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Designing Safer Tugs – Going Beyond Existing Statutory Stability Criteria

Govinder Singh Chopra, SeaTech Solutions International (S) Pte Ltd, Singapore

SYNOPSIS
The recent number of tugs capsizing raises the question as to whether the International Maritime Organization's (IMO) criteria for stability is adequate. Its applicability to tugs and offshore workboats such as PSVs, diving support vessels and anchor-handling tugs, however, appears to be limited. These operations are completely different from commercial vessels and these boats have to withstand much harsher operating environments. The stability criteria must cater to actual operations and consider the dynamics and motions of these boats in the seaway. This paper will analyse the limitations of present criteria, with case studies to demonstrate the need for modification, and will then go on to suggest a direction for further research to develop stability criteria better suited to tugs and similar workboats.

INTRODUCTION

There is a well-known Chinese saying: "Oceans can support the ship and they can also capsize it". Under extreme operations and environmental conditions, beyond acceptable limits, every vessel can capsize. The IMO's Maritime Safety Committee emphasised that "ships are to be designed and constructed for a specific design life to be safe and environmentally friendly, when properly operated and maintained under specified operating and environmental conditions, in intact and specified damaged conditions throughout their life" (IMO, 2009)[1].

The IMO criteria for stability have evolved over the years and have proven to be reasonably adequate for commercial shipping. But are the same set of criteria adequate for workboats such as tugs and offshore support vessels?

The main differences between workboats and commercial vessels lies in their multiple modes of operations and the harsher operating environment leading to higher vulnerability and risks. The operating modes of workboats are more diverse and multifarious – eg towing, pushing, escort, berthing, salvage. Workboats carry out different operations, as and when required, and the duties these vessels may be asked to perform are sometimes unpredictable.

Table 1: Main difference of workboats and commercial vessels

	Workboats	Commercial Vessels
Characteristics	• Length <100m • Power horses • Highly manoeuvrable • GM approx. 1m • Low freeboards	• Length >100m • Optimised power for economic speed • Need assistance for manoeuvres • GM >2m • High freeboards
Modes of Operation	• Ocean towing • Harbour service • Berthing • Escort • Pushing • Side Tow • Salvage • Unpredictable • Firefighting	• To carry cargo, or passengers from point A to point B
Operating Environment	• Wind – 35 knots • Currents – 1.5 knots • Waves – 6m • Difficult to stop operations even during harsh sea conditions	• Can reduce speed or change course • Operators will try to avoid seasons where sea conditions are harsh; some may have fixed operating months where they can predict the sea conditions
Propulsion	• Conventional twin screw • ASD • Tractor • Rotor	• Conventional single screw

Table 2: Roles and responsibilities for the safety and stability of workboat (Rohr, 2003)[2]

	Responsible	Accountable	Consulted
Design for Stability	Designer	Designer	Regulator
Produce for Stability	Building Yard	Operator	Regulator / Operator
Operate for Stability	Operator	Operator	Regulator / Operator

We all understand what an accident is – it is something that happens to the 'unfortunate others', and, unfortunately, it is generally after the accident that the regulations are made to prevent such accidents happening again in future. The responsibility for the safety and stability of a workboat appears to be a shared responsibility *(Table 2)*.

A gradual shift of mindset is required from this shared responsibility concept. It must be clear that stability is the *sole* responsibility of the operator. However, it is the responsibility of the designer, regulators, trainers, equipment suppliers and other stakeholders to ensure competency and training for the operator, a seaworthy vessel for operation, and timely decision-assisting guidance for safe operations. Safety is not to be left to chance, but must be inherent in every element and block of the entire system.

Historically, stability has remained a design issue, and the designer is required to follow the various regulations and standards. Designers realise that the present IMO criteria for stability are not adequate and most of them have developed their own in-house standards. It would be imprudent to leave the standard of safety to individual designers' standards. Safety must not become an element of competitive advantage for designers. We must have a harmonised, uniform standard, and the regulators need to raise the bar for stability and safety for all workboats.

There is the inevitable compromise between safety and the economies of operations, and the workboat design will normally be optimised to meet regulatory minima, as it gives the most economical solution within acceptable safety standards.

For workboats which may have several modes of operations and unpredictable operating conditions, it becomes crucial to develop a limiting operability envelope, together with practical methods of assessing the level of safety in the range of sea states in which the workboat would remain safe from capsize. It is very important that the regulations lay down realistic and relevant criteria for stability to comply with. We should use what we learn from the past incidents to improve safety for all, by developing simple formulae and alarms which may offer operators ready and quick means of safety assessment.

PRESENT IMO STABILITY CRITERIA

The conventional fundamental principles for stability evaluation remain valid, but we need to adopt and adjust these criteria to the actual operations and at the same time raise the standard with higher safety margins. The goal is to ensure adequate reserve buoyancy, positive GM, and ensure there is always sufficient righting energy along with watertight integrity, in all conditions of operations.

The four pillars of stability against capsize are:

1) GM – statical/initial stability regulations
2) Righting energy – dynamic stability regulations
3) Freeboard – load line regulations
4) Watertight integrity – load line regulations

The vessel geometry and hull form fixes the vessel's stability characteristics at the early design stage, such as KM, KN, etc. Each hull form being unique, the stability form characteristics may be different. However, for a given set of vessel dimensions, there is little room for designers to drastically change these stability form characteristics. The vessel arrangement, depth and weight distribution fixes the vertical curve of gravity. Together, this decides the vessel's stability at the early design stage. Every workboat delivered and sailing today complies with the IMO stability criteria, which is a statutory requirement for the certification.

GM – statical/initial stability regulations

The origin of the first-generation intact stability regulations can be traced to the pioneering works of Rahola in 1939. It is based on the traditional empirical and statistical approach. Stability of the ships that capsized were compared with those with a long accident-free history. The stability parameters were calculated in calm and still waters as then, unlike the present day, it was not possible to compute and evaluate ship motions in a seaway.

GM is the most basic and elementary stability criterion to quantify the ship's stability. Specification of a minimum value of initial GM and freeboard sufficed as the sole numerical stability criterion in use until the 1940s. The value of GM is easy to calculate, its meaning is relatively simple to understand, and the

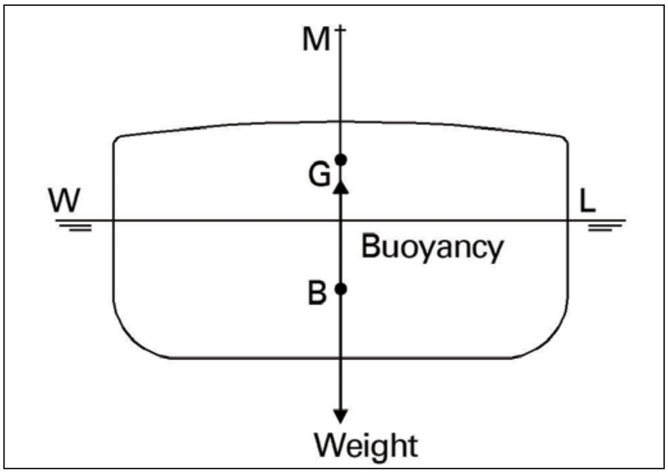

Figure 1: Statical/initial regulations under the IMO general criteria

effect of its magnitude on the heel response is readily predictable. However, GM is only a valid measure within small angles of heel – less than 5 degrees. For workboats, the required GM in the IMO criteria is only 0.15m. This is extremely inadequate for the powerful tugs of the present, and the required value must be increased substantially and also related to the workboats' bollard pull to be realistic *(see Figure 1 on opposite page)*. In the absence of a valid IMO criteria, designers have been guided by the Argyriadis formula:

$$\text{GM} = \frac{SHP\ x\ h}{100\ \Delta \frac{f}{B}}\ \text{(ft)}$$

Where:

- *SHP* shaft horsepower per shaft
- Δ displacement, long tonnes
- *f* minimum freeboard along the length
- *B* moulded beam
- *h* vertical distance from propeller shaft centreline to towing bitt

Murphy modified the basic formula as follows:

$$\text{GM} = \frac{N(SHPx\ D)^{2/3}\ x\ Sh}{76\ \Delta \frac{f}{B}}\ \text{(ft)}$$

Where:

- *N* number of screws
- *D* propeller diameter
- *S* fraction of propeller circle cylinder intercepted by rudder turned to 45 degrees

The US Coast Guard used the Murphy Criterion until 1971, when the factor of 76 in the denominator was changed to 38, resulting in a twofold increase in the required GM. Another criterion is the standard proposed for Norway which was experimentally derived by towing a model with a block coefficient of 0.5 sideways at a speed of 4 knots. The standard requires:

$$\text{GM} = \frac{h_1 + \frac{d}{2}}{5f}\ \text{(m)}$$

Where:

- h_1 : height of towing bitt above waterline
- *d* : draught
- *f* : minimum freeboard along length

The major limitation of the GM criterion is that it is valid only at angles of heel less than about 5 degrees. These expressions are unable to predict the response of the workboat at heel angles near capsize and their use is both arbitrary and inaccurate. A more sound approach for large angles of heel is based on GZ and balancing the heeling or overturning moment induced by either the tug or tow with the available righting moment below a critical angle, such as either the angle of downflooding or the threshold of capsize.

Righting energy – dynamic stability regulation

The concept of energy balance is that the righting energy must be more than the capsizing or overturning energy. However, the present IMO criteria *(Figure 2)* are for commercial shipping operations, but do not cater for workboat operations and operating conditions, which result in a different set of forces and overturning moments. In the absence of suitable criteria from IMO, classification societies have laid down criteria for workboats' energy balance *(Figure 3)*, considering towing, fire-fighting and crane operations.

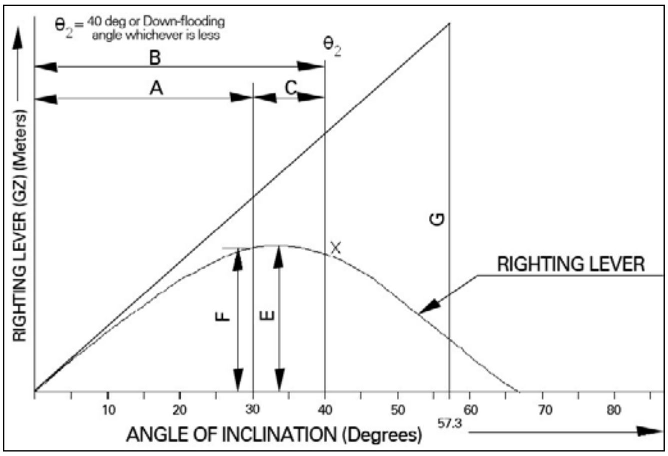

Figure 2 : IMO general criteria for dynamic stability

IMO general criteria:

- A Area under GZ curve up to 30° ≥ 0.055m-rad
- B Area under GZ curve up to θ2 ≥ 0.09m-rad
- C Area under GZ curve bet. 30° and θ2 ≥ 0.03m-rad
- E Maximum GZ to occur at angle ≥ 25°
- F Maximum GZ ≥ 0.2m

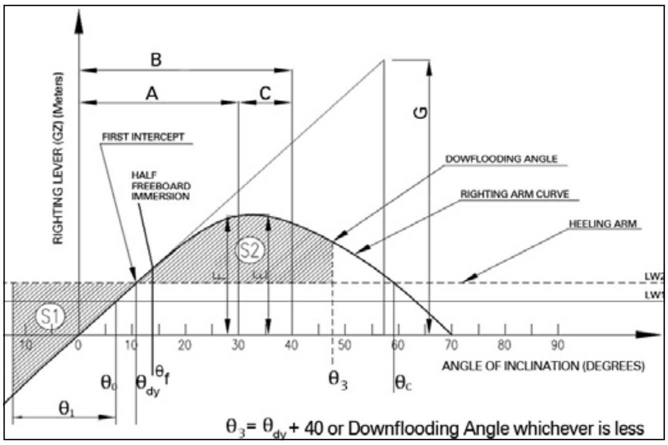

Figure 3: Classification society/IMO weather criteria

IMO weather criteria:

1) θ0 ≤ 0.8 x θde or 16°, whichever is less
2) S2 ≥ S1

ABS towing criterion and fire-fighting:

1) S2 > 0.09m-rad

ABS fire-fighting criteria:

1) S2 > 0.09m-rad
2) θf > θdy

ABS escort criterion:

1) θ0 < θde

The IMO general criteria and weather criteria were developed using the hull forms and proportions of commercial vessels. Workboats have very different proportions and hull forms, and this renders the criteria not suitable and in some cases inadequate. Additionally, there is an urgent need to include all other operations that the workboat may be required to perform, and make the criteria more performance-based.

Freeboard – load line regulation

The load line concept was developed for commercial shipping to prevent overloading vessels and jeopardising their safety. Samuel Plimsoll was instrumental in drafting the Merchant Shipping Act and convincing the British Parliament to finally enact this in 1890. The Load Line Convention followed in 1930. Freeboard, and the minimum bow height, has an effect on various vessel characteristics:

- Shipping green water;
- Deck immersion;
- Reserve buoyancy;
- Righting energy;
- KG values.

The concept of freeboard is still valid. However, the value in the present regulations is obtained arbitrarily and empirically without scientific basis. For some workboat operations, a lower freeboard at the stern may be necessary. This conflicts with the stipulated freeboard and may result in a design which is not suitable or unsafe for certain operations.On the other hand, workboats with the minimum statutory freeboard may not prove to be very suitable for operations in harsh sea conditions.

Watertight integrity – load line regulation

One of the crucial means of ensuring adequate stability involves providing external watertight integrity so that the hull boundary remains effective in providing buoyant force and righting energy. The downflooding point is the point at which water could enter the hull boundary which provides buoyancy when the vessel heels due to an external overturning moment *(Figure 4)*. The requirements for watertight integrity are contained in the Load Line Regulations, and this is directly related to the downflooding point which is a critical factor in the IMO stability criteria.There are basically two types of downflooding points assumed in the stability calculation:

- weathertight openings
- unprotected openings

The most common unprotected opening is the engine room ventilator, since provision of air to combustion machinery is necessary for operations. The possibility exists that in certain conditions, however, some of the unprotected openings may also need to be closed, such as during the preparation for severe storms or for the duration of the tow and when the hull is unmanned and not in an operational condition.

Weathertight openings are those openings that are provided with weathertight closing appliances, which can be closed in bad weather. Providing weathertight closures on openings into the buoyant envelope removes them from consideration as downflooding points, because they are assumed to be effective in preventing the ingress of water during intermittent immersion. Such openings need a minimum height (sill height) above deck so that when open, water ingress is minimised. However, for small workboats which also have a lower freeboard, this sill height may not be adequate. There is a need to adopt the Load Line Regulations to workboats and base the requirements with greater emphasis on physics and operational requirements.

LIMITATIONS OF PRESENT IMO STABILITY CRITERIA

From the previous section, it is clear that the present IMO stability criteria are totally inadequate, and also do not consider the different operations of workboats which may take place with simultaneous wind, waves and currents. The reaction or forces from the thrusters to counter the environmental forces/moments resulting in additional heeling moments need to be added in the 'weather criteria', along with crane, towing, or manoeuvring operations undertaken by the workboat *(see Figure 5, opposite)*.

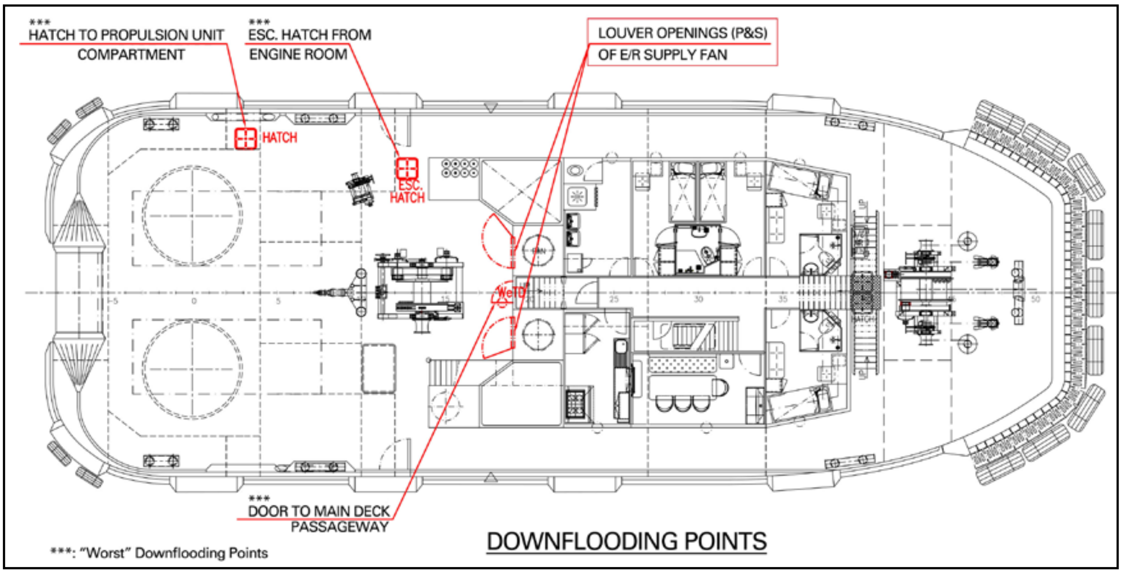

Figure 4: Downflooding points

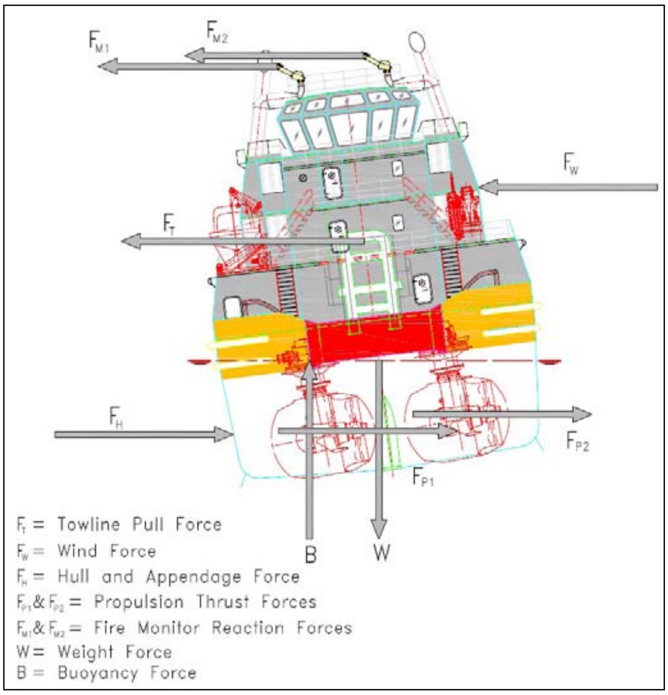

Figure 5 : External forces and heeling moment during tug operations

In addition to the operations which are performed usually at low speeds, on some occasions, the tug performs certain operations at higher speeds.

Reports from a recent tragedy concluded that the major cause of the accident was apparently due to suddenly turning both the thrusters to maximum 'hard over' position while the tug was moving at its maximum full speed ahead during sea trials for a steering test.

Another high speed operation is escorting in both direct and indirect modes. There is adequate awareness of this operation within the industry, and

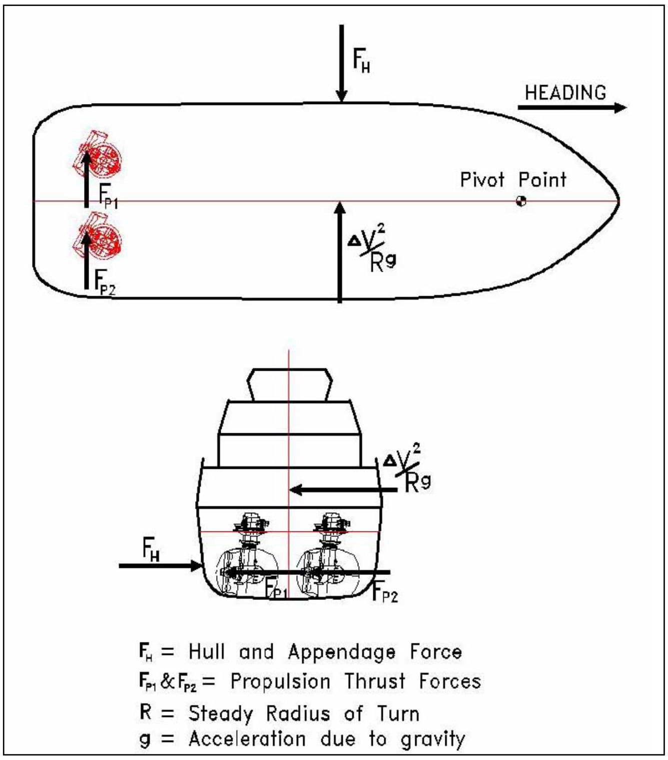

Figure 6: High speed operations – turning

we would greatly appreciate the classification societies recognising this aspect and laying down good and adequate stability guidelines and criteria for escort tugs. These criteria need to be included in the IMO stability measures *(Figures 6 and 7).*

Further, during operations, the watertight integrity may be quite different from the 'as-designed' or 'as-regulated' conditions. For actual realistic operating conditions, a 'worst' downflooding point for those weathertight openings which remain open may need to be considered, and higher sill heights made mandatory

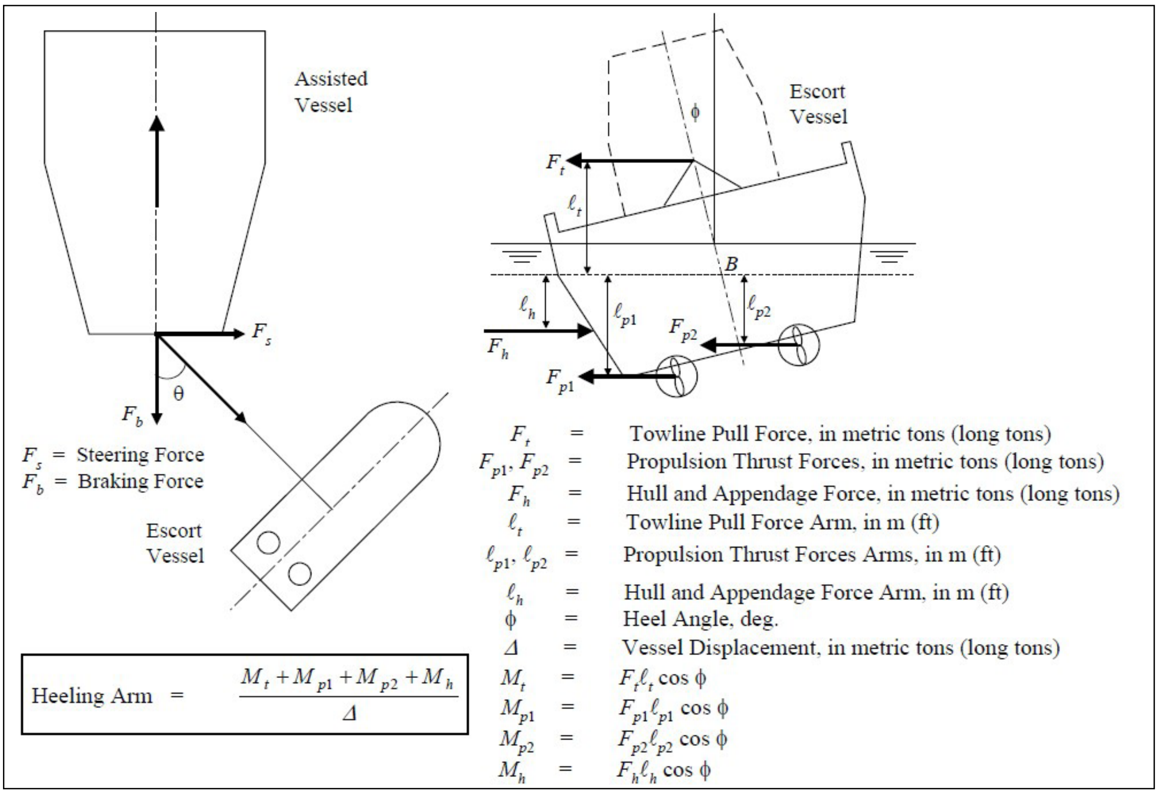

Figure 7: High speed operations - escort

in the regulations. The bar must be raised and additional decision-assist guidance must be provided to the operators to ensure safer tug operations.

OPERABILITY ENVELOPE

For safe operations, a limiting envelope could be provided for the operator's guidance for each mode of operation. Such an envelope will provide the following limits which the operators may monitor closely:

Limiting KG

The limiting KG is the maximum KG complying with a prescribed and applicable set of criteria at a given draft and given sea conditions.

Limiting heel

This is another useful guidance for operators. The heel needs to be less than the angle at which water may flood the vessel through openings left without weathertight closures.

Limiting speed

For higher speed operations, it is essential to advise the operator on the limit speed for safe operations.

Limiting sea conditions during different modes of operations

Perhaps this is the most critical guidance for the operator – limiting sea conditions i.e. the wind, wave, and current limitations where the different operations may be carried out.

RAISING THE BAR

The present regulations for safety and stability need to be reviewed in a holistic manner for workboat applications. This may result in a separate 'code for workboats'. It is appreciated that some classification societies are quite responsive to this proposal and we urge them to continue this work. Ship designers need to take the lead and initiate further research, and together with other stakeholders, prepare proposals for more meaningful requirements for safety and stability, and table these proposals at the IMO meetings.

Ship designers must have representation on the various committees of IMO which deliberate on safety requirements. Stability related information must reach the operator, and the operator must receive adequate training where necessary to full understand the stability requirements. Training standards must be uniform globally for the international industry.

AUTOMATION

Workboat operations are hazardous and dangerous. 80 per cent of accidents have been due to human error. Moreover, manning or crewing is a major cost in all operations. Consequently, more automation and reduced manning would be the logical direction for the future. Automation for operation, monitoring and feedback is essential. However, before we go for complete remotely operated workboats, we would need to develop sufficient intelligence in the robots to equip them to take decisions in unpredictable situations, which, to date, only the human brain is able to do.

CASE STUDIES

Stability investigations were carried out on existing designs of tugs, in order to have a better understanding of the limitations of the present energy stability criteria as applied to tugs, and then identify areas where the criteria may be modified to take better account of the actual operating conditions. The parameters of the five tugs are shown in *Table 3*.

Tug	LOA	LBP	BEAM (MLD)	DEPTH (MLD)	DESIGN DRAFT	BOLLARD PULL
	(m)	(m)	(m)	(m)	(m)	MT
Tug 1	25.80	21.910	9.50	5.00	4.00	40
Tug 2	32.50	24.830	10.50	4.90	3.90	45
Tug 3	28.70	23.800	9.80	5.25	4.35	55
Tug 4	33.00	27.640	11.60	5.60	4.40	65
Tug 5	50.00	42.000	16.00	7.50	5.50	110

Table 3: Principle dimensions of tugboats

Dominant Criteria

Limiting KG values were calculated under four different draft conditions for all the criteria as defined in *Figures 2 and 3 (page 3)*:

1) General stability criteria;
2) Weather criteria;
3) Towing and fire-fighting operations;
4) Turning operations with steady wind of 35 knots.

Criteria or turning operations were as follows: equilibrium heel on turn <10 degree or deck immersion. Investigations revealed a certain pattern in the criteria, which was most dominating at different draft loading conditions *(Table 4)*:

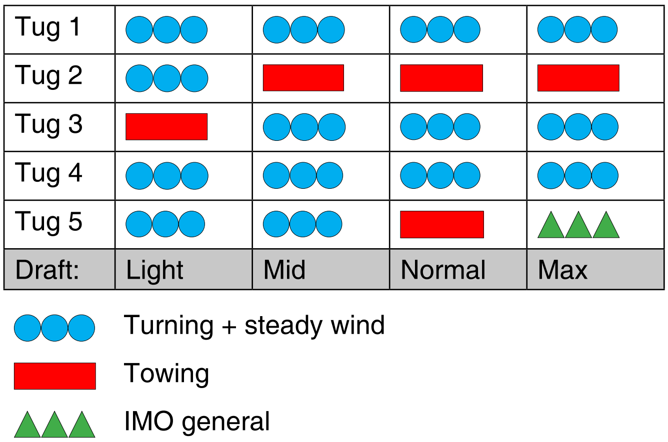

Table 4 : Dominant criteria of tugs under four different loading conditions

Limiting KG Curves

Limiting KG curves were then plotted *(Figures 8 & 9, opposite)* for each dominating criterion for the following cases:

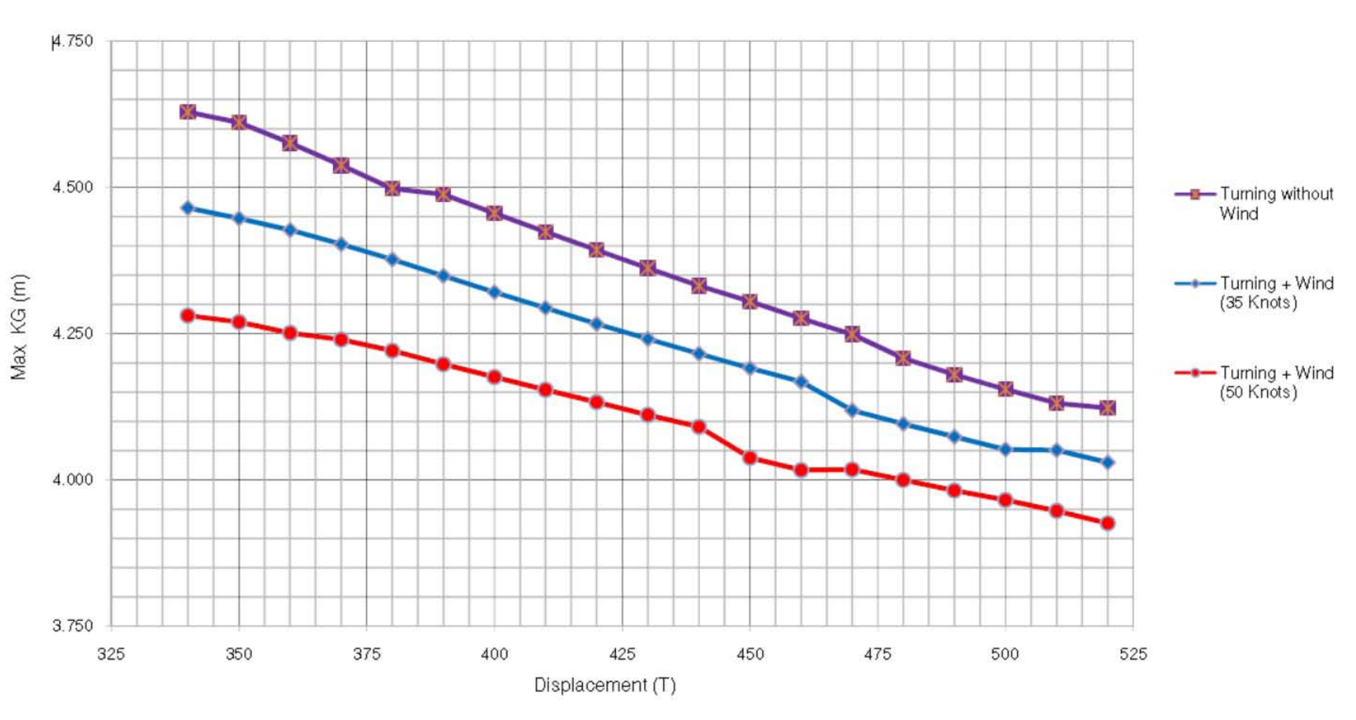

Figure 8 : Limiting KG – dominant criteria – turning

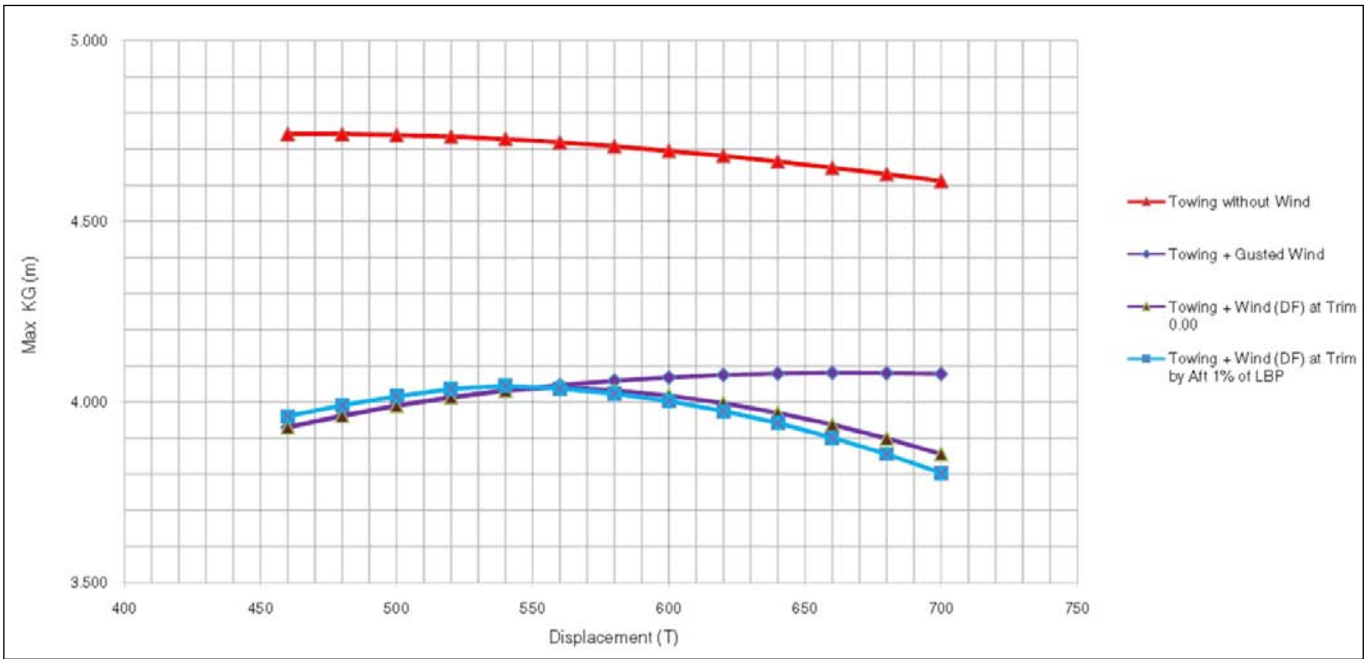

Figure 9 : Limiting KG – dominant criteria - towing

1) Without wind;
2) With wind (35 knots);
3) With wind and 'worst' downflooding (DF) point *(see Figure 9)*;
4) With wind, 'worst' downflooding (DF) point and aft trim 1 per cent of LBP *(see Figure 9)*.

For turning dominant criteria, Tug 1 and 4 have the dominant criterion for all the four draft conditions. Tug 1 was selected because the limiting KG of Tug 1 is lower than that of Tug 4. For towing dominant criteria, Tug 2 was selected as it has this dominant criterion for three of the four drafts conditions. During turning, there is a significant impact with wind and directly related to the wind speed. There is also a significant impact of downflooding point and aft trim on the reduction in the limiting KG *(see Table 5, below)*.

As expected, the most significant impact is on the downflooding point at the highest drafts and aft trim.

Turning		Towing	
Turning with Wind Speed (35knots)	Turning with Wind Speed (50knots)	"Worst" Downflooding Point	With Aft Trim
2.3%	4%	16.4%	1.4%

Table 5: Percentage reduction in limiting KG

CONCLUSION

There appears to be a strong case for modifying the existing IMO criteria to include the following:

- wind, wave and current forces superimposed on the existing criteria for towing, firefighting operations etc
- more fail safe means to ensure external watertight integrity
- definition of downflooding points to be changed to include access openings on main deck
- the effect of aft trim to be considered
- effect of thruster forces leading to additional heeling moments during turning with wind effect to be included.

Training and communication procedures need to be made uniform for the industry to ensure the operator is competent and his knowledge is constantly updated.

For operator's guidance in decision making, easy to use stability advisory tools (software) should be made available with built-in limits from the limiting envelope. The operator should be provided with clear instructions on limiting operating parameters.

Further detailed research would be required, and collaboration with other stakeholders, to analyse further existing designs with inputs from operators on their operational requirements, and finally provide a basis to develop modified stability criteria for workboats. Ship designers should have more direct access to the relevant IMO committees along with other stakeholders to ensure that the safety and stability requirements regulated are realistic and suitable for intended operations. We should not wait for another tragedy to raise the safety standards.

REFERENCES

[1] IMO, 2009, *Report of the Maritime Safety Committee on its Eighty-sixth Session*

[2] Rohr, J, 2003, *Stability Management for DP Platform Supply Vessels*, Dynamic Positioning Committee, Dynamic Positioning Conference Paper, Houston, Texas