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The State of Tug Safety Today

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SYNOPSIS

The early months of 2015 witnessed more than a few accidents involving tugs, and unfortunately also a significant loss of life. Tug power/size ratios and the overall propulsion and winch configurations used today have far exceeded those envisaged when the current rules and regulations for tug stability and other safety considerations were developed, mostly in the early 1970s. This paper looks at some of the issues facing tug safety today and offers some suggestions for avenues of further research and development.

INTRODUCTION

At the 1st International Tug Conference[1] in 1969, there were no less than four papers addressing the specific topic of tugboat safety. At the subsequent 2nd International Tug Conference[2] in London (1971) a further two papers were presented related directly to tug safety. Admittedly, some of these papers wrapped tug safety in rhetoric related to the merits of specific types of propulsion machinery or towing gear, but most importantly these conferences were the first time that people in the industry joined together to freely discuss and debate this critically important topic.

Figure 1 illustrates however that subsequent conferences, at least until about 2010, dealt only sporadically with this issue. It is interesting therefore that, more than a generation later, in the past three conferences there has been a resurgence of focus on this topic (largely related to the subject of SafeTug and the push for harmonisation of Class Rules for tugs). In 2016 there are at least two papers dedicated to this topic. This trend certainly suggests that the topic, for whatever reason, is uppermost in the minds of at least a few. It is hoped that this paper will bring it forward in the minds of many.

The overall safety of tugs can be considered as a triad of highly inter-dependent elements as illustrated in *Figure 2, overleaf*.

At the apex of the triangle is **design**. Without a proper design the other two factors cannot be realised, nor overall safety achieved. The base of the triangle comprises the sister elements of **application** and **operation**. Before selecting any tug for a job the owner/operator must first know if it is a tug which has actually

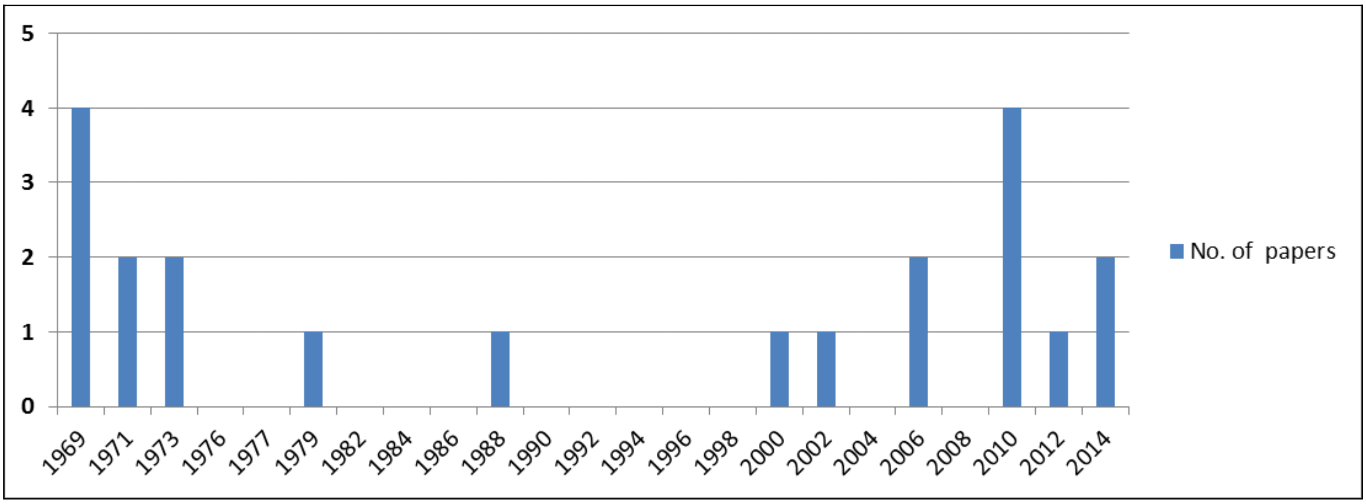


Figure 1: Number of safety-related papers at ITS

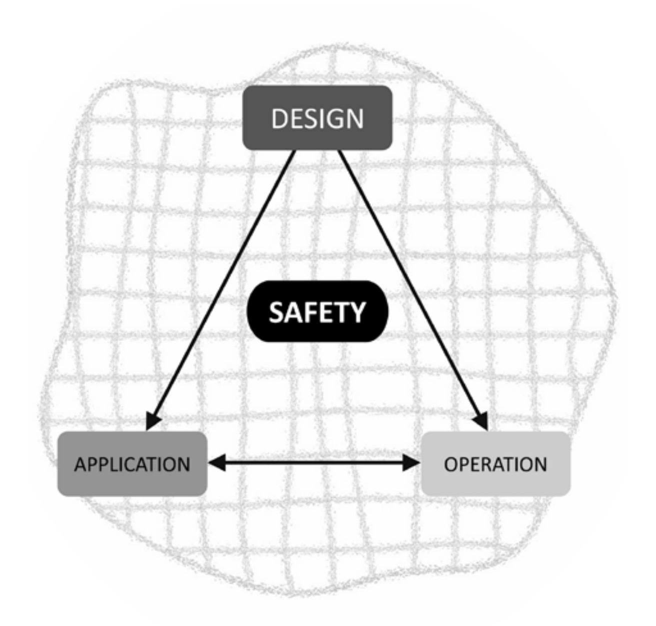


Figure 2: Tug safety depends on three critical elements

been designed for the intended application (ship-assist, escort, towing or whatever) and if so, will the intended operation be consistent with the boundaries imposed by the design and the application. The key constituents (among many) of each of these elements are shown in *Table 1*.

DESIGN	Hull Form Stability Towing Gear Configuration Propulsion Configuration Structural Adequacy
APPLICATION	Ship-Handling Escort Towing Salvage/Rescue
OPERATIONS	Sea Conditions Weather Positional Relationship to Attended Vessel Crew Training Crew Familiarity

Table 1: Constituents of critical elements

Design constitutes all that is required to define a safe tug in engineering terms, but has it been executed with a clear understanding of what the tug is meant to do… or even may do in its lifetime? **Applications** are the 'what' of the equation; what single or multiple specific tasks are expected of the tug and in what range of conditions? Has the **design** fully addressed the demands of each intended use? Finally, **operations** are the 'how'; encompassing the methods of application; where in relation to the attended ship or tow will the tug be deployed, the weather and sea conditions prevailing, and the training and experience of the crew (and especially the master) for each specific task.

Much has been written recently concerning the safe operation of tugs, and by extension to some degree the right application of tugs. Notable on this topic are recent articles by Hensen[3] and van der Laan[4]. However, this paper will focus primarily on those aspects of tug design which most impact overall tug safety, and how the information developed during the design process can be best conveyed to owners and operators to influence the other two critical dependencies. 'Design' encompasses everything within the control of the naval architect, but that cannot be developed without a clear understanding of the risks associated with each specific type of application, of how and where tugs operate in relation to the tow during each type of operation, and finally with consideration of the manner in which the tug may actually be operated.

THE CHANGING FACE OF TUG DESIGNS

In 1970 there were still many single and twin screw, relatively low-powered tugs performing ship-assist work. The concepts for the first Schottel/BCP Z-drive tractor tugs were introduced by Corlett and Bussemaker[5] at the 2nd International Tug Conference, and contemplated tugs from 6.4 to an awe inspiring 54 tonnes BP in the largest (33m) tug of the proposed series. Mr Baer, of Voith fame, in the discussion of that paper, professed "we are now going to build (Voith) tractors up to 15 tons pull and I think this is just enough to handle any size of ship." (It is highly likely that '15 tons' is a transcription error and it really ought to have been 50 tons BP). Regardless of 15 or 50 tonnes, how times have changed! Today a new tug of 50 tonnes BP or less is rare for any ship-handling task in a major port.

The Z-drive tug, and specifically its ASD configuration, has evolved as the dominant tug type of choice worldwide; Z-drive tractors are rare, and VSP tractors have their continued share of devotees. The Rotor®tug[6] initiated the development of a whole range of new ideas about tug design, and ways to do ship-handling with tugs in more efficient (or at least in different) ways is the subject of ongoing conceptual development, including the potential for completely unmanned tugs such as the RAmora concept[7].

Unfortunately, the measure of merit for tugs, at least in terms of their stability and basic safety, has not changed much since 1970. What has really changed is the size of ships and the pace of international shipping and with it the commensurate demands placed on tugs, tug crews and on pilots to move these ever larger and more cumbersome ships into place as quickly as possible. Tugs have grown substantially in power, but not so much in size, at least not in length. Regulations 'pressure' owners to build either under 24m to avoid loadline rules or under about 32m in order to stay under 500grt and thus avoid SOLAS and various more costly manning regulations and licensing requirements. The consequence is packing ever more equipment and power into vessels with relatively short, fat hulls in comparison to the more slender styles of a generation or two ago.

Accordingly, the basis for analysing tug stability by classical methods is certainly no longer valid. We in the design community must be certain that we can assure our clients and their crews of a safe boat, and the owners need to know that the tug they purchase can truly be relied upon to work safely and protect their crews in the roles for which it was intended. If a vessel is used inappropriately it cannot be assumed that safety is assured.

Regrettably, one does not have to look far to find instances of tugs involved in accidents of one form or another. Critically, there have been more than a few tug capsizings recently involving loss of life. The most significant of these was the sinking in China in 2015 of ***Wanshenzhou 67*** *(Figure 3)* with the astounding loss of 21 lives, which most certainly places this amongst the worst tragedies in tugboat history. One can only hope that the real and complete facts of this incident will emerge soon, so that the industry as a whole can benefit from a proper understanding of how such a tragedy could happen with a new vessel.

Figure 3: The capsized tug **Wanshenzhou 67**

In addition, we have witnessed the recent over-running of ***Fairplay 22*** (Netherlands, 2011) the girting of ***North Arm Venture*** (British Columbia, 2009), the ***Bourbon Dolphin*** incident (Orkney, 2007), and the girtings of ***Diver Master*** (Denmark, August 2014), ***Sea Bear*** (US East Coast, March 2015) and ***Asterix*** (UK, March 2015). In British Columbia there was a total of six small tug capsizings or girtings in 2015. These are certainly a statistical aberration in a local industry with generally a very good safety record, but there were common threads to all those losses which fortunately did not involve any loss of life. In the US, the major and recurring cause of tug accidents seems to be the extremely aggressive behaviour of various bridges over the inland waterway system, capsizing towboats and barges with amazing regularity, although coastal towing there is also certainly not immune from incident!

This recent series of losses, statistically aberrant or not, should give us as designers, and in fact everyone in the industry, pause to consider the real causes of such incidents, and more importantly what can be done to prevent recurrences. This call has been made before at these conferences. Gerry Banks, at the *ITS 2000 Convention*[8], challenged the adequacy of the then present rules regarding tugs for escort duty, stating: "...there are instances when the rules become outdated and ineffective simply by the way our operations evolve when we strive to offer solutions to issues raised by our customers or indeed by ourselves. We therefore appeal to the State regulators and others to address this concern now, and not wait for the accident to occur and then react, by which time it would be too late, at least for some."

It is posited in this paper however that it is not to the regulators to whom we must turn for a solution, but to ourselves who best know the industry, the issues, and the challenges.

A COLLECTIVE RESPONSIBILITY

Participants in these important conferences have a collective responsibility to act professionally and co-operatively to address the real concerns about tug safety that arise and which affect all aspects of our industry.

No-one questions that towing can be a dangerous activity, but why is it that in today's world what can only be considered as 'unsafe' vessels are being put into service in such duties? The Chinese tug was running on trials, tripped, capsized, and sank within seconds: "Initial investigations found that it capsized due to 'improper operations'. According to the JMSD, the tugboat operators did not complete the compulsory procedures needed for trial operations, nor did they report the tug's conditions to authorities. The boat sank in the midst of a full circle swinging due to improper handling."[9]

Regardless of whether an 'authority' has seen the condition of the tug or not, how is it possible that a supposedly modern vessel could be designed and built today in accordance with apparently current standards and then capsize just by executing a turn, regardless of how fast or 'improper'?

It is quite fair to say today that this incident is further evidence that the technology of tug design and operations has far outstripped the regulations which are intended to govern vessel safety. It is now almost solely our responsibility as professional engineers and naval architects to ensure that the tugs we design are as safe as they can possibly be for our clients and their operating crews. The limits set by virtually all regulations do not provide a sufficient basis for ensuring safety in tugs today, at least in part because they do not address all of those three fundamental elements discussed earlier.

Unfortunately there are also those who feel that by relying solely on local or even class society regulations for tug safety that all will be well. Even more critically, there are those who believe that by simply just meeting the minimum standards of such regulations that they have designed a 'safe' vessel. Nothing could be further from the truth: undoubtedly that tug will be less expensive than one where significant care has been exercised in every aspect of the design, but is it really suitable for the tasks ahead, especially after a few years of weight growth, etc? Some very serious research is required immediately to ensure a much better understanding of how tugs react to all of the forces encountered in typical operations, which are indeed dramatically different from those of 20 or 30 years ago. It cannot be hoped that flag state authorities will step up to do the research necessary in any reasonable time frame, nor do they typically have the expertise necessary to understand the complexity of a modern tug or even normal tug operations.

A few classification societies have thankfully embraced the concept of harmonised rules for tug design and tug safety, with Bureau Veritas taking a strong lead and doing excellent work to improve safety standards for and aboard tugs. We at Robert Allan Ltd are very pleased to support and participate actively with BV, Lloyd's and ABS in this critically important work.

But should we rely solely on rules to define safety or should we not be acting as serious engineers and doing our very best independently to ensure that every aspect of our designs are as safe as possible? It is almost impossible to develop a completely foolproof design, as designers have no control over the manner in which the vessel will be operated. We can, however, do our best to identify areas of operation where there are serious risks if the tug is mishandled or used in an inappropriate application. We also have today some extremely powerful tools at our fingertips with which to evaluate the 'safety envelope' of a tug and then clearly advise the operator where he may expect to be pressing the margins of safe tug operations.

There is indeed a collective responsibility within this industry to ensure tug safety:

- Naval architects must do their work professionally and responsibly, with a clear understanding of the intended duties.
- Owners must ensure that they fully convey to the naval architects what tasks they expect the new tug to do, and in what sort of conditions.
- Owners must then ensure that the tug is used within those boundaries.
- The builder must adhere to the design and in particular respect the weight and stability characteristics as defined by the naval architects.
- The naval architects must clearly define the boundaries of safe operation for the design.
- The operator must ensure that they are familiar with the limitations of the specific tug and not use it for applications for which it was clearly not intended.

Unfortunately the industry is now in a situation where the ultimate safety of a tug is often left in the hands of the operator. Tug masters today are given extremely powerful, complex and versatile machines to work with, and in many instances have not been given a suitable 'instruction manual' to guide them. At present our engineers are actively working to rectify that situation, and some options for such guidance are presented later in this paper.

OPERATIONAL RISKS

Some of the more safety-critical aspects of tug operations today are described below, as are some ways in which careful and responsible design can be applied to hopefully address the problems:

Ship-handling

The recent losses of ***Fairplay 22*** and ***Diver Master*** illustrate the perennial problem of tugs being over-run at the bow of the ships they are attending. In those cases inadequate stability and an inappropriate choice of an older tug of limited capability for the task were cited by the investigators as contributing causes to the loss of the tugs and crew.

Capt Hensen, writing in *International Tug & OSV* in August 2012[3] described these accidents and several more of the same type, and summarised some of the issues associated with tugs in this mode of operation. He concluded that a tractor tug is the safest tug to use in the bow tug position. However, a well-designed ASD tug that can steer effectively running at relatively high speed astern can also perform this duty equally well, and exercise exactly the same forces as a tractor tug.

The Z-Tech ASD design[10] was developed for exactly this sort of bi-directional operation. Similarly a Rotortug has equal or better capabilities than a tractor in this bow-tug situation. However far too many ASD tugs are badly designed for this purpose and have square, bluff transoms which result in a virtually uncontrollable tug when running astern at any speed, or which build up a large wall of water which then collapses over the stern resulting in the tug burying its stern in the sea, further putting the tug and crew seriously at risk.

Therefore, because there are more than a few very poor ASD tug designs in service, a whole genre of tug type is unfortunately being characterised as inappropriate for this admittedly dangerous task. The designer must fully understand where the safe operational limitations of each design are, understand how the hull they design will behave in all expected operations, and clearly inform the tug owner and the operator about the limits of safe operation in each case in terms of, for example, speed, operating location, yaw angle, heel angles, etc. The owner and the operator must understand and heed that advice.

Powered turns

The ability of some tugs with omni-directional drives to 'self-bury' their decks during high-speed turns or even when running straight astern is another phenomenon which requires careful assessment. It is quite probable that this was a contributory cause of the sinking of ***Wanshenzhou 67***. The fact that some tugs can develop

Name	Date Lost	Location	Length	Beam	Depth	GRT	NRT	Year Built	Age
Harken 10	Sept. 28	Sandheads	14.6	5.94	0.34	9.85	6.7	1992	23
Sea Imp X	Sept. 22	Fraser River	10.27	5.33	0.7	9.36	6.36	1988	27
Ocean Gordon	Sept. 11	Vancouver Harbour	14.54	5.49	0.52	9.61	6.53	1989	26
Hodder Ranger	Jun. 19	Port Mellon	10.21	4.39	1.25	9.99	6.79	1979	36
Syringa	Mar. 18	Sechelt	10.85	3.87	1.65	14.57	9.91	1960	55
The Log Baron	Mar. 15	Cape Caution	10.58	3.44	1.49	12.05	8.19	1962	53

Table 2: Particulars of tugs lost in BC Waters, 2015

sufficient forces to put themselves in precarious positions such as that illustrated in *Figure 4* highlights the need for a careful assessment of the dynamic forces involved in such manoeuvres as part of the basic design process. At Robert Allan Ltd we have long recognised the risks associated with such tug behaviour and in general our hull forms are configured to develop lifting forces during rapid astern and lateral movements.

Figure 4: ASD Tug 'self-burying' during a powered manoeuvre

Unfortunately, this is not a universal design characteristic amongst tugs. When side-stepping or in fast turns, wall-sided hull forms build up water which can collapse over the deck resulting in serious loss of waterplane inertia and a consequent 'dive' under continued application of power. If all closures are not in place during such an event the results can be catastrophic. Such a characteristic is very difficult to analyse, however, and requires a completely different approach to the appraisal of tug stability. The expanding use of CFD within the industry however does provide us with the tool to identify flow behaviour around a hull in such a situation, and then hopefully guide designers to smarter hull shapes. However, as increasingly we see some designs being plagiarised without attention to such details, one cannot expect that all designs will inherit these safety features, even if copied from leading sources.

Barge-handling

In the last few months of 2015, no less than six tugs sank in the coastal waters of Western Canada, mostly with barges or other vessels in tow, the normal modus operandi in those waters. Fortunately no lives were lost (this time!), but there are many common elements amongst the tugs lost that should be a cause for serious concern, not least amongst the many owners locally who operate very similar tugs, and the crews that sail them. *Table 2 above* shows the principal characteristics of the recently sunk tugs:

These small tugs are not typical of worldwide operations, designed as they are to a unique set of local regulations, but it is immediately obvious what they have in common:

1) all are 'under tonnage' – most built to be under 10grt and all built to be under 15grt;
2) the 'rule depth' of these tugs are ridiculously below any realistic value (which would typically be about 2.5m or more).

This 'fiddle' of reduced hull depth was the norm in tugs built before the tonnage measurement rules were changed (about 1997) where 'phony' sheet metal floors were installed to reduce the measured internal depth of the ship. Tonnage measurement surveyors unfortunately accepted this subterfuge as legitimate. The other common factor among these tugs is the distinct lack of freeboard, as evidenced by the following photographs *(Figures 5a, 5b, 5c and 5d)*:

Figure 5a: Small coastal tugs of BC with extremely low freeboard

Figures 5b, 5c, 5d: Small coastal tugs of BC with extremely low freeboard

In each case shown above the minimum freeboard appears to be about 100-150 mm at best.

Because of their artificially small size, measured by GRT, all the subject tugs were (at the time of build) uninspected under the Canadian regulations. Thankfully, in about 1997 the tonnage measurement rules were changed to the international standard, so such small tugs can no longer be built to achieve these regulatory hurdles. They do however continue to operate! These tugs were built to avoid various limits in the Canadian rules pertaining to vessel inspection requirements and crew licensing requirements. One could state fairly that the rules gave rise to a generation of marginally safe vessels. This subject was covered in more detail in a recent article by this author[11]. This is but one example of how regulations can give rise to potentially poor designs without adequate margins of safety for long term operations. One can see even more examples of this sort of situation amongst the world's fishing fleet.

There is no requirement in Canada, nor seemingly in any other jurisdiction, for ANY vessel to update its stability information beyond the initial certification, unless it is significantly altered. The inference is that the rules assume no weight growth or weight shift in the boat within its service life, whereas almost all in the industry know the opposite to be true. As weight increases, as it universally does (on tugs as well as on humans!), stability is adversely affected. Can it be assumed that the issue at play in the above incidents is in fact simply one of weight growth? It is intuitive and fair to assume that these under-tonnage tugs with low freeboard had a very low margin of stability beyond the regulatory minima even when built, so it is quite conceivable that after 20-30 years of operation the safety margins inherent in the rules have been eroded. Couple that loss of safety margin with the potential impact of external towing/girting forces (not considered in the regulations) and capsizings are regrettably quite predictable. Is it responsible to design to such low margins without considering the long term effects? Should regulators not be raising red (or at least 'amber') flags when margins are so low on new vessels?

Owners cannot really be blamed for trying to take maximum advantage of rules which have been put in place, supposedly for their safety, but when the net result is a set of vessels which are inherently less safe than their slightly larger cousins, is it surely not time to question the efficacy of those rules? Although one might argue that as these vessels have been working for many years they must be safe, the counter-argument is that the degradation of stability is an inexorable, constant process and every day of operation represents a further step in the loss of margins of safety. At the very least the ongoing compliance with original regulations ought to be monitored and demonstrated.

The above-mentioned incidents aside, recent incidents of tug loss while barge-handling are thankfully still relatively rare, but the well-documented girting of ***North Arm Venture*** in Skookumchuck Narrows, north of Vancouver *(Figure 6* and www.youtube.com/watch?v=JgC2SOQNCTk)2009) illustrate graphically how large overturning forces can develop quickly and cause a girting.

Figure 6: Girting of tug **North Arm Venture** *in strong current*

The absence of any towline pull criteria for tug safety in the Canadian regulations is (or at least should be!) a longstanding embarrassment to that country. Designers must be aware of the potential for such incidents and use the best tools available to make tug designs as capsize-resistant as possible. One cannot design against the 'irresistible force' (such as a runaway barge over-riding the tug), but one must pay attention to the relative position of thrust and towing points and understand how tugs operate in this type of barge-handling operation.

In addition, as described by the Captains Livingstone in 2012[12], guidance and training should be provided to tug masters about how a tug could be most safely handled in the full range of operating circumstances, especially in this sort of potential tripping scenario. All of this information must go well beyond providing the basic stability data required for regulatory compliance.

It is also important to continue to hammer away at the regulatory authorities who put such regulations in place without a full appreciation of the potential impacts on safe operations.

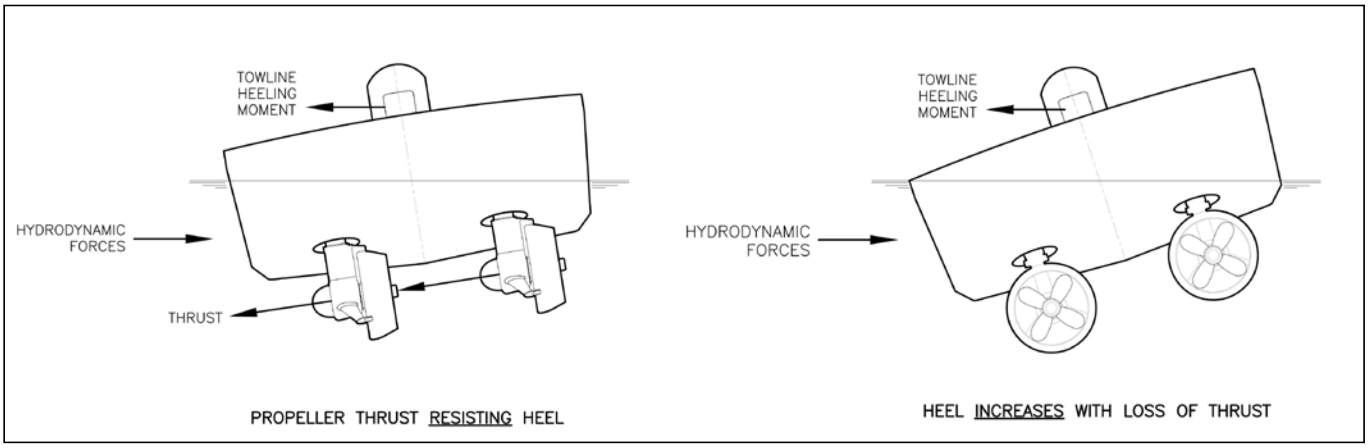
Ship escort

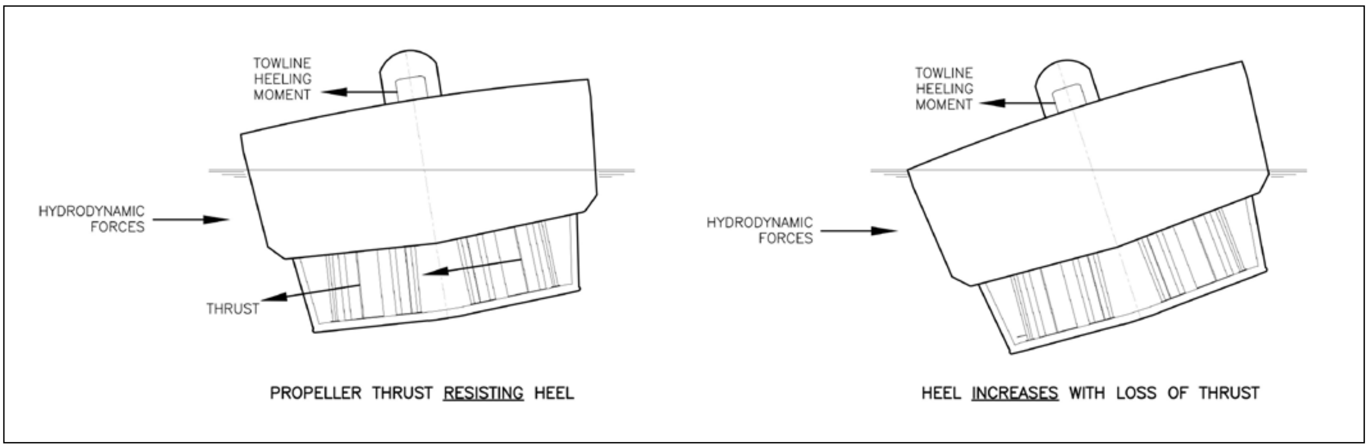
The forces exerted on a tug during escort operations are definitely the highest conceivable for a controlled 'design condition' representing intended operations. The tug is deliberately heeled over to a relatively large angle and is expected to sustain a high lateral load for the duration of that operation.

It is important to remind ourselves that barely 25 years ago such an intended operation had never been contemplated with tugs. The dynamic loads in this operation, which are imposed by sea-state or by small changes in thrust, yaw and heel must also be accounted for, but are not simple to predict. The presence of an auto-rendering winch is intended by regulation to be the safety valve which prevents an overload (of excessive heeling force) in such a situation.

However, failure to use this device properly, such as locking or bypassing the rendering function, will jeopardise safe escort operations. With the high forces involved and the fact that during indirect operations thrust becomes a significant component of the stability equation, the potential for a sudden change in righting moment due to loss of or even an application of thrust needs to be carefully assessed.

Understanding how to establish a 'fail-safe' configuration of design is critical to ensuring that in the event of a failure of a propulsion unit there is no chance that the tug could be tripped. The stability of tugs in escort mode needs to be assessed much more rigorously than it is at present, taking into account the dynamics involved in all modes of operation, especially where thrust is providing a significant righting component. *Figures 7.1-7.3, below and overleaf*, illustrate how propeller thrust is accounted for in typical escort operations for a range of propulsion configurations, and what the stability impact is when that thrust is dropped suddenly.





Figures 7.1 and 7.2: ASD Tug (top) and VSP tug (bottom): Loss of propulsion causes sharp increase in heel

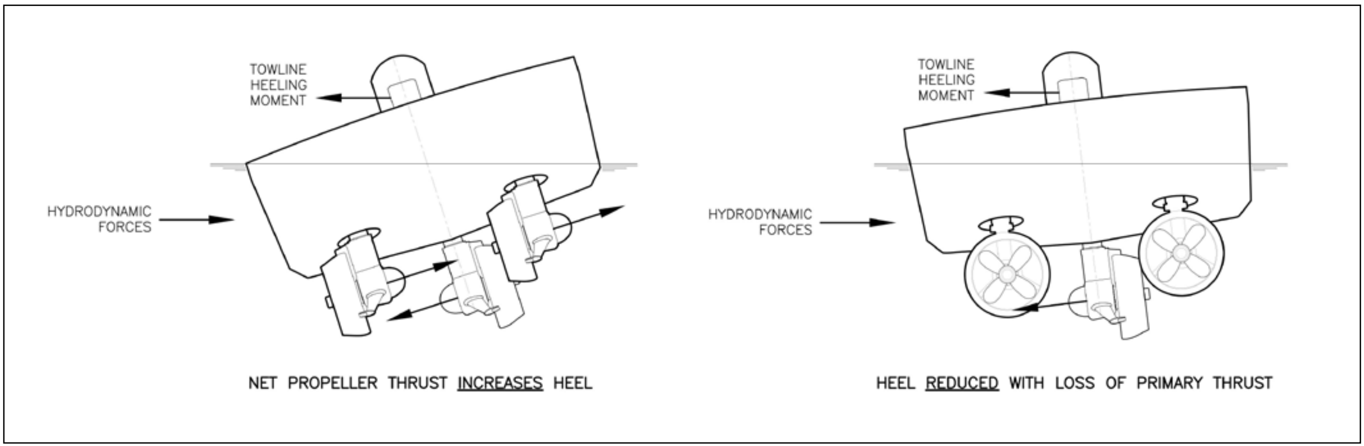


Figure 7.3 Rotortug: Loss of forward propulsion causes a sharp reduction in heel

The lack of freeboard indicated in many tugs engaged (perhaps inappropriately) in escort operations is also alarming. A plethora of photos *(eg Figure 8)* exist on the internet illustrating so-called 'escort tugs' with their decks completely awash, a situation which ultimately could result in another fatal incident.

Figure 8: Tug with low freeboard engaged in escort towing, burying its decks to the extreme. Can this really be considered 'safe'?

Critical to understanding this issue is the fact that in the vast majority of cases tugs are capable of generating towline forces which exceed those permissible for compliance with the escort stability criteria of classification societies. When these are steering forces with a high lateral component, the heeling forces on the tug are high and the ultimate safety of the tug is then almost entirely in the hands of the master. When the forces have a large braking component, which is typically the highest force which can be developed in escort towing, then typically the tug is more longitudinally aligned to the towline, and the heeling forces are less.

Figures 9 and 10 illustrate a typical force envelope for an ASD tug; the former representing the overall force-generating capabilities of the hull, and the latter representing what is available within the allowable stability criteria limits. The red-shaded areas in *Figure 9* therefore represent what can be considered as an 'Excess Fs' zone, and a tug master needs to understand the potential implications of working there. Hopefully he will instinctively recognise when working with decks awash, and that this represents an undesirable (or at the very least a 'cautionary') condition.

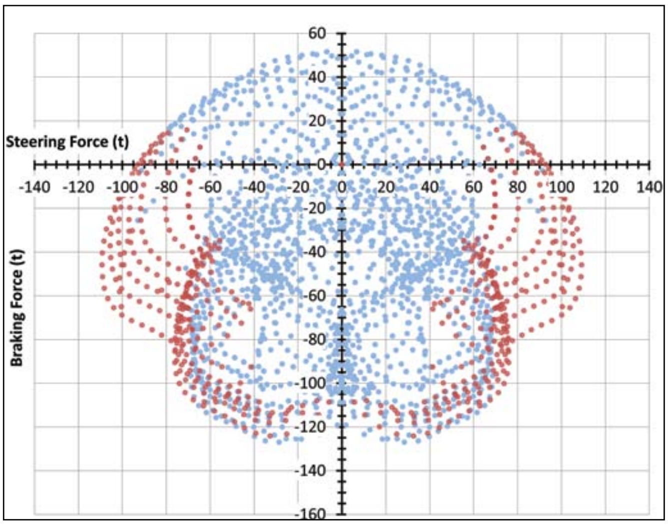


Figure 9: Force envelope for a typical ASD Tug – overall force-generating capacity

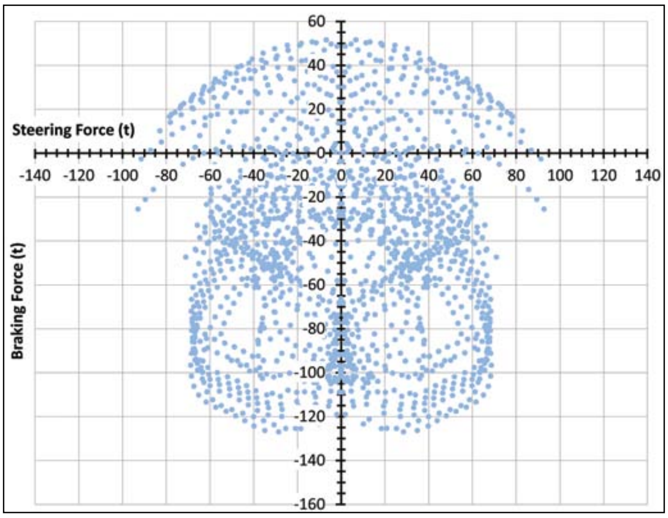


Figure 10: Force envelope within allowable stability criteria limits

A tug is not necessarily immediately imperilled when it moves into the Excess Fs zone, but the master must be aware that he is at least in a cautionary zone where his actions will have increasingly significant consequences, and a wrong reaction might be dangerous.

In the design process it is the naval architect's responsibility to evaluate the force-generating capabilities of the escort tug hull and appendages, and then to provide a hull form with the stability characteristics to support those forces, all ideally within the limits of the class stability criteria. However, since not all rules are yet equal in their requirements for escort stability, then not all tugs are created equal, even though they may appear to have equivalent 'approved ratings'. The accurate prediction of escort forces remains a complex engineering task, and until the recent advent of readily available CFD – or at least the use of a comprehensive model test – the escort forces generated by any specific hull form could not be predicted with great accuracy. *Figures 9 and 10, above*, represent what can happen when a tug, not necessarily designed for escort duties, is used in that service. The tug may well be able to generate high steering forces (especially when the deck is immersed) but is unable to balance those with sufficient stability. The photograph in *Figure 8, above*, represents just such a case.

So how, as an industry, should we move forward to ensure that tugs are truly safe, both for the crews that work them and for the clients that own and use them? With the growth in power/size ratio of tugs over the last two decades it is fortunate that in most cases added beam has been the only saving grace. But just creating 'fat boats' is not the real answer to many of these safety issues. Much more extreme measures are required in understanding and analysing tug escort stability.

REGULATORY ISSUES

The recently published tug safety guidelines from Bureau Veritas[13] reflect a major and important step towards a more rational and service-based approach to tug stability. The proposed rules for tug stability at least address the relative advantages of tractor tugs, Rotortugs or ASD tugs where the thrust points and towing points are separated by a substantial longitudinal distance. Unfortunately the rules do not identify exactly what constitutes an acceptable separation and it is conceivable that the unscrupulous 'rule-bender' may insist that because there is (say) just one metre of longitudinal separation then that vessel should be given the appropriate credit. One really needs to understand the dynamics of how each individual tug behaves under the influence of a line pull which generates yaw and heel simultaneously, when applied either gradually or suddenly, and also what happens when one of those forces (towline or propulsion) is suddenly interrupted.

ABS (who since 2013 have somewhat mystifyingly included the requirements for escort tugs under Offshore Support Vessels[14]) have recently defined a broad scope of requirements for escort towing stability:

> *The vessel is to comply with the requirements of Appendix 5-3-A3 with the following quasi-steady factors accounted for:*
>
> *i) The stability analysis is to consider all potential attitudes of the escort vessel relative to the direction of line pull, the maximum line pull, and the resultant combination of heel and trim on the escort vessel.*
>
> *ii) The stability analysis is to include the effects of skegs and other appendages on both the reserve buoyancy and the lateral resistance of the escort vessel.*
>
> *iii) The stability analysis is to include the contribution to heel and trim of the propulsion system in conjunction with maximum line forces.*
>
> *iv) The stability analysis is to include an evaluation of the reaction of the escort vessel to an instantaneous release of the line forces, and the propulsive forces.*
>
> *v) A heel angle limit is to be established. Forces acting on the escort vessel, including the conditions noted under item (iv) above, are not to submerge the deck edge.*

The implied scope of analysis is laudable, but the question is how to actually do such an extensive analysis in an accurate and meaningful manner. Then, perhaps more importantly, how do we convey that information to the man driving the tug? How will Class verify that the analysis submitted in support of these requirements is indeed accurate? Only a highly detailed model test program and/or extensive CFD analysis can hope to provide the answers which will satisfy these criteria, and it must be done individually for each tug design, and maybe even for each vessel in a series, as weight and GM are seldom identical even for sister vessels. So the cost of addressing tug stability to the full degree of detail implied in these rules could rise from something around US$10,000 to well in excess of US$100,000! (Did that get your attention?)

Our company is presently evaluating ways in which to accurately address item (iv) of the list above: the impact of a sudden loss of towline or propulsive forces, which is the most difficult of these new criteria to analyse accurately. This analysis determines how roll angle and yaw angle change dynamically in relation to each other and in relation to time in the moments following such an event. Figure 11 illustrates the output of this form of analysis for a nominal escort vessel design. It is important to note that this particular analysis was executed to prove the veracity of the analytical method, rather than representing a specific vessel, so the graphic is illustrative only.

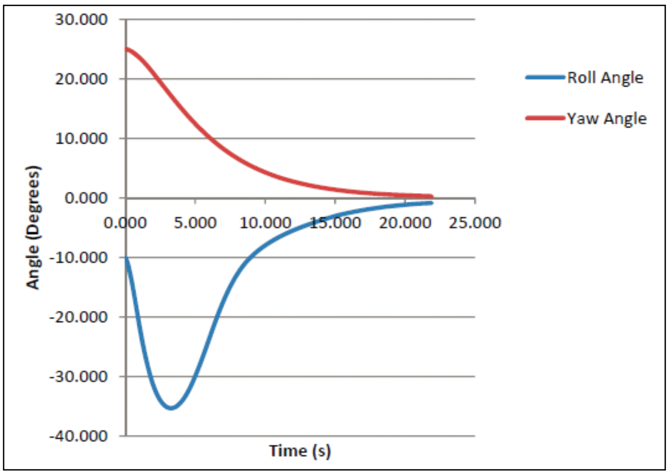


Figure 11: Typical roll and yaw characteristics of a tug under sudden loss of power

The analysis illustrates that it takes relatively little time to yaw, returning to the axis of the applied force. Roll is quite different, as the vessel starts at a typical escort heel angle of about 12 degrees, then responds dramatically to the loss of righting force, heeling quickly to a high angle and then gradually and uniformly degrading to close to an upright position as yaw increases. The high energy effects are all effectively concluded within the first 15-20 per cent of the elapsed incident time. But what does this mean in terms of tug safety? A typical righting lever curve *(Figure 12)* shows that as long as the down-flooding points are outside that maximum dynamic heel range then the tug should have more than sufficient righting energy to be safe (assuming the heeling force has been released!). But what happens to the crew in those first few seconds? The associated accelerations can be very high, so the potential for injury is also very high.

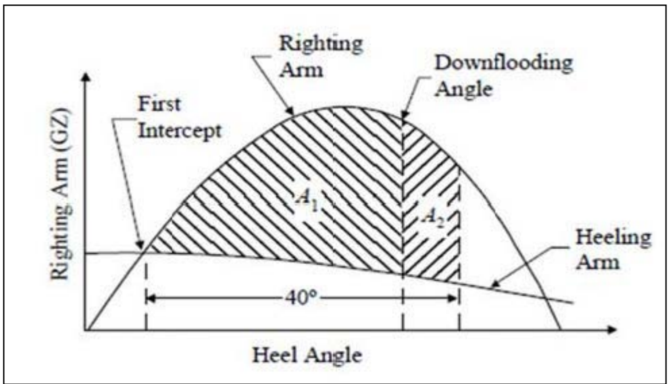


Figure 12: Typical GZ curve with a heeling arm

Being heeled over from 25 degrees to 35 degrees in very few seconds is undoubtedly a scary proposition, especially if totally unexpected, and the reactions of the crew in those moments could be critical to the ultimate safety of the tug. Also note, most critically, that this indicated amount of heel would fail the associated ABS criteria (v) above, which requires that the maximum heel angle under this action must not exceed the angle of deck edge immersion. It is submitted that compliance with that criteria under real dynamic forces is very likely impossible, even with extremely capable and very stable tug designs. So here is a new and recently imposed regulatory criterion which is highly difficult to analyse and which to all intents and purposes cannot be satisfied by what are known to be very capable and seaworthy tugs.

However, if one addresses this requirement by a simple quasi-static, balance of moments method (which is the presently agreed procedure) it can be demonstrated that the resultant heel angles stay within the required angle of deck immersion. Clearly this is a significant discrepancy in results which requires resolution. One must wonder if a detailed analysis underlies the imposition of such a criterion or if it is merely a desired outcome. The development of such a set of criteria, without any apparent review with industry, results in exactly the rather irrational and inequality of regulations within class societies which was argued against by this author at *ITS 2006*[15]. If such rules are followed accurately, analysing the real dynamics of tug motions, the net result will likely be that owners will avoid that class society in favour of other classes which do not impose such a complex requirement, with its attendant high costs. That is not a highly desirable outcome as these rules at least have identified the need for more extensive analysis.

FOR THE GUIDANCE OF THE MASTER

It is known that a certain amount of training in ship stability is part of the curriculum for tug masters. But it is not apparent that this training extends to the details of escort towing in particular, and maybe not even to the stability of tugs during more conventional line towing and ship-handling operations. Undoubtedly the vast majority of approved stability books languish in a drawer under the chart table for the life of the tug, and those are not likely to contain anything about the specific limitations of the vessel. Appendix A is an example of the sort of generic language which is presently required by most class societies and likely by the majority of flag state authorities for inclusion in stability books, and is in all likelihood very similar to what appears in 99 per cent of documents today.

It is the responsibility of the designer to ensure that, to the maximum extent possible, the envelope of safe operation of every tug is carefully examined and then described to the master (and his employer) in terms that are readily understood, and ideally clearly graphically illustrated. This should be in the form of a document independent of, but obviously related to the stability book, which could be described as *Guidelines for Safe Operation of Tug 'x'* (or similar). It must be tailored to each individual tug in accordance with the results of the complete stability analysis covering all intended operations.

The recently published *Guidelines for Safe Harbour Towage Operations* published by the European Tugowners Association[16] is an extremely helpful reference in this regard, but it is an industry-generic document. Robert Allan Ltd is in the process of developing as a high priority a template for a new form of document which will ultimately be provided with each of our designs to provide tug masters with the maximum amount of information possible concerning the safe operation of their specific tug. Some of the features of this document (in this case specifically for escort tugs) will be the following:

1. Limiting heel angles during escort operations;
2. Limiting towline angles for escort;
3. Notes about equipment load ratings;
4. Descriptions of tug reactions under equipment failure;
5. Impact of speed on towing forces;
6. Effect of tug draft and trim (load condition) on escort forces;
7. Directional stability characteristics

In addition to this, we strongly advocate for the inclusion of, as standard outfit in tugs, and particularly on escort tugs, of an electronic heel alarm, such as that illustrated in *Figure 13*. A simple pendulum or bubble type inclinometer lacks the resolution at the relatively small range of angles involved to provide clear visual and audible triggers to the master. The electronic type of device could easily be programmed to indicate three zones of heeled-over operation, which could, arbitrarily, be set to the following:

- Green: anything up to the angle required by Class for approved escort operation;
- Amber: angles beyond the regulatory limit but where the dynamic (rather than sustained) stability characteristics are still safe;
- Red: angles of heel beyond which the margins of safety for dynamic operation are not sufficient.

The exact break points for these zones needs further analysis and will obviously differ for every tug. The heel indicator must therefore be easily programmable on installation in each individual tug.

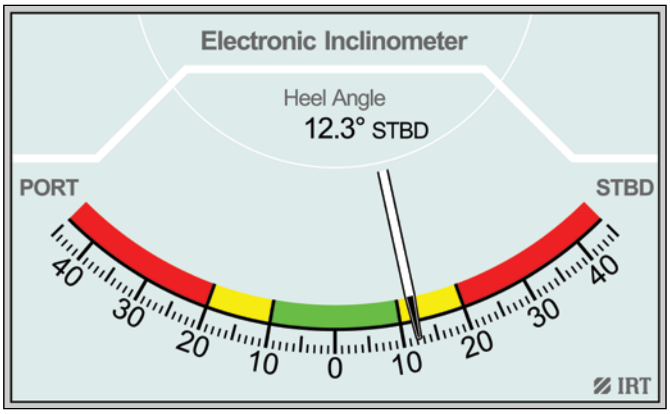


Figure 13: Example of an electronic heel alarm
Image: Daniamant Electronics A/S DanEI-300 Inclinometer

These are all critical issues. The industry has so far been able to largely avoid any serious incidents with escort tugs, but it is clear this may simply be a matter of good fortune as inadequate, (or at best inappropriate) tugs are being assigned to this onerous task. When the tug industry is regularly challenged to assure tanker owners that tugs can be provided which will save their ship from grounding in extremis, and they see examples of so-called escort tugs with their decks completely awash, how can they (or by extension the many detractors of oil shipments of any kind!) be expected to believe that these are capable tugboats, and by extension that we really know our business? The dynamic response of tugs in these critical scenarios needs further investigation and as an industry we must strive to achieve a truly common understanding of what form of analysis is necessary to prove that a tug is indeed as safe as possible. Then we need to agree on how to accurately and fully convey that information to the tug master so that he can work his tug as fully and as safely as possible while still knowing how far he can push the envelope.

This paper does not offer all the answers to these critical issues, but hopefully it raises many critical questions and suggests some ways in which to move ahead to establish defensible safety and stability criteria and the associated operational safeguards.

As designers and engineers we will continue and strengthen our commitment to the design of truly safe tugs, for all reasons. Owners and operators must also join in this effort to be certain that the tugs of tomorrow (and indeed the many of today!) are indeed as safe as they can possibly be.

APPENDIX A

Typical current tug stability book language:

Compliance with the stability criteria does not ensure immunity from capsizing, nor absolve the master from his responsibilities. The master should therefore exercise prudent judgement and good seamanship having regard for the season, weather forecast and navigational zone; and should take the appropriate action as to speed and course depending on the prevailing circumstances.

Before a voyage commences, care should be taken to ensure that any sizeable pieces of equipment have been properly stowed and/or lashed, to minimise the possibility of both longitudinal and transverse shifting due to rolling and pitching accelerations while at sea.

A ship, when engaged in towing operations, should not carry deck cargo, except that a limited amount, properly secured, which would neither endanger the safe working of the crew on deck nor impede the proper functioning of the towing equipment, may be acceptable.

The number of partially filled or slack tanks should be kept to a minimum due to their adverse effect on stability.

When actual loading conditions differ from those included in this stability booklet, calculate the vessel's stability to assure that an adequate margin of safety is maintained with respect to compliance with the minimum regulatory requirements.

REFERENCES

[1] Proceedings of the *1st International Tug Conference* 1969

[2] Proceedings of the *2nd International Tug Conference* 1971

[3] *Safe Tug Operation: Who takes the lead?*, Capt Henk Hensen, *International Tug & OSV*, July/August 2012

[4] *Safe Tug Operation: A Naval Architect's View*, van der Laan Dr M, *International Tug & OSV*, January/February 2013

[5] *Tractor Tug Family Fitted with Rudder Propellers*, Corlett Dr E C B & Bussemaker Ir O, *2nd International Tug Conference*, London, 1971

[6] *Rotor Tugnology*, Kooren T, Quadvlieg F, Albers A, *ITS 2000* Jersey

[7] *Revolutionary RAmora Brings Teleoperated Capability to Ship-handling Tugs*, den Hertog V, and Lisagor Dr O, Robert Allan Ltd, Canada

[8] *Safety versus Performance*, Banks G, *ITS 2000* Jersey

[9] *22 Dead after Boat Capsizes in East China*, Sina English News, 17 January 2015 (and various other sources) citing Jiangsu Maritime Safety Administration (JMSA)

[10] *The Evolution of the Z-Tech Concept*, Allan R G, *ITS* 2008 Singapore

[11] *The Safety of Tugboats in BC*, Allan R G, *Western Mariner Magazine*, December 2015

[12] *Girting/Tripping*, Livingstone Capt George & Livingstone Capt Grant, *ITS 2012*, Barcelona

[13] *Safety Guidelines for Design, Construction and Operation of Tugs*, Bureau Veritas Guidance Note NI 617 DT R00 E, July 2014

[14] *Rules for Building and Classing Offshore Support Vessels, (Part 5, Ch13, Sect 4, Intact Stability)*, American Bureau of Shipping, 2014.

[15] *A Proposal for Harmonised International regulations for the design and Construction of Tugboats*, Allan R G, *ITS 2006* Rotterdam

[16] *Guidelines for Safe Harbour Towage Operations*, European Tugowners Association, February 2015