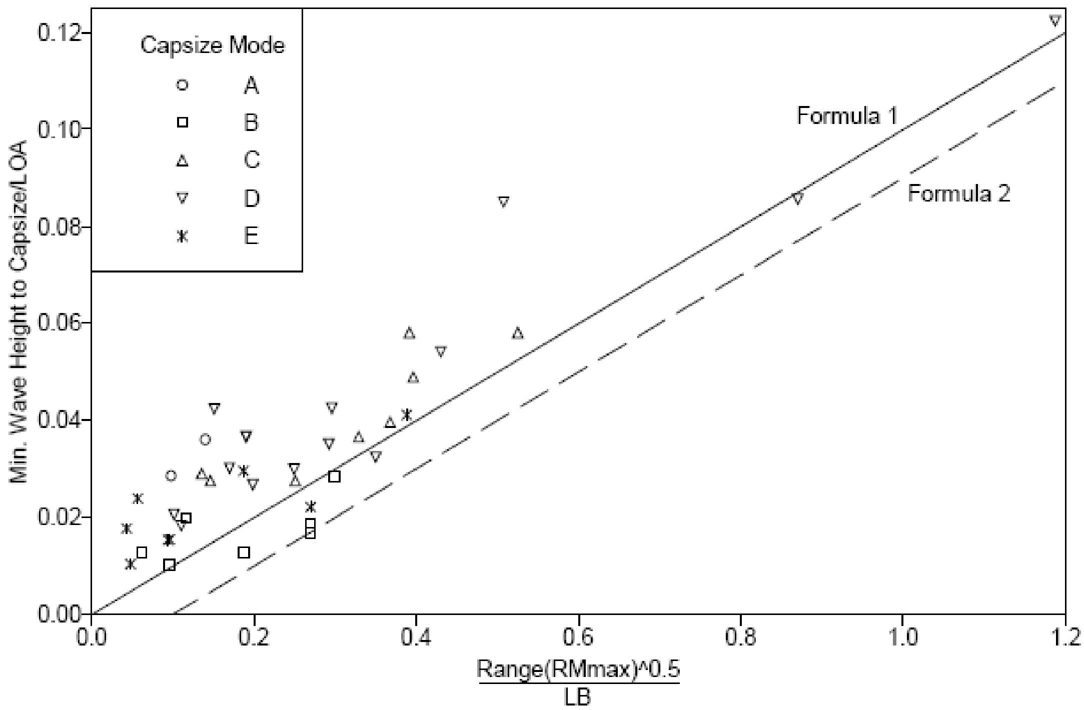

Figure 5-1 Wolfson Test Data

Figure 5.1 is a copy of part of Figure 30 from the Wolfson Report [Ref 1] which helps to illustrate this. The various capsize modes are not of concern here as they are not reflected in the criterion. Formula 1 represents the line through the model test points recorded from the tank experiments. Formula 2 is a similar line above which all the experimental points fall, so it can be used as a safe limit.

Wave Height = [Range x $(RM_{max})^{0.5}$] / 10B – L / 100 Formula 2

L is the overall length of the vessel.

Formulae 1a and 2a are the same as Formulae 1 and 2 but define the Significant Wave Height, assuming this to equal on half of the maximum wave height.

Significant Wave Height = [Range x $(RM_{max})^{0.5}$] / 20B Formula 1a

Significant Wave Height = [Range x $(RM_{max})^{0.5}$] / 20B – L / 200 Formula 2a

Formula 2a therefore represents the Significant Wave Height characteristic of a safe limiting sea state for operation of vessels as recommended by the Wolfson Unit. To avoid confusion in this report, wherever not specifically stated, the term 'Wolfson Criterion' generally refers to Formula 2a and significant wave heights are used.

The maximum residual righting moment RM_{max}, is derived from the righting lever (GZ) curve and the displacement (Δ) corresponding to the condition being assessed from the relation:

$RM_{max} = \Delta \times GZ_{max}$

So Formula 2a might be usefully written:

Significant Wave Height = [Range x $(\Delta GZ_{max})^{0.5}$] / 20B – L / 200

In this formula GZ_{max} refers to the residual value of GZ_{max}.

Figure 5.2 illustrates the definition of these terms in the form of a GZ Curve with a heeling lever (HL). The maximum absolute value of GZ occurs at angle of α_{GZmax} and the value of the heeling lever at this angle is HL_{α}. The angle of downflooding discussed in the following section is shown as $\phi_{d/f}$.

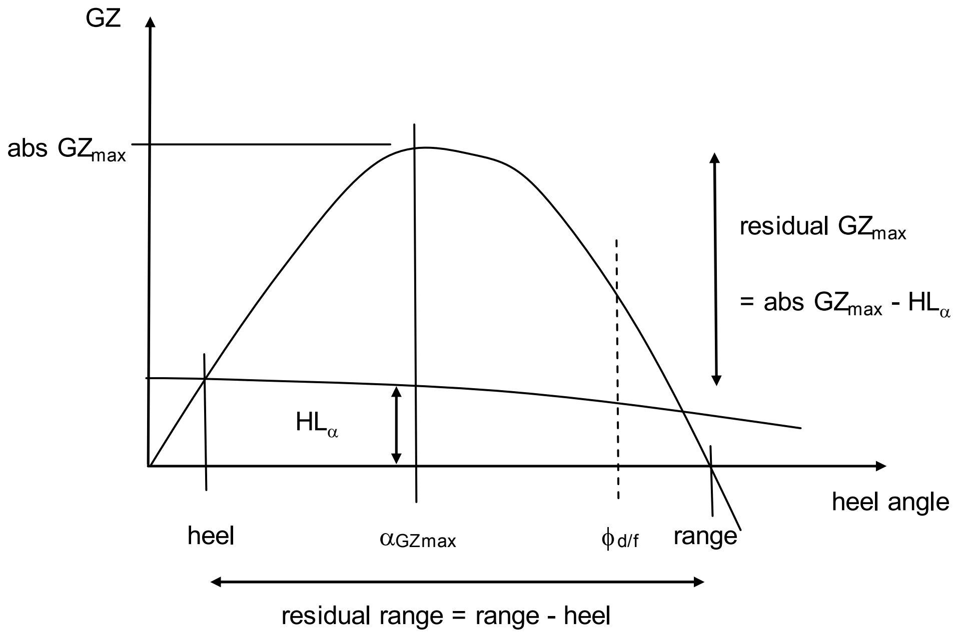

Figure 5-2 Input Data to Wolfson Citerion

Assumptions about downflooding and the residuary values of Range and GZ_{max} follow in the next section.

5.6 Analysis and Assumptions

5.6.1 Downflooding

The Wolfson Report [Ref 1] suggests the following approach to downflooding, when applying the criterion:

"If serious downflooding would occur at an angle lower than the residual range of stability, the stability curve should be truncated at that angle, as is the case in the HSC Code methods of assessment."

For the current Research Project 583 it is assumed that there will not generally be serious downflooding through openings above the final equilibrium waterline, which are only briefly immersed for short periods of the roll evolution. This was agreed in discussion at an early meeting with MCA.

Only in specific incidents where there is a possibility of sudden major downflooding is the stability curve considered to end at that point. However there are no such cases in the incidents considered for this report. The MAIB and similar reconstructed damage cases allow for progressive flooding into open compartments from waves, in the calculation of the righting lever curves themselves. In these circumstances the residual stability still remains at that point and is not truncated. In some cases the residual stability reduces to a minimal amount until the wave height to capsize is very small.

5.6.2 Residual Stability

The residual values of GZ_{max} and positive GZ range used as input to the Wolfson Criterion are after the deduction of heeling levers due to the effects of wind, crowding of personnel or in some cases the snagging of a fishing net. This is illustrated in Figure 5.2.

The stability information available from Trim & Stability books usually includes a suitable GZ curve, or this can be derived from crosscurves (KN values) plotted or tabulated, using the relationship:

$GZ = KN - KG \sin \phi$,

where KG is the vertical height of centre of gravity above baseline and ϕ is the angle of heel.

In many cases the Trim & Stability books do not include a wind heeling lever curve to go with the GZ curve. If the casualty report mentions an initial angle of heel due to wind or other effects, this can be used to add a steady heeling lever line intersecting the GZ curve at the heel angle. This in turn can be used to determine the residual values of GZ_{max} and GZ range for input to the Wolfson Criterion.

For ferries being assessed under Section 7.5.2, to consider the impact of applying the Wolfson Criterion on operations, there was no wind heeling information in the Trim & Stability books. These ships were not involved in reported casualties so there is no stated initial heel condition. In the absence of wind heeling values the effect of passenger crowding and high speed turn were taken in combination. Although it is unlikely these effects will occur together, their combined effect may be of similar magnitude to a wind heeling moment. Also it allows the concept of residual stability to be included in the evaluation of the Wolfson Criterion, which is an important aspect of the formula.

5.6.3 Tests Using In House Data

Records held by BVT Surface Fleet include comprehensive intact and damage stability analysis for a number of warships and naval auxiliaries. Although this research project is aimed at commercial ships operating worldwide it is useful to consider how application of the Wolfson Criterion would impact on the stability assessment of these vessels. The theoretical application of the method is equally relevant to any type of vessel and there is also a current trend for warships to comply increasingly with commercial standards.

Section 7.5 of this report is concerned with the impact of the Wolfson Criterion on existing ships and the results of these investigations for military ships are discussed in Section 7.5.1. This includes quantifying the effects of the wind heeling and downflooding assumptions referred to above.

5.7 Conclusion

As already seen from Section 2, there is a scarcity of capsize incidents due primarily to wave action, across the range of vessel types operating worldwide. Section 5 has shown how relevant stability information can only be obtained for a few such cases, some of which are from official marine accident investigation reports. The quality and scope of stability information obtained was quite varied, often limited to intact conditions without wind heeling data. Some additional data could be derived and the methods and assumptions have been detailed.

6 Literature Survey

6.1 Introduction

Part of this task was to conduct a literature survey of published reports and papers that could provide additional data relating to the capsize of ships in waves. This includes model test data or numerical simulations as well as any real ship data that may be available. There is much published work on the topic, potentially of interest but few of them present data, such as righting lever (GZ curve) characteristics, suitable for input to the Wolfson Criterion for comparison.

6.2 Results of Survey

6.2.1 HARDER

One of the most valuable sources for this was a series of downloadable reports relating to model tests conducted under the HARDER project [Ref 3]. This was a European collaboration for Harmonisation of Rules and Design Rationale (HARDER) for ships, led by Det Norske Veritas.

The results that were most amenable to use as a check on the Wolfson Criterion were from the model tests for:

DCRR01 Large dry cargo ro-ro (212 metres overall)

PRR01 Medium Passenger ro-ro (194 metres overall)

PCLS01 Large passenger cruise ship (280 metres overall)

DCCS01 Large dry cargo containership (190 metres overall)

Each of these was tested in damage condition and subjected to waves, with the outcome recorded, i.e. whether or not capsize occurred. Because they were tested at varying draughts, a large number of results were generated. Suitable data was presented in the reports for 27 capsize cases plus 11 survivals. This is only a small part of the total test program from HARDER, using the above models plus some others, but they provide sufficient points to evaluate the Wolfson Criterion. The results are presented in Section 7.4.1.

6.2.2 Other Sources

Abstracts from various technical reports available for purchase were examined but it was generally not clear these contained the specific data required, so they were not pursued.

As mentioned in Section 4.3 one suitable case study was provided by Technical University of Athens (MTUA) following a direct approach. Other universities and research establishments were checked by internet search. Unless material of this kind is already in the public domain these organisations cannot normally release it except under contract.

The scope of this project did not include allowance for costs relating to obtaining information from external stakeholders, other than the specific principal sources stated in the methodology, i.e. the Lloyd’s Register Fairplay casualty database and the Meteorologiocal Office hindcasts. Purchasing of external data did not extend to the wider literature search.

A review of the last 5 years of articles in the RINA journal ‘The Naval Architect’ contained references to various conferences relating to ship stability analysis and regulation, papers and articles about topical marine casualties, investigations and lessons learnt. Although there was much relevant information none of these sources contained the specific data needed to become case studies for input to the Wolfson Criterion.

Downloadable marine accident investigation reports were sourced as a significant input to this study. These are described in Section 3.

Other technical reports available for download from the internet, providing useful records for this study were obtained from The Royal Society [Ref 4], the UK Society for Modelling and Simulation [Ref 5] and ITTC [Ref 6] websites. The specific reports are detailed in Section 9, which contains hyperlinks to these web pages. The Royal Society reports are available for download only after registering there. These sources produced data sets for four more model test cases plus a mathematical simulation, which were input into the Wolfson Criterion formulae, as reported in Section 7.4.2.

Further internet searches for ship capsize material produced several more reports developing theoretical methods of analysis, model test results and case studies, but none of these contained the relevant data required for input to the Wolfson Criterion.

6.3 Conclusions

The literature survey yielded no further real ship incident cases with data suitable for input to the Wolfson Criterion. It did however produce many model test results with this information, principally from the HARDER project. The numerical comparisons with the Wolfson Criterion are presented in Section 7.

7 Input of Data into Wolfson Criterion

7.1 Introduction

The following section takes the information referred to in the previous sections, uses it as input to the Wolfson Criterion then presents the results in a similar format to the original Wolfson Report [Ref 1] for ease of comparison. There are two aspects to the analysis.

- Checking validity of Wolfson Criterion method by using real ship incident data as test (Sections 7.2 – 7.3). This is also supplemented by comparison with other model test results (Section 7.4).
- Applying the criterion to existing ships and asking operators how such a rule would impact on their operations if it were to become an MCA requirement (Section 7.5).

Section 2.5 describes the wave definitions and assumptions and Section 5 the stability aspects of the analysis, with the Wolfson Criterion itself defined in Section 5.5. This section of the report presents the results of the analysis.

7.2 Real Ship Cases to Test Wolfson Criterion

From all the foregoing sections of this report the total number of fully documented cases of ships either capsizing or surviving heavy seas is 11, as follows. This list is limited to cases where all the necessary input to the Wolfson Criterion is available:

- C1 - 20 metre fishing vessel capsized. Poor inherent stability.
- C2 - 21 metre fishing vessel capsized. Inadequate watertight closures.
- C3 - 23 metre fishing vessel/guard ship capsized. Progressive flooding during synchronous roll.
- C4 - 33 metre fishing vessel capsized. Flooding after net snagged.
- C5 - 2500 gross ton cargo ship capsized. Cargo shift and flooding after synchronous roll.
- C6 – 4400 gross ton passenger ro-ro ferry capsized after grounding. Progressive flooding.
- S1 – 3000 gross ton cargo ship survived storm.

- S2 – 10000 gross ton ro-ro cargo ship survived storm.
- S3 – 24000 gross ton cruise ship survived storm.
- S4 – 29000 gross ton passenger ro-ro ferry survived storm.
- S5 – 30600 gross ton passenger ro-ro ferry minor damage in storm.

7.3 Real Ship Results

The Wolfson Report [Ref 1] presents the results of model tests in Figure 30 plotted as points compared to the proposed Wolfson Criterion lines by Formula 1 and 2 (see Section 5.5 of this report for explanation). For ease of comparison the results of this study are presented in the same format, but using Formula 1a and 2a, since significant wave heights are quoted throughout. According to the criterion, points below the 2a line should be safe from capsize, while those above the line are at risk. The results are plotted for the 11 vessels listed in Section 7.2, individually identified and by whether or not they were cases of capsize. These are plotted here as Figure 7.1.

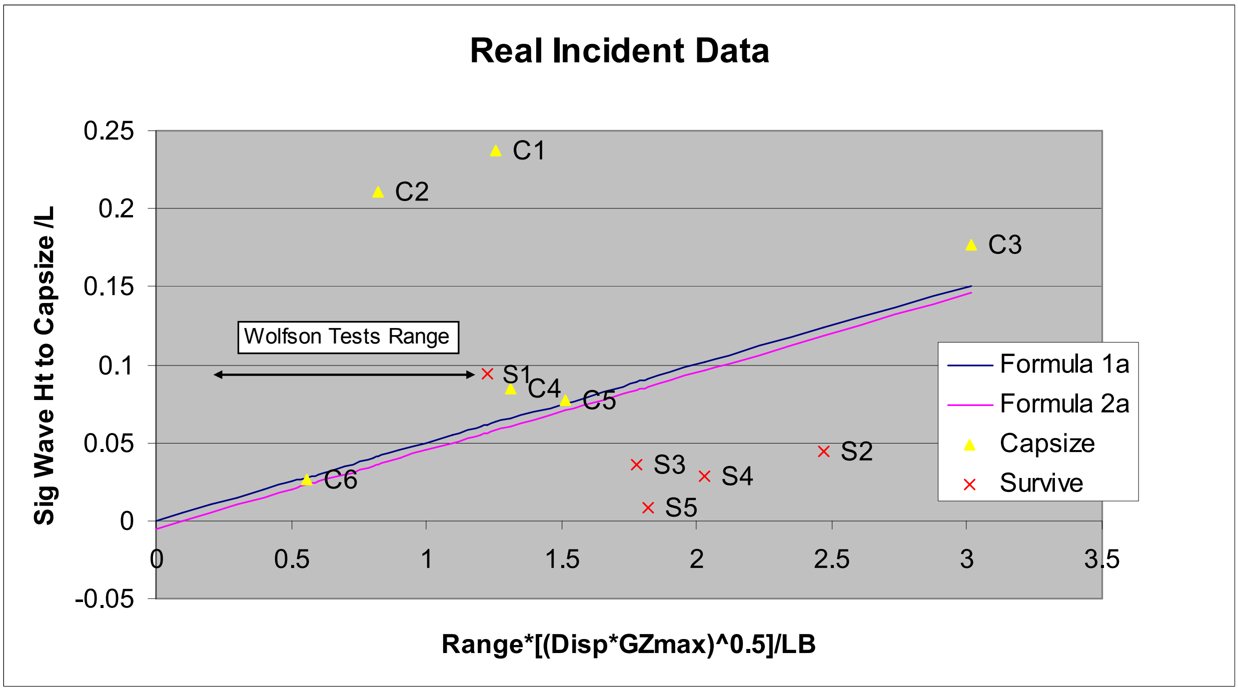

Figure 7-1 Real Ship Results

The points are well scattered, but this is not unexpected as the cases vary considerably in their degree of proximity to the point of capsize. Case C1 may have been vulnerable to capsize in waves considerably smaller than experienced, while Case S5 was probably at little risk of capsize even in larger waves than actually occurred. The nature of real ship data is limited to the conditions that prevailed, whether they passed or failed the criterion and what was the actual outcome. There is insufficient data to define boundaries. The only point which does not apparently conform to the criterion is:

- Case S1, which failed the criterion but survived in reality, possibly because of good seamanship. As described in Section 4.2, the master decided not to turn the ship. If he had presented the vessel at the most critical heading with respect to the direction of waves experienced, the ship might well have been in danger of capsize.

Two points lie very close to the limiting lines. These are:

- Case C5, which was reported to be an instance of synchronous roll combined with shifting cargo.
- Case C6, where the ship had gone aground sustaining bottom damage more onerous than required to be assessed under current regulations.

From the evidence of this limited real ship data there is nothing to contradict the validity of the Wolfson Criterion. While the data conforms to the broad trend, it does not clearly support the positioning of the lines defining the safe limit to be applied as a criterion. Due to the limited number of documented real incidents it is necessary to further consider model tests that may offer more data points for comparison.

7.4 Model Tests and Simulation Compared to Wolfson Criterion

7.4.1 Results from HARDER Reports

The main source of independent model test data providing the required input for comparison with the Wolfson Criterion is the HARDER project results, described in Section 6.2. The combined results for four different ship types, identified only by whether or not they capsized, are presented in Figure 7.2. This uses exactly the same format as the real ship results in Figure 7.1 and the original Wolfson Unit report [Ref 1].

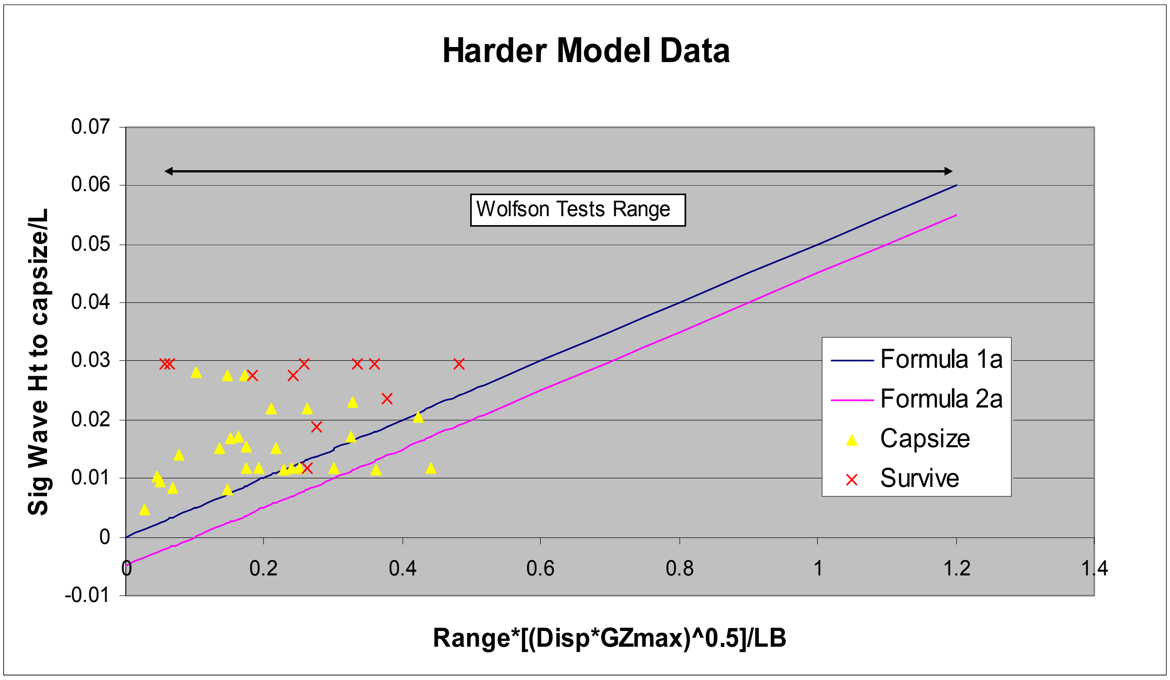

Figure 7-2 HARDER Model Results

It is noticeable that these HARDER model test results cover only the lower part of the range of parameter,

[Range x (Displacement x $GZ_{max})^{0.5}$] / LB,

when compared to what was tested in the original Wolfson model tests. Although the HARDER models are of large merchant ships rather than the small high speed craft models tested by Wolfson Criterion, they are all in damaged condition, so have reduced residual range of stability and GZ_{max} values. All the points represent cases where the model was close to capsize. None of the cases which survived did so with a large margin of stability.

Figure 7.3 is an alternative presentation of Figure 7.2 identifying each test point with the specific ship model, as described in Section 6.2. It is a busy diagram, in some ways less easy to follow than Figure 7.2, but all capsize cases are represented by triangles of different colours so that the two figures relate.

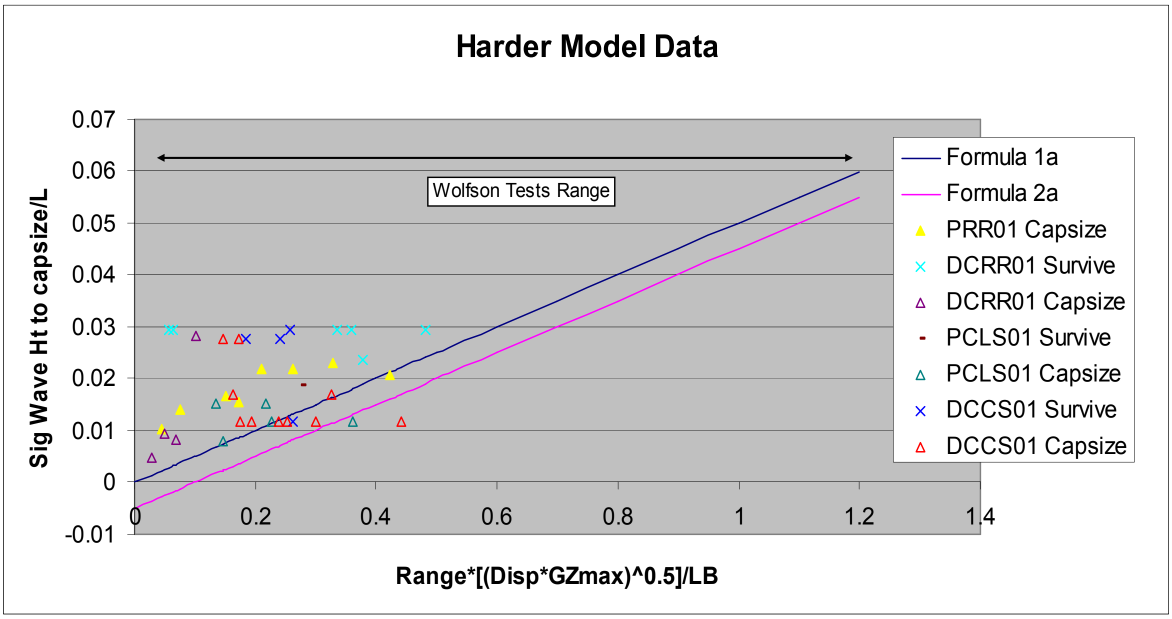

Figure 7-3 HARDER Model Results Identified

These HARDER model test plots do not convincingly support the Wolfson Criterion. Two capsize cases fall below the Formula 2a line, intended to indicate 'safe' from capsize, according to the criterion. Many survive cases are well above both the lines (especially DCRR01 and DCCS01) and in general the data do not exhibit a trend that follows the Wolfson lines even vaguely. Because all the cases were close to the point of capsize, greater linearity would be expected if the data was supporting the Wolfson findings.

7.4.2 Other Results from Literature Survey

As described in Section 6.2.2 the literature survey did result in five additional capsize case data points for comparison with the Wolfson Criterion. Figure 7.4 is a plot of 3 model ships [Ref 4], one mathematical ship simulation [Ref 5] and a further model test [Ref 6] which was also simulated by numerical methods. All are capsize cases, four occurring in following or quartering waves and the fifth in beam seas. Figure 7.4 compares them to the Wolfson Criterion.

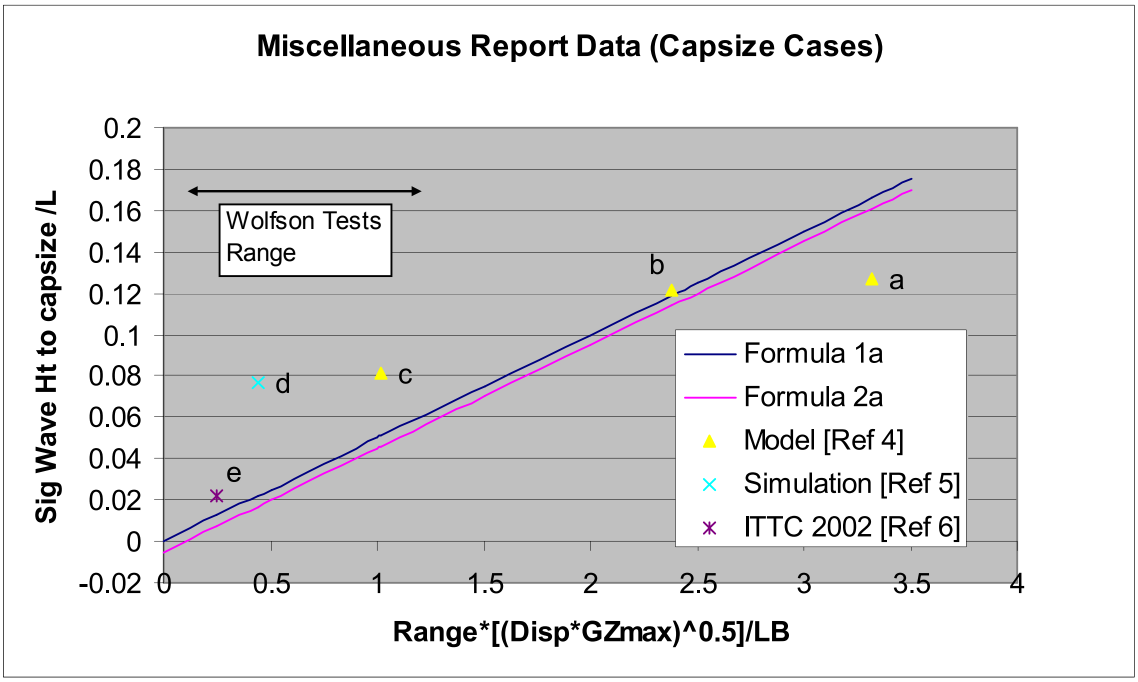

Figure 7-4 Further Model & Simulation Comparisons

The points are identified on Figure 7.4 as follows:

a. purse seiner 80 gross tonnage (loss on wave crest or plough in)

b. purse seiner 135 gross tonnage (broaching)

c. container ship162.7 metres overall (low cycle resonance)

d. tanker 58.6 metres overall (roll-yaw simulation)

e. passenger ro-ro 179 metres overall (damaged, irregular beam seas)

The first three model test cases are examples of different capsize mechanisms, noted in brackets and described in the report [Ref 4]. In case (a) the model capsized at the same wave height by either of two different mechanisms depending on ship heading and speed. These capsizes both occurred on the 'safe' side of the Wolfson Criterion line, so point (a) does not support the criterion. This vessel had an unusually large range of stability but water was trapped on deck. The other points are consistent with the criterion, though point (b) is right on the capsize line by Formula 1a. This still leaves a small safety margin if Formula 2a is taken as the criterion.

Case (d) was from a non-linear mathematical model of a reconstructed real ship incident [Ref 5].

Case (e) was a model test used as a benchmark for comparing simulation results across ITTC members. It appears to be one of the HARDER Project models, but not one of the runs already reported in Section 7.4.1 above.

7.5 Impact of Wolfson Criterion on Existing Ships

7.5.1 Military Ships

Because a certain amount of warship and auxiliary stability data is held in house by BVT Surface Fleet it was possible to assess compliance with the Wolfson Criterion for these types of ship and examine the effect of varying assumptions. Stability data for warships is confidential and it is not appropriate to classify this report so that it can be disclosed here. However some of the findings can be described in so far as they have a bearing on how the Wolfson Criterion can be applied to ships in general.

For a large warship or auxiliary vessel the limiting wave height can be calculated by the Wolfson Criterion as around 15 to 20 metres when the ship is intact. When wind heeling is applied and residual GZ values are taken, the wave height for capsize can drop to about 10 metres, in the most critical seagoing condition. Table 7.1 shows how this wave height further reduces when progressively more severe damage conditions are considered and also the effect of truncating the GZ curve at the angle of downflooding.

Table 7-1 Military Ship Examples

Case	Limiting Wave Height by Wolfson Formula 2a
Intact no wind	15 – 20 m
Worst intact case with wind heeling**	10 m
Truncating GZ at downflooding angle	Reduce 20 – 25% (Case** 8 m)
Damage no wind	4 – 13 m
Worst damage case with wind heeling*	2.2 m
Truncating GZ at downflooding angle	Reduce 4 – 24% (Case* 2 m)

So based on intact stability, the limiting wave height is not particularly constraining to operations. This applies even when the onerous assumption is made that the GZ curve is truncated at the angle of downflooding. As stated in Section 5.6.1, this assumption does not apply in this study.

When looking at damage conditions the situation is different. It is normal for warships to be designed to survive severe combat damage as part of their battle strategy, rather than just the natural hazards of collisions and groundings. The object is to be able to continue operating autonomously after damage for as long as possible until they can reach safety, away from the combat zone, for evacuation or salvage. Warships are vulnerable to capsize from waves if they are damaged to the maximum extent specified in the design, which may be a number of compartments, in excess of requirements for commercial vessels. The Ministry of Defence standard for stability in waves is based on ratio of restoring to heeling energy (see Annex D). This is similar to, but not the same as the Severe Wind and Rolling Criterion of European Directive 98/18/EC (also IMO Resolution A749E) currently under discussion for adoption for passenger ships under SOLAS.

In essence the Wolfson Criterion can be interpreted as saying that in order to be safe from capsize in the worst design damage condition, operations throughout the life of typical warships should be limited to about 2 metre seas. This would clearly not be a practical application of the criterion. It also illustrates the effect of applying it more or less stringently to ships in general.

7.5.2 Commercial Ferries

The information made available by some UK ferry companies was less comprehensive than the in house military ship data. It was agreed not to disclose individual operators, ship names or data that would enable this to be identified. Access was allowed to Trim and Stability books for typical ferries, not involved in incidents, but in order to assess how introduction of the Wolfson Criterion might affect operations.

The data viewed was limited to intact stability in certain standard conditions of loading, but a range of ferry types were examined. The smallest were engaged on short crossings between slipways and the largest on overnight passages between ferry ports. Where GZ curves were not available these could be constructed from tabulated KN curves (crosscurves) using the relationship given in Section 5.6.2. As explained in Section 5.6.2, in the absence of wind heeling levers, heeling affects from high speed turn and passenger crowding was taken. Where there was no current heeling lever requirement this could not be included in the assessment.

Figure 7.5 shows the limiting safe wave height for operation which would be calculated by application of the Wolfson Criterion (formula 2a) to a range of ferries, based on their intact stability. The points with initial heel correspond to the points directly above for the same vessels when initially upright. Not all ferries have initial heeling data. The simplified plot mixes ferries across a range of different passenger classes, so there is only a vague trend of increasing safe wave height with ship size, but it does show some typical ferry results.

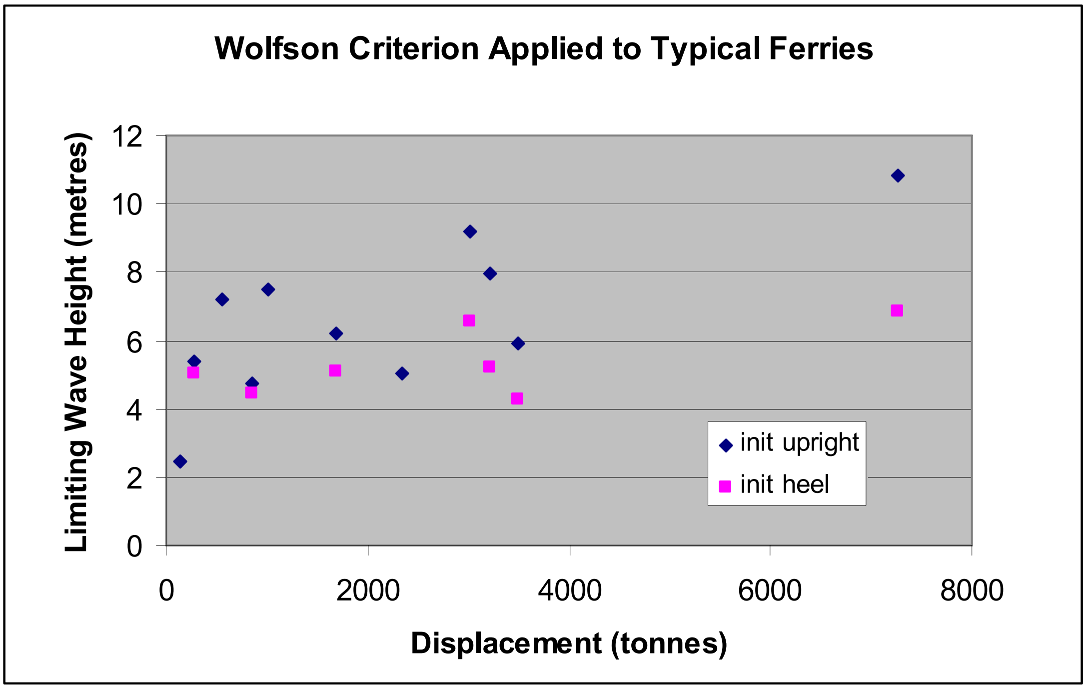

Figure 7-5 Typical Ferry Data

The ferry operators were advised of the hypothetical implications of using the Wolfson Criterion as a method of assessment and invited to comment. The general view was that it would be unlikely to impact on operations as the ferries do not currently leave harbour in these conditions. The small ferry limited to 2.45 metre wave height could not safely load vehicles at an exposed slipway in such waves, so would not be placed in service. Ferry cancellations due to heavy weather are generally at the master's discretion and across the range of ferry sizes the main concern is safe berthing and manoeuvring in and out of harbour. Conditions that would put the ship in danger on passage would only occur when the situation in and around port has passed the point of safe manoeuvring.

7.6 Conclusions

This section presents the results of inputting data sourced from all the preceding sections in to the Wolfson Criterion for assessment of its validity and impact when applied across all types of ship. The conclusions arising from this are therefore the conclusions of the study as a whole. These are discussed and summarised in the following section of the report.

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8 Discussion and Conclusion

8.1 Discussion

8.1.1 Extrapolation from Original Model Tests

It seems intuitively questionable to take model test results from small high speed craft as the basis for a criterion to be applied across all ship types. In theory model tests can always be scaled to represent larger prototypes but this may not always be realistic. Large ships are not generally geosyms of small ships. Especially when considering damage cases, larger vessels will normally have larger numbers of proportionately smaller compartments, with greater asymmetric flooding possibilities.

The Wolfson Unit view appears to be that the method is equally applicable to all ship cases. It merely assesses the wave height to cause capsize based on the residual righting moment characteristic. Because it uses residual righting, this can be for any degree of damage, or undamaged and also with any upsetting moment applied to give an initial heel. Such a diversity of hull types were tested and all found to fit a broad trend, so that issues of scaling are secondary.

It is certainly true that larger ships damaged to the extent their residual stability parameter is of similar magnitude of the original Wolfson HSC model test values will capsize in the same range of wave heights. This is supported by the independently conducted HARDER model tests. However, as seen in Figure 7.2, they do not show a trend consistent with the Wolfson Criterion line within this range.

Furthermore, the limited real ship data obtained in the course of this research project, especially for larger intact vessels, shows in Figure 7.1 that the range of data goes far beyond what was tested in the models. This is also true of the additional model and simulation data plotted in Figure 7.4.

The measure of residual stability used as the base of plots for presenting data both in the Wolfson report [Ref 1] and this report is:

[Range of stability x $(\Delta GZ_{max})^{0.5}$] / LB

The original Wolfson model tests covered approximately the range 0.05 – 1.2 for this parameter. The HARDER model tests are in the range 0 – 0.5 and the real ship data collected under this study are in the range 0.5 – 3. Although the higher values follow the extrapolated Wolfson trend reasonably well it is difficult to be confident in the criterion beyond the original range without conducting more model tests.

Even from the additional model test results plotted in Figure 7.4, point (a) passed the Wolfson Criterion with a residual stability parameter as high as 3.3 due to a large range of stability, but actually capsized. The report [Ref 4] states there was water trapped on deck, but this is not accounted for in the input to the criterion. If all effects degrading stability are included in the calculation of residual stability for use with the Wolfson Criterion this may result in better consistency. This is not always practical however, as in this example where the quantity of water on deck prior to capsize was unknown.

8.1.2 Practical Considerations

Considering the Wolfson Criterion across the diversity of possible damage requirements could introduce inconsistencies in practice for different types of vessel.

For example it could be a small fishing boat vulnerable to capsize because of a limited GZ_{max} due to high KG after the addition of equipment. At the other extreme it could be a very stable naval platform which has been damaged to such a degree that residual range of stability is poor.

Hence to apply the criterion universally to all possible types of ship as a commercial standard would penalise ships already designed to more stringent standards of damage stability.

It also depends what other stability standards apply in conjunction with the proposed new criterion. The original Wolfson testing shows it could be applied as an addition to the HSC Code [Ref 2] to rectify an apparent shortcoming in that standard. The report on MCA Research Project 509 [Ref 1] showed that for vessels marginally compliant with the HSC Code there was a theoretical possibility that they could be vulnerable, although no actual incidents of capsize in waves have been identified. Also it is unlikely to be a real problem as these vessels tend to have large stability margins. The models tested required unrealistically high centres of gravity to achieve the lower limit of stability permitted by the HSC Code.

The Wolfson Criterion was developed from these tests on models of high speed craft, while this report has considered the validity of the criterion across all types of ship.

The criterion could identify an inherent weakness in the intact stability of the fishing boat example above, though in most cases this would already be picked up by current regulation. For large ships designed to sustain damage conditions, direct application of the Wolfson Criterion would generally be more onerous than current regulation, as evidenced by the military ship examples in Section 7.5.1.

For a consistent approach across many ship types the Wolfson Criterion could be accounted for as a new limit state in probabilistic stability. This would cover the worst scenarios, but not all occurring concurrently. However it would require a considerable amount of development to review the method in conjunction with the particular stability requirements. This would only be justified if the criterion itself is validated and from the findings of the present study, this looks doubtful. There is a real risk that a comprehensive series of dedicated model tests could prove inconclusive.

8.1.3 Potential of Wolfson Criterion

Some consideration has been given to the potential of the Wolfson Criterion to practically improve safety across the wider fleet, if it were to be validated. The method as it stands has some potential as an advisory guide to designers and mariners. It provides a measure of vulnerability to capsize under wave action for ships in various conditions of loading or damage.

If applied across all current stability requirements to simply state the hypothetical maximum significant wave height for safe operation, it could be used as a guideline to assess risk or limit operations, if deemed appropriate. The HSC code [Ref 2] already uses limiting sea states, but it may be inappropriate and impractical to extend the concept formally to apply worldwide.

Ships do not generally have instrumentation to measure wave heights. Significant wave height, defined as the mean of highest 1/3 of waves in the sea spectrum, is supposed to correspond approximately to how the sea appears to an experienced mariner trying to judge wave height, so it requires subjective judgement and is far from an exact science.

But before the criterion can be used even for advisory purposes, it should preferably be validated by model tests or simulations designed specifically for the purpose. The available real ship data and published model results identified in this study do not provide sufficient validation, nor indicate that this would be achieved by further development.

8.2 Conclusions & Recommendations

1. The findings of this report from Research Project 583 are made without prejudice to the findings of Research Project 509. The Wolfson Report [Ref 1] states that the HSC Code [Ref 2] may not ensure an adequate level of safety, when used in conjunction with the sea state limiting permit to operate, applied by MCA. It recommends implementation of the Wolfson Criterion as an addition to that standard in order to rectify this.

2. The scarcity of real ship data for this study is partly due to the rarity of capsize events caused primarily by wave action. Less than 4% of all serious LRF casualties in heavy seas were capsizes and most of these had concurrent ship deficiencies, such as inadequate stability or watertight integrity, severe damage, shifting cargo or the snagging of a fishing net.
3. Of capsize and survival cases identified, numbers of incidents that could be fully analysed to check the Wolfson Criterion were also limited by availability and release of relevant stability information.
4. The resulting number of real ship incident cases in heavy seas, suitable for comparison with the Wolfson Criterion, from the original LRF listing of 855 produced for this project, was 6 capsizing + 5 surviving.
5. Most of these examples had levels of residual stability above and beyond the range of the model tests from which the Wolfson Criterion was derived. They were however broadly consistent with the criterion, with some exceptions.
6. Many potential capsizes may have been averted by good seamanship, e.g. avoiding beam or quartering seas. Real ship data is limited to conditions that actually prevailed rather than idealised test points.
7. Model tests on large oceangoing vessels (mainly 38 cases from the HARDER project) show that in damaged conditions they can have similar levels of residual stability to the HSC model tests. However they do not exhibit a similar trend and the results are only partly consistent with the Wolfson Criterion.
8. Overall there seems to be insufficient compelling evidence to justify consideration of the Wolfson Criterion beyond its original scope of HSC vessels.
9. Ferry operators advised that operation of services are limited by conditions for berthing and manoeuvring in and out of port, before conditions on passage become an issue. Based on calculations of wave height to capsize when intact, using the Wolfson Criterion, the ferry operators judged that services would already have been cancelled in such conditions.
10. If applied to larger ocean going ships the Wolfson Criterion would only become limiting after severe damage. This would penalise operations of ships designed to higher damage stability standards.
11. To consider the Wolfson Criterion across the worldwide fleet would probably require it to be included as part of the probabilistic damage approach. There is a lack of real ship incidents of this kind, for ships meeting current standards. This implies no particular problems with the current method of assessment and therefore there is no compelling need to find an alternative method of assessment.

9 References

1. Research Project 509, HSC – Evaluation of Existing Criteria, Summary Report. Wolfson Unit for Marine Technology and Industrial Aerodynamics, University of Southampton, Report No. 1807, March 2005.

2. HSC Code - International Code of Safety for High Speed Craft, IMO 2000.

3. Harmonisation of Rules and Design Rationale (HARDER) Model Test Results – Reports 3-31-D-2001-01-0 (-02-0, -05-0, -07-0, -09-0, -10-0, -11-0, -13-0, -13-1) all June, 2001. (Weblink requires MCA logon). http://projects.dnv.com/harder_int/partners.html

4. Capsize of ship models in following/quartering waves: physical experiments and nonlinear dynamics, Naoya Umeda and Masami Hamamoto, Osaka University. Published by The Royal Society 2000. http://publishing.royalsociety.org/

5. Control of ship capsize in stern quartering seas, AS White, PT Gleeson, M Karamanoglu, School of Computing Science/University of Natal/Middlesex University. International Journal of Simulation Vol 8, No.2, July 2007, UK Society for Modelling and Simulation. http://ducati.doc.ntu.ac.uk/uksim/journal/Vol-8/No-2/paper-3.pdf

6. Proceedings of the 23rd ITTC, Venice 2002. Report of Specialist Committee 'Prediction of Extreme Ship Motions and Capsizing'. http://ittc.sname.org/proc23/Extreme%20motions.pdf

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Annex A MCA Letter of Authorisation

Text of letter printed on headed paper from MCA Southampton office, enclosed with all written requests for information:

To whom it may concern

RESEARCH PROJECT 583 – EVALUATION OF NEW INTACT AND DAMAGED STABILITY CRITERION – LETTER OF AUTHORISATION

We refer to the above mentioned research project contract.

This research project is specifically concerned with the minimum wave height to cause capsize for a variety of ship types. Extensive model testing was conducted in a previous study and simple relationships were established between wave height to cause capsize and certain ship characteristics. A major aspect of the current project is to compare these findings with actual operational experience of the behaviour of ships in heavy seas.

The Maritime and Coastguard Agency (MCA) has selected the contractor BAE Systems to commence this project. This contract began in December 2007 and is due to end December 2008.

As part of the contract, BAE Systems will be approaching other maritime administrations and operators for data relating to incidents involving capsized vessels. The names of any operators/vessels and any information provided to MCA will be treated in the strictest confidence.

If you have any queries or would like to contact the MCA directly, please do not hesitate to contact -- **(details given)**

Annex B Standard Letter to Operators

surface fleet

12 February 2008

Sent to 22 Ship Operators on above date, accompanied by MCA Letter of Authorisation
Letter customised slightly for the different addressees.

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Ref: PN0710696/MC.2/1/00

Dear Sir

MCA Research Project 583

We have been contracted by MCA to undertake a research project relating to the behaviour of ships in heavy seas. It follows on from an earlier study of minimum wave height to cause capsize, based on model tests of a variety of ship types, intact, with initial heel and damaged. What is needed now is to compare the findings of this work with actual operational experience.

We very much hope you are able to provide some ship data for comparison with the model test studies to help us formulate realistic trends for ship behaviour in heavy seas. The information collated from many sources will be used ultimately to develop improved safety standards and will not be identified as individual ship incidents. See enclosed Letter of Authorisation from MCA.

The most valuable information for this study is evidence of actual incidents at sea where wave height or sea state was recorded. Incidents of interest are reports of ships which have rolled excessively or actually capsized due to wave action. Lloyd's casualty reports are being sought separately but may lack certain information. For such incidents, even if they do not amount to marine casualties, it is hoped ship operators can help by sourcing information from voyage reports or log book entries. See Annex A enclosed for details of specific information we are seeking.

Please respond to myself at the above address, Block COC(E), 2nd Floor, by Email or telephone as noted below. In my absence ask for my colleague Andrew McCrimmon on 0141 957 4315.

Yours faithfully

Tom Carreyette
Consultant Naval Architect
Surface Fleet Solutions - WDS

Direct tel: 0141 957 2424 Direct fax: 0141 957 2429
E-mail: tom.carreyette@baesystems.com

ANNEX A

For direct comparison with the model test study the following tabulated information is required for the incidents being evaluated, as applied to the ship at the time of the incident:

Ship name	*
Ship LR/official number	*
Flag	*
Ship type & size (eg approx Gross Tonnage)	
Length overall	
Breadth overall	
Date/time of incident	$
Position of incident (descriptive or lat/long)	$
Incident description (eg heavy roll/angle if stated, deck immersion or capsize)	
Concurrent ship faults (eg fire, engine failure, damage/no. of flooded compts if stated)	
Wave height or sea state at time of loss/incident	
Wave direction relative to ship's heading	
Vessel condition at time of incident (displacement/draught and any initial heel)	
Stability characteristics of vessel (GZ curves intact and after any initial heel or damage)	**

*These items need not be disclosed if dimensions, displacement and GZ curves (or data) are provided. Otherwise we need the ship's identity in order to search further for this information.

$Required if wave height or sea state not recorded.

**Specific information required from GZ curves is:

- Residual GZ_{max} x displacement and
- Residual Range of positive GZ

The Residual values are after reduction for any wind heeling effect and damage, if applicable. If GZ curves are provided we will calculate/estimate this, but these values can be provided if preferred.

It is likely not all of the above information will be available for all incidents. We are therefore interested in capsize or heavy roll incidents where at least some of these aspects are recorded and we can make reasonable assumptions about the remaining details.

Where a ship is identified by name/official no. at time of incident (and date stated), we can look up certain particulars in Lloyd's Register of Ships and if time and location is noted we may be able to get retrospective sea state data from Met Office records. We may also be able to obtain stability information pertaining to the incident from the marine administrations, including MCA for UK flag vessels.

This request is being sent to a large number of ship operators and related organisations. Please provide what information you can to assist us and MCA in building this record. Individual cases will be kept in confidence. See enclosed Letter of Authorisation from MCA.

Annex C Met Office Beaufort Table

Specifications and equivalent speeds

Beaufort wind scale	Mean Wind Speed		Limits of wind speed		Wind descriptive terms	Probable wave height in metres*	Probable maximum wave height in metres*	Seastate	Sea descriptive terms
	Knots	m/s	Knots	m/s					
0	0	0	<1	0-0.2	Calm	-	-	**0**	Calm (glassy)
1	2	0.8	1-3	0.3-1.5	Light air	0.1	0.1	**1**	Calm (rippled)
2	5	2.4	4-6	1.6-3.3	Light breeze	0.2	0.3	**2**	Smooth (wavelets)
3	9	4.3	7-10	3.4-5.4	Gentle breeze	0.6	1.0	**3**	Slight
4	13	6.7	11-16	5.5-7.9	Moderate breeze	1.0	1.5	**3-4**	Slight-Moderate
5	19	9.3	17-21	8.0-10.7	Fresh breeze	2.0	2.5	**4**	Moderate
6	24	12.3	22-27	10.8-13.8	Strong breeze	3.0	4.0	**5**	Rough
7	30	15.5	28-33	13.9-17.1	Near gale	4.0	5.5	**5-6**	Rough-Very rough
8	37	18.9	34-40	17.2-20.7	Gale	5.5	7.5	**6-7**	Very rough-High
9	44	22.6	41-47	20.8-24.4	Severe gale	7.0	10.0	**7**	High
10	52	26.4	48-55	24.5-28.4	Storm	9.0	12.5	**8**	Very High
11	60	30.5	56-63	28.5-32.6	Violent storm	11.5	16.0	**8**	Very High
12	-	-	64+	32.7+	Hurricane	14+	-	**9**	Phenomenal

i These values refer to well-developed wind waves of the open sea.

ii The lag effect between the wind getting up and the sea increasing should be borne in mind.

Annex D MOD Standard for Stability in Waves

The stability standard for UK warships (Def Stan 02-109, formerly NES 109) accounts for rolling in waves by an area ratio criterion. The area between the GZ curve and the wind heeling curve taken from the angle of steady wind heel up to the angle of downflooding must be at least 40% greater than the area between righting and heeling curves measured back from the steady heel angle to an arbitrary roll back angle of 25 degress below this. The requirement is illustrated in Figure 7.4. After damage there is a similar requirement but with a roll back angle of only 15 degrees. This criterion is sometimes described as the ratio of restoring to heeling energy, or A_1/A_2 in Figure 7.4. This ratio is to achieve 1.4 minimum.

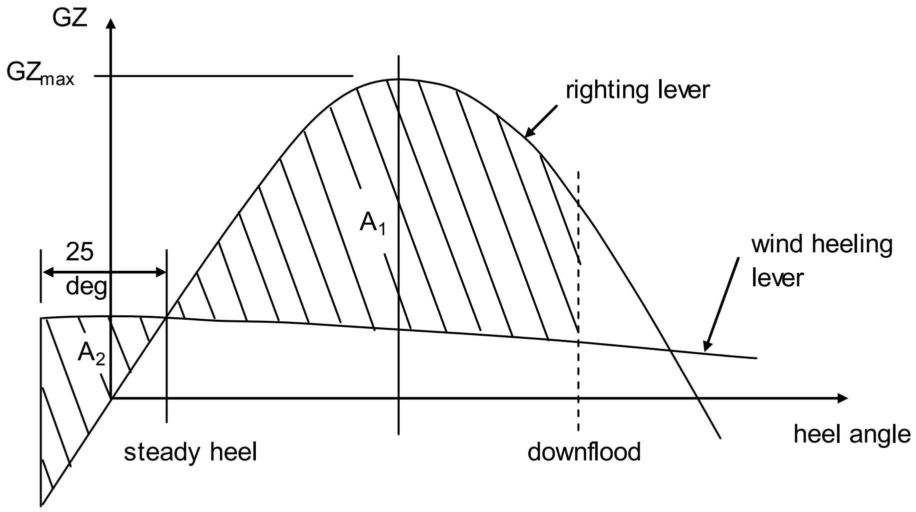

Figure D-1 MOD Standard for Rolling in Waves

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