Landing Craft Stability Standard

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ABSTRACT

The same stability criteria are applied to large and small naval ships and have served them well for many years. Landing craft are very different to warships (around which the standard was designed) putting into question the applicability of naval stability criteria and the assumptions regarding the risk of craft loss. A research programme to derive a new stability standard for UK landing craft is described. Detail is provided regarding the method for establishing operational doctrine, the associated landing craft specific stability hazards and the derivation of new stability criteria that will form a key element of the future standard.

KEYWORDS

Craft; Doctrine; Dynamic; FREDYN; Freeboard; Landing; Stability; Standard.

INTRODUCTION

Landing craft are complex marine vehicles. They are required to operate in a range of sea environments both independently and from motherships and beaches. Whilst doing this they must carry a wide variety of payloads including passengers. As a consequence of these factors the craft operate under limitations on deadweight and environment.

Accordingly, the safety standards for landing craft have to adequately address all these roles and activities. Stability criteria applied to Royal Marine landing craft have traditionally been a derivative of Def Stan 02:109. These in themselves are derived on longstanding criteria developed by Sarchin & Goldberg based on WWII frigate hullforms. Whilst their applicability to landing craft may not be inappropriate, although challenging (e.g. achieving the max GZ >30 degrees), the levels of risk and robustness of the individual criteria and criteria set are not known.

The design of landing craft is often challenging as the craft when operated from motherships (e.g. Landing Platform Docks (LPD)) have a constrained size envelope. Some of the other factors influencing the design are:

- Draught constrained by depth of water over mothership dock sill;
- Weight constrained by davit launch;
- Beam constrained by mothership dock dimensions;
- Range & speed requirements;
- Cargo weight & load and offload arrangements;
- Crew access.

This paper describes the considerations, methodology and process for the development of a bespoke stability standard for landing craft. The scope of the standard will address all the performance requirements of the Naval Ship Code (2009). The key lines of development described in this paper are focussed on the unique aspects of landing craft and thus the aspects requiring special consideration. In doing so the foundation of the development has been the doctrine for operation of landing craft.

DOCTRINE

To inform the development of the standard and ensure that it adequately addresses the primary stability hazards it was necessary to verify the current understanding of landing craft operational doctrine. This was done through engagement with Landing Craft Utility (LCU) and Landing Craft Vehicle and Personnel (LCVP) coxswains in a series of stability related doctrine capture workshops.

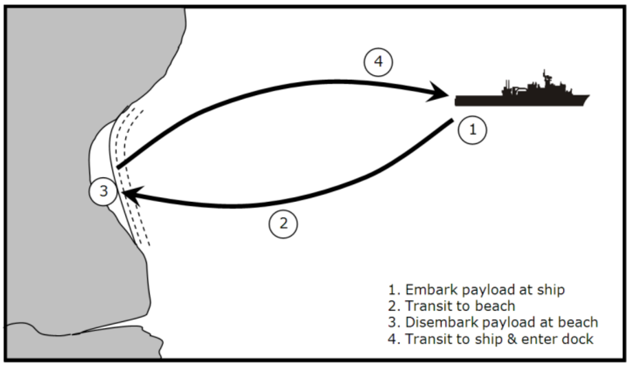

Fig. 1: Vignette used in operator doctrine capture workshops.

Each of the workshops adopted a common format and question set to ensure a consistent approach and thereby allow comparison to be drawn across the three groups of operators visited. A key element of the workshops was use of a common vignette against which the questions were pitched (Figure 1). These questions were designed to determine the doctrine employed during normal and wartime operation and their experience of landing craft operation. From their responses it was possible to establish a common picture of the evolutions that could be expected to occur.

Key conclusions specific to landing craft operation and design drawn from the exercise are as follows:

- There was a consistent approach to landing craft operation across each group of operators;
- The coxswains' recollections of landing craft handling, seakeeping and cues to adjust heading and speed are the same;
- The actions taken by the coxswains following these cues were broadly similar;
- The LCU Mk10 does not suffer from regular green seas whilst operating within the prescribed operational envelope;
- Green sea events are used as a primary indicator to the coxswain to change course/speed.

Potential stability safety hazards associated with the operational doctrine were identified during the exercise. These hazards are being used to inform the development of the new stability standard. Some examples of these hazards are illustrated in Table 1, below.

Table 1: Stability hazards identified during doctrine capture workshops.

Key Event	Hazard(s)
Interpretation of Sea Conditions	The provenance of surf height limits for landing craft is not known. Inaccurate sea state assessment.
Damage / Loss of Watertight Integrity	The internal geometry / constrained compartments of landing craft prevents effective damage control. Raking damage that affects two compartments (including main engine room).
Beach Approach and Departure	Insufficient power or propulsor emergence and subsequent loss of control in surf zone. Capsize in surf zone on approach to beach due to wave action. Capsize in surf zone during 180 degree turn due to wave action.
Green Seas / Water in Well Deck	Effect of green seas and the ability to remove entrained water.
Loss of Power / Steerage	Loss of propulsive power during operation (transit/open water and surf zone).
Payload Unloading, Loading, Positioning & Securing	Embarking unknown vehicle weight/VCG (e.g. due to payload of vehicle). Retraction through surf zone with unknown trim / list / draught.

STABILITY STANDARD STRUCTURE

Watertight Integrity

The programme will develop standards for each of the performance requirements for watertight integrity. Whilst most of these are relatively straight forward some require special attention due to the design and operation of landing craft.

The standard will address the need for protection of the forward part of the ship from both collision with floating objects (e.g. whilst entering an LPD) and from grounding (e.g. on unsurveyed rocks).

The open nature of the typical craft with high bulwarks requires the drainage of the cargo deck to be efficient as trapped water on deck leads to a reduction in stability. The study has focussed on researching the sizing of freeing ports stipulated by different Administrations for a variety of craft. A direct approach to sizing freeing ports relating the height of bulwarks, deck area and possible reduction in stability has proved unsuccessful. No direct relationship to the sizing required by Load Line and stability parameters could be derived.

Green water is one of the key cues to handling of the craft and heading and speed would be altered to remove the frequency of such events. Current arrangements on UK LCU Mk10's are designed to Load Lines rules and it was reported during the doctrine workshops that when water enters the deck it drains away quickly and efficiently.

The design constraints for landing craft results in some challenges for the protection of vents. Bespoke arrangements are normal practice and designs must consider the operational environment and additional influences such as accidental damage from payload handling, operation in cold weather and damage from debris.

Reserve of Buoyancy

A range of areas are being developed to support the requirements for reserve of buoyancy, such as the construct of loading conditions and the subdivision of landing craft. The programme will also review the damage extents currently applied to landing craft and develop requirements that better reflect the hazards from operation e.g. damage from grounding. The outcome will also define a distinction between safety (damage from grounding & collision) and capability (damage from hostile action).

A further key line of development surrounds the performance requirements for freeboard. A ship's freeboard provides a safety margin for buoyancy and stability above that required for static equilibrium in calm seas to allow the ship to operate in a seaway. Freeboard has a direct effect on the relative height of the gunwale and wave crests; it can therefore influence the incidence and quantity of green seas. Altering freeboard also allows the designer to influence intact stability, damaged condition reserve of buoyancy and damaged stability.

Construction of the requirements for freeboard consisted of firstly defining the performance requirement associated with freeboard; and secondly, arriving at a consistent definition for how freeboard is measured that can be applied to the wide range of landing craft designs that the standard is intended to cover.

Considering first the performance requirements, these have been developed to support the functional objective that the ship shall have sufficient freeboard to prevent excessive shipping of green seas in any foreseeable operating condition. This in turn leads to performance requirements that can be summarised as:

- Have a minimum freeboard to ensure an adequate reserve of buoyancy. As a minimum, the freeboard shall meet the requirements of the Merchant Shipping (Load Line) Regulations (1998);
- Have a minimum height of side to limit the shipping of green seas to a level at which, any resulting entrapped water does not threaten the stability and buoyancy of the vessel;
- Remain afloat following the loss of hull integrity resulting from foreseeable damage and following shipping of green seas.

The second area of development concerned the consistent definition of freeboard. Whilst at face value, this may appear a simple task it is much complicated by the variable nature of landing craft designs.

Both the Naval Ship Code and the Merchant Shipping (Load Line) Regulations both use a similar definition for freeboard that refers to freeboard as the distance measured vertically downwards at amidships from the upper edge of the deck-line to the load line.

In the case of landing craft, the freeboard definition can become a significant design driver. The lowest deck exposed to the external environment is invariably the vehicle deck (Figure 2), the height of which can prove critical to achieving a balanced design. In the example in Figure 2, increasing freeboard and consequently vehicle deck height, results in raising the payload centre of gravity which may result in an associated reduction in stability. Furthermore, it may also limit the capability of the landing craft as vehicle deck height can drive bow ramp length and gradient, or can limit the beach gradient on which the landing craft payload can be disembarked. These competing design requirements may result in a solution where the vehicle deck is placed as low as possible.

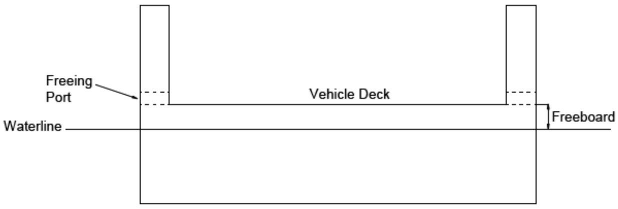

Fig. 2. Freeboard measured to vehicle deck.

In extreme cases this can result in landing craft designs where the vehicle deck is below the waterline, for example the UK LCVP Mk5. Applying the existing freeboard definition in this instance, results in a negative freeboard value.

A more suitable definition of freeboard was required to allow the design requirements to be articulated appropriately. A solution was found in the Maritime and Coastguard Agency definition for Small Commercial Vessels and Pilot Boats (2004):

"Freeboard means the distance measured vertically downwards from the lowest point of the upper edge of the weatherdeck to the waterline in still water or, for an open vessel, the distance measured vertically downwards from the lowest point of the gunwale to the waterline."

An open vessel being in this case a landing craft that may not be fitted with a watertight weatherdeck over part of its length.

It is not appropriate to always measure freeboard to the top of the bulwark as Regulation 2 of the Landing Craft Stability Standard requires all exposed decks to have an efficient means of drainage. This may take the form of freeing ports or a pump arrangement. In the case of freeing ports, unless they have a watertight closure, water is able to enter the vehicle deck as well as drain from it which limits the reserve of buoyancy.

However, a bulwark with openings such as freeing ports can still be effective at minimising the shipping of green seas. This is particularly true where openings are arranged or provided with suitable protection to prevent ingress of water during transient immersion.

Therefore freeboard is defined to ensure adequate reserve of buoyancy and the height of side is defined to limit shipping of green seas.

Reserve of Stability

The goal of the research is to develop quasi-static stability criteria similar to the scope that are currently employed on such craft. These will be based on a dynamic analysis and capsize risk methodology using FREDYN that has been benchmarked against model tests.

A 1/16th scale model of a generic LCU-type hull was constructed and tested in large seas to measure seakeeping data for FREDYN validation and to assess the dynamic stability of landing craft (Figures 3 & 4). The model was tested at a single displacement with multiple VCGs and two different sizes of freeing ports. The model scale was chosen to provide a nominal model length of 1.5m.

Fig. 3: Free running experiment model.

This set of model tests was undertaken in the Ocean Basin at QinetiQ Haslar during June 2009. For this study, the model was tested in stern and stern quartering seas in the intact condition. It was predominantly tested in stern seas, since these were considered most likely to induce broaching motions and water on deck problems; particularly in the steep, near shore wave conditions. The tests were conducted at close to 5 and 10kts (full scale) in order to capture any dynamic stability effects, such as broaching. Different sized freeing ports were achieved by commencing the experiments with one size of freeing ports and then permanently making the ports larger part way through the tests. This change in size represented an increase in freeing port area of 50%. The model was run at two relative wave headings, two speeds and in five combinations of regular wave frequency and height. Steep, irregular waves representing sea states 4 and 5 were also tested.

Two loading conditions were tested with the VCG of the first set at the limiting value for compliance with Def Stan 02:109, the second was set with an increase of 0.4m at full scale. The model did not demonstrate any instability in the load conditions initially chosen, and so additional experimental runs would be conducted at the 30 degree heading (stern quartering seas) and at 10kts with higher VCGs, in order to determine the point of vessel capsize.

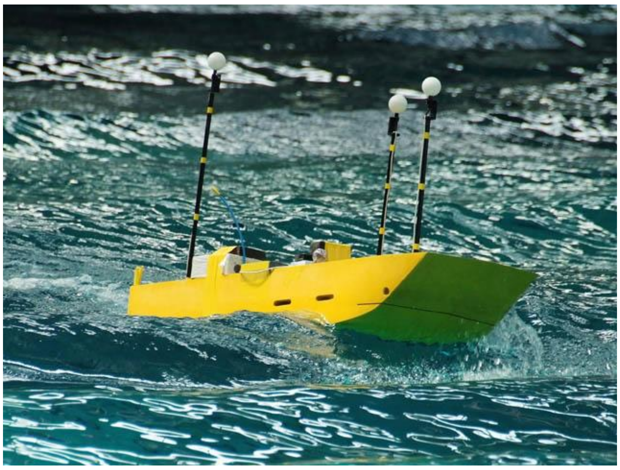

Fig. 4: Free running experiment model

Due to the relatively unusual box shape of the LCU hull design, the original SHIPMO calculation method in FREDYN for added mass and damping calculations was not considered accurate enough in FREDYN. The new SHIPMO2006 code can account for more unusual ship forms and was considered as being more pertinent for use for this shape of hull form. The internal arrangement of the vessel was modelled in FREDYN, based on the Paramarine model. The vehicle deck region was modelled in FREDYN as a large damage compartment with openings above the side deck edge; this allowed water to flow on and off the vehicle deck in a realistic manner during FREDYN simulations.

A selection of static and dynamic roll decay data from the experiments was used to compare and tune the FREDYN model for the generic LCU. FREDYN was originally developed for frigate forms. As the generic LCU is quite different in shape, there was a need to perform some tuning of the roll decay characteristics of the FREDYN model.

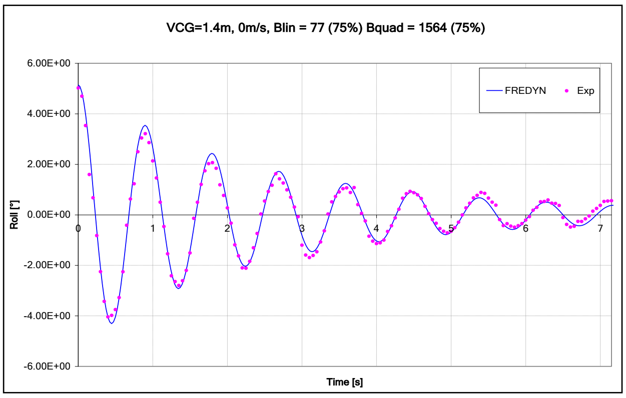

Fig. 5: Static roll decay comparison.

A direct comparison between the motions recorded during the experiments and the motions predicted within FREDYN was undertaken. For regular seas, in addition to RMS values, the period of oscillation and correlation of the time based traces of roll, pitch and heave were used to characterise the quality of the FREDYN simulations in the more stable conditions. In the high VCG conditions, the comparisons were more related to the prediction of motion ‘events’, such as large roll angle excursions and capsize events.

Difficulties were experienced achieving adequate replication of the tank model track due to the manoeuvring model in FREDYN and its constraints on waterjet bucket angles. Once these were addressed a good correlation of the track lead to a good correlation with the model tests.

The higher VCG runs showed more frequent capsize with a similar time trace prior to capsize and then a good correlation of the capsize mode between FREDYN and experiment. A point to note is that the LCU experiment model often survived more wave encounters prior to capsize, whereas the FREDYN simulation predicted capsize earlier, although following the same capsize mode as the experiment.

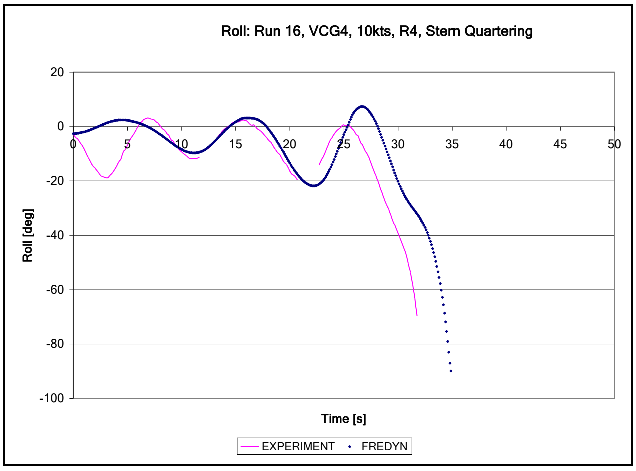

Fig. 6: Capsize model test/FREDYN comparison.

As part of this phase of work, an initial computational study using probabilistic risk calculations to investigate the envelope of the dynamic stability performance, based on the way in which the vessel is operated, is to be investigated. By varying the vessel load conditions (displacement and vertical centre of gravity), the static stability parameters used in the current intact criteria assessment will vary. Conducting simulations for a number of loading conditions will provide probabilities of loss of the vessel due to loss of buoyancy or stability in all these conditions.

Information from the doctrine workshops on how the operators selected speeds and headings and the cues they used were distilled down into a set of realistic scenarios and input parameters for use in the simulations.

It was clear from the workshops that there are two distinct phases to the operation of the landing craft: the transit from mothership to shore in open ocean and the time spent in surf conditions near to the beach.

To investigate the performance in the transit phase, the intact stability study involves running the CRNavies PCAPREF program, which utilises FREDYN as a subroutine, to calculate probabilities of intact vessel loss in a seaway. Two speeds were identified from the workshops, 5.0 and 7.5kts, with the lower speed only used in bow and bow quartering seas. The headings were found to be of equal probability, so a range of headings from 0 to 180 degrees in 30 degree intervals are being calculated.

Two displacements were selected, with four VCG conditions that span the current intact stability criteria from pass to fail. A full and reduced freeboard height was also created for four of the conditions to identify the effect that freeboard height has on the heavy weather survivability. Based on the current guidelines and the workshop discussion, the wave condition limit for these craft is currently sea state 5; if encountered, the craft should head for shelter. Taking this into consideration, a maximum significant wave height of 5m would be used in the simulation, which actually equates to a sea state 6, in order to extend the operational envelope in the simulations. The wave height condition is varied in 0.5m increments. A cut down wave scatter table was selected and the probabilities factored to produce a value of 1 for these craft.

For the definition of the capsize point in the PCAPREF calculations, a value equal to the roll angle at which the gunwale would submerge was selected, as it has been seen in the experiments that a substantial intake of water onto the vehicle deck rapidly leads to loss of the vessel. These capsize risk calculations will be reported in future papers.

Safety of Embarked Persons

The performance requirements of the Naval Ship Code stipulate the assessment of the impact of craft behaviour on personnel activities and safety arrangements. This aspect of the programme is envisaged to adopt current standards with little development needed.

Preservation of Life

The landing craft should provide a safe haven for those onboard following an extreme event until the point of evacuation. Craft similar in size to landing craft have little survivability beyond damage to a single compartment. The craft are limited in range and at present have a limitation of 20nm from a safe haven or mothership. It would possibly be at disproportional cost to require enhanced survivability for such simple craft. The focus of this research line is to ensure that the escape and evacuation arrangements are balanced with the craft ultimate stability performance.

Provision of Operational Information

The role of these craft as highlighted in the vignette (Figure 1) is complex and the payload may vary greatly and also the weight of vehicles may, on occasions, not be known. One of the challenges is determining if the craft are overloaded. A load line mark is not appropriate as the craft is loaded when aground and not in environmental conditions where the draughts can be read to any reliable accuracy. The operator guidance provided to the coxswain needs to reflect closely how the craft are operated, as such the format of traditional Stability Information Books is not appropriate. The key facets of operator guidance are:

- Clear and concise instruction on stability and maintaining watertight integrity;
- A matrix of payloads, their locations and particular fluid restrictions;
- A simple method of determining the stability of unique payloads.

The impact on the designer is ultimately a greater range of loading conditions for assessment and conversion of the output to a form that is simple to interrogate by the coxswain. This in itself is a great challenge for naval architects who in the main design operator guidance that has to meet often a conflicting role for both Administration plan approval and use by the operator.

CONCLUDING REMARKS

The risks associated with the application of traditional warship, frigate based, stability criteria to small craft with different L/B ratios is under development. Landing craft although they look simple are complex to design, having to satisfy a number of key constraints. Furthermore, the role of carrying a wide variety of cargos and the environment they operate in has lead to the need assess the risks associated with the application of current standards and to derive a bespoke cohesive stability standard. The key knowledge vacuums where resource is being concentrated are:

- Operator influences and ship-handling cues;
- Freeboard requirements;
- Stability criteria;
- Damage extents;
- Operator guidance.

This paper has described the progress made so far on understanding the influences on the stability of landing craft. Adopting the systems approach to developing a new bespoke standard should provide coherency and transparency encompassing all areas of the NATO Naval Ship Code Chapter III performance requirements.

DISCLAIMER

The statements and opinions made in this paper are those of the authors and may not represent those of the UK Ministry of Defence or BMT Defence Services Ltd.

REFERENCES

MCA MGN 280 (M) Small Vessels in Commercial Use for Sport or Pleasure, Workboats and Pilot Boats - Alternative Construction Standards, 2004

Merchant Shipping (Load Line) Regulations 1998

Naval Ship Code, Allied Naval Engineering Publication 77, December 2009