ON THE SAFE PILOTAGE OF SHIP'S WITH PROPULSION THAT CAN AZIMUTH FOR STEERING

(DOI No: 10.3940/rina.ijme.2015.a1.282)

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SUMMARY

From the thrusters on smaller, but numerous, harbour support vessels through to the pod-drives on cruise ships and ocean going liners, azimuth control has rapidly established itself in the maritime industry. From the design of the ship, to the training of personnel and the development of operational procedures, the industry has risen to meet the demand. However, this rapid evolution has not allowed sufficient time for the propagation of knowledge throughout the different disciplines. On a day-to-day basis, maritime pilots must deal with such ships, coping as they do, with an as yet unstandardized environment. This paper presents the findings of an EU project (AZIPILOT) considering accidents and incidents and concerning the training and operational practice of ships equipped with Azimuth Control Devices (ACD's).

1. INTRODUCTION

The content of this paper reports on the findings of a project; which tackled the problem by bring around the table representatives form four key industry sectors; specifically:

- Hydrodynamic Modelling specialists;
- Marine Simulation (hardware and software) manufacturers;
- Maritime Training facilities (computer simulation and manned model facilities)
- Operational Practitioners including maritime pilots, ship operators/managers, pilot association and end-users.

In total 15 partner organizations participated in the project, aided by a wide variety of industry experts; interacting through a project Advisory Committee. The aim of this paper is to bring together relevant knowledge, through a process of review, surveying maritime personnel and by interviewing subject experts. The study focuses on three areas;

- Existing recommendations, criteria and their application;
- Existing operational practice;
- Accident and incident reports.

The objective is to identify critical shortcomings and thus map out the landscape for future research, training, higher education and policymaking.

1.1 TECHNOLOGY OVERVIEW

There are various different types of ACD that may include: electric azimuthing pods; mechanical thrusters; Voith propellers; pump jets. In addition these devices may have various configuration that may include having either pushing or pulling propellers (or both), accelerating or decelerating nozzles, be in contra-rotating configurations and may include a variety of forms of control flap. Also, examples are found where the unit is on the opposite or both ends of the vessel. This might include double ended ferries (with an ACD at each end) or a double-acting tanker (which goes astern in ice effectively placing the ACD at the front). It is identified that while each of the above may have its own subtle variations they all have a commonality in that they steer the vessel by producing a force that can be applied in any horizontal direction. From the point of view of the operator, this makes a clear distinction from the more conventional propeller and rudder combination. The work in this paper focuses on how this distinction effects the application and validity of specific criteria and the safe operation of ships equipped with ACD's.

2. EXISTING RECOMMENDATIONS, CRITERIA AND THEIR APPLICATION

The Member states of the International Maritime Organisation (IMO) use the Organisation to agree standards covering all aspects of maritime safety, security and pollution prevention for international shipping. The main instruments considered herein are:

- The Standards for Ship Manoeuvrability, MSC.137(76);
- Provision and Display of Manoeuvring Information On Board Ships, [Annex of] Resolution A.601(15);
- The Safety of Life at Sea convention (SOLAS);
- The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW).

2.1 IMPLICATIONS FOR THE STANDARDS FOR SHIP MANOEUVRABILITY

The IMO manoeuvring criteria, MSC.137(76), are a well known and documented set of trials that strive to prevent the building of ships that do not meet the criteria. In this, they are clearly not presented as an optimum but more as a minimum safe limit. The criteria include the four well know tests for: Turning Ability; Initial Turning Ability; Yaw Checking and Course keeping Ability; Stopping Ability. Woodward [1] suggests that the performance limits proposed by the IMO criteria should not be any different for ACD ships. They provide (as they stand) a suitable minimum operational envelope; outside of which ships would be unsatisfactory. However, the paper draws into question the specified application of helm angle; which has no direct comparison with ACD's (maximum rudder angles are not applicable when 360 deg. vectoring is available). Nevertheless, the conclusion of the paper finds that applying the criteria like-for-like makes an entirely equivalent evaluation of performance; vindicating the direct use of the criteria for ACD ships. The crash stop appears on face to be more complicated as it can be performed in alternative ways. However, the IMO required manoeuver is found to be by far the least effective option, and is thus considered a good means to prevent the building of ships that are unsatisfactory.

2.2 IMPLICATIONS FROM SOLAS

SOLAS is generally considered to be the most important of all international treaties concerning the safety of merchant ships. The full text of SOLAS was interrogated within the project to identify relevant items. Topics covered do include safety of navigation, however no specific item is found that relates to ACD's.

2.3 IMPLICATIONS FROM STCW

The 1978 STCW [updated 2010] places the emphasis firmly on demonstrating competence, rather than simply undertaking training. Again, the text was interrogated to identify relevant items. As with SOLAS, STCW contains no items specifically relating to ACD's. However, it does invite the introduction of specialised modules to complement training needs. This fits very well with the motivations of this study as it provides a potential foundation for any proposed ACD training programs.

2.4 RELEVANCE FOR CLASSIFICATION SOCIETY RULES

While some classification societies have developed rules for ACD's, they are related to structural arrangements and strength. In some cases a rule derived for rudders is being applied to ACD's. The rule requires that the power and torque capacity must be such that a rudder can be swung form 35^{o} one side to 35^{o} the other side with the ship at maximum speed, and also that the time to swing from 35^{o} one side to 30^{o} the other side must not exceed 28 seconds. Actual, this test is intended to qualify the strength of the rudder-stock and was not derived as any measure of the steering response. If applied to large ACD's (such as electric pods) it would impose an inappropriately high slew-rate, which could lead to spike loads [2].

2.5 MANOEUVRING INFORMATION ON BOARD SHIPS

The IMO provides recommendations for 'Provision and Display of Manoeuvring Information On Board Ships'; specified within the Annex of Resolution A.601(15). This includes the 'Recommendations on the Provision and the display of Manoeuvring Information on Board Ships'. Figure 1 provides relevant extracts from the resolution. Considering Figure 1 (a), by implication it would appear that all ships over 100 meters should be furnished with all three pieces of information (pilot card; wheelhouse poster; manoeuvring booklet). However, it should be noted that IMO does not carry the authority to police such implementation; this is achieved through such actions as SOLAS. The implementation of the recommendations is the responsibility (and to some extent, to the discretion) of the national Administrations (Flag State Control). To this extent item 2.1.1 is [implied as] required under international law as it refers to SOLAS. On the other hand, item 2.1.2 may be implemented at the discretion of the relative

(a)	*2.1*	*The Administration should recommend that manoeuvring information, in the form of the model contained in the appendices, should be provided as follows:* *.1 for all new ships to which the requirements of the 1974 SOLAS Convention, as amended, apply, the pilot card should be provided;* *.2 for all new ships of 100 meters in length and over, and all new chemical tankers and gas carriers regardless of size, the pilot card, wheelhouse poster and manoeuvring booklet should be provided.*
	2.2	*The Administration should encourage the provision of manoeuvring information on exiting ships, and ships that may pose a hazard due to unusual dimensions of characteristics.*
	2.3	*The manoeuvring information should be amended after modification or conversion of this ship which may alter its manoeuvring characteristics or extreme dimensions.*
(b)		*"The manoeuvring characteristics may be determined by conducting special manoeuvring trials or by computer simulation techniques or by estimation".*

Figure 1. Extract from IMO Resolution A.601(15)

Administration. It should also be noted that 2.1.1. is for *all new ships to which the requirements of the 1974 SOLAS "apply"*; and, strictly speaking, not the SOLAS convention itself. In fact, no mention of the Pilot Card appears in SOLAS; meaning that it is at least feasible to neglect even this if the nations Administration so wishes. From Figure 1 (a) it may appear that all Administrations could (in theory) chose not to implement this recommendation; making the resolution somewhat redundant. Nevertheless, there are other influential factors that may stimulate implementation. Firstly, for a ship to meet Class, the Classification Society concerned will undoubtedly require compliance. Secondly, the owner of a new vessel may request compliance of certain recommendations as part of the specification of a new build. Notwithstanding, it is not at this stage known to what extent various Flag States do or do not require adherence and thus what extent of the world fleet does or does not adhere. It should be further noted that the specific text contains the statement given in Figure 1 (b). This has a serious implication for ACD ships wherein little or no validation is made of the capability or accuracy of simulators or estimations. Thus, it is reasonable to assume that the information provided on such ships could (in some cases) be substantially misleading.

2.6 DO EXISTING SHIPS MEET THE CRITERIA?

The study also investigated the compliance of existing ship to the manoeuvring criteria. Published data is scarce in this area nevertheless three examples were found; one from the open literature [3] and two in private communication. For these three cases each ship complies, more or less, with the necessary criteria. However, some indication is given that ACD ships do tend to be less course-stable. This is not necessary a problem; the IMO criteria do prevent the building of ships that do not meet with the criteria. However, it is certainly worth being aware of this less-stable tendency; especially in conditions that might change the performance in a detrimental manner. For example, the IMO criteria must be conducted in deep-water and ships typically become more course-stable in shallow water. However, Yasukawa [4] presents results for some ship-types wherein the turning parameters are reduced in shallow water. This could result in a ship with already minimal course-stability becoming problematic when in harbour [and thus in close proximity to hazards].

3. EXISTING OPERATIONAL PRACTICE

The project considered also existing operation practice through both a worldwide survey and through dedicated interviews with maritime personnel who have experience using ships with ACD's.

3.1 SURVEY AMONG MARITIME PILOTS WORLDWIDE

The United Kingdom Maritime Pilots Association (UKMPA) performed a survey among the pilots and Pilots Associations all around the world in order to collect some relevant information concerning their experience with ACD's and the way they are trained for the use of such systems. The questions asked can be categorized as follows:

- Pilots using ACD's;
- Pilots having received training specifically for ACD's;
- Pilots having been provided with guidelines about the use of ACD's.

The survey collects the responses of 2334 pilots of a total of 8044, which represents 29% of the total. The survey revealed that the great majority of the respondents (98%) deal with ships that have ACD's. However, despite nearly all respondents reporting to have to deal with ACD's ships, less than a third reported having had any training (736 out of 2334). Also, the results reviled that only 35% of the trained pilots received this training at a dedicated facility. To put in another way, though most pilots have to deal with ACD's, only about one-in-ten have attended a dedicated training program.

3.2 INTERVIEWS WITH SHIPS MASTERS

Within the scope of the project the UKMPA conducted informal interviews with a great many maritime personnel. In addition, the UKMPA conducted formal interviews with the Masters of three large and prestigious ACD cruise ships. Transcripts of the interviews are available on the AZIPILOT web-site [5]; with the main finding (*together with comments and remarks*) summarized herein.

Generally speaking, experience with training was reported to be good, however the brevity of training was noted. Dedicated ACD training typical amounting to one and a half days of a more general five-day program. It was emphasised that training must take place before arriving on-board; as arriving without training could easily lead to someone becoming overwhelmed. It was noted that even a short course allowed personnel to arrive on-board with a reasonable idea of what was going on. Nevertheless, it was also noted that there was still a great deal to learn at handover.

In response to questions regarding intuitive use, respondents commented that ACD's requires a completely different mind-set. Comments indicated that a risk with ACD's comes about because you have more control but if you do not properly understand the system your expectations of its capabilities may be wrong. Similarly, without experience an individual's expectations of their own skills can exceed their actual capabilities. It is further noted that the technology is excellent but the amount of power you have available is limited and there are definite limitations in what you can do safely. In addition, this problem can be compounded, as it can be difficult to get personnel in company offices to understand the limitations.

Further comments brought attention to an M-notice that gives guidance for the training for Masters and Chief Mates of large ships and ships with unusual manoeuvring characteristics [6]; but which is unfortunately not mandatory. Generally, it was felt that if you consider the risks of what could go wrong then common sense would suggest training is necessary. Also it was pointed out that, with so many ships going to the same places and experiencing the same problems, it is unfortunate that there is no formal way of sharing experiences and good practice.

When considering operational practice various tactic are adopted. One Master indicated that he approaches the berth as if on a conventional ship; saying that going sideways just uses a lot of power and energy, which costs money. Another indicated that he initially used the T-bone approach (for about a year) but then became adept at using a more sophisticated technique using azimuth angles.

NB: The T-bone approach (with one ACD fwd/aft and one athwart ships) is sometimes adopted as it is quite intuitive. In this mode the helmsman need only consider forward/aft thrust on one unit and use the other like a stern thruster. It is worth noting that this practice is discouraged by manufactures as it can damage the bearings. To reverse the thrust a reversal of the shaft rotation is required. This necessitates the rpm to go through zero, which can result in a loss of the oil-film on the shaft bearings. Tests have shown [7] measurable levels of metal particulate come through in the oil in relation to such operations.

Regarding procedural issues, one master described how the control handles on his vessel are not synchronised. He pointed out that when you move from one control position to another [for example to a bridge wing] you have to be very careful on what is set before pressing the take over button.

NB: Problems with transfer of control often came up through the project; appearing to be a possible area for concern and thus improvement.

Finally, when considering the pilots contribution to the bridge team, it was noted that it was often difficult to explain what was going on. The hands-on nature of the controls makes it difficult to vocalise the aims and intentions when manoeuvring.

NB: Other areas of the project found that this problem was exacerbated by non-standardised terminology (different manufactures use different names for the various modes of operation). Further, some bridge arrangements were found to be not conducive to good communication with the pilot; having a more aircraft like control layout [leaving the pilot to stand at the back].

3.3 SURVEY AT TRAINING CENTRE

A survey was also made with maritime personnel who were attending a manned-model training course at Port Revel; under taking a course for pod-driven ships.

A questionnaire was completed by 25 people (mainly pilots); with the average age of 49 years old. Only 8 (32%) of them declared that they have already received in the past some kind of training about the use of pods. When asked about the main reason for having attended the training course, 44% answered that it was for Career reasons, 24% for Safety reasons; 12% for Regulations and 8% for knowledge and understanding.

The large majority (76%) considers the ACD's intuitive and easy to use. When asked about the importance of having an ACD system (controllers, type and model) for training that is exactly the same as the one present on the ship they will work on, the replies vary considerably. We can say that the average result of this question is that it is quite important to have the same system on board but not strictly necessary.

Extracted from the findings, the following list gives the ideal aims that a training course should have, according to the people surveyed:

- Practical use of the system;
- Hands-on use;
- Understand the ship's reactions;
- Principles of use of the system;
- Learning about the emergency procedures;
- Limitations of use;
- Safety matters.

4. ACCIDENT AND INCIDENT REPORTS FOR SHIPS WITH ACDS

Within the project, accident and incident reports for ships equipped with ACDs were collected and reviewed; considering specifically operations. The objective was to establish the type and commonality of various accidents and incidents, with the intention to discuss the perceived causes of the incidents as reported. Since an inherent safety threat will always exist with ship operations (for our discussion, manoeuvring operations) we must address the vulnerability factor in order to minimize the risk. Correctly identifying the actual cause of an incident will equip us better for a positive response in prevention. The main areas of focus include:

- Survey of mistakes and discussion of causes;
- Review of perceived and actual risk;

- Discussion of possible causes of perception gaps;
- Explore possible recommendations for corrective action.

The review was conducted using published reports from Government Agencies forming part of the Marine Accident Investigators International Forum. Members include International Agencies conducting their investigations in accordance with the Code for the Investigation of Marine Casualties and Incidents (IMO Code) published by IMO in 1997 through its resolution A849(20).

Depending on the consequences of a Marine Casualty the Code classifies such incidents that have caused damage or danger as a Very Serious Casualty (VSC), a Serious Casualty (SC), a Less Serious Casualty (LSC) or a Marine Incident. Typically it is only VSC or SC that warrants a full investigation and is therefore available in the public domain. Only reports in which the operation of ACD's has been highlighted as a factor were reviewed. Reports of accidents involving vessel propelled by ACD's but in which the operation of the ACD's was not a factor in the incident have not been considered. The published reports cover a period from 1991 through to 2009.

In the first of ten reports reviewed, a ferry made contact with a shore installation in Vancouver in January 1993; Burrard Beaver [8]. The Master reportedly could see the radar presentation of the dock ahead and ordered the Mate twice to alter course to starboard. Instead, the Mate held to and increased the alteration to port believing that this was necessary to clear another swinging ship. The Master, realising the situation, intervened [but not in time] by altering the direction and thrust of two after ACDs.

Conclusions found that the Mate, who was at the controls and had conduct of the ship, did not carry out the Master's orders. The Mate could not see the radar screen but continued with a course alteration to port instead of stopping or reversing the ships engines to give more time to evaluate the situation. The Mate did not fully appreciate the manoeuvring characteristics of the ship.

In the second report, a ferry collided with pontoon and moored yachts in British Columbia in November 1995; Mayne Queen [9]. Directional control of the ship's forward propulsion was lost during the unberthing manoeuvre. The main findings conclude that there had apparently been an incomplete transfer of propulsion/steering control from the arrival console to the departure console. Also, evidence indicates that the propulsion was not declutched before the marina dock was struck. It is also noted that the Master was not given a re-familiarization period before assuming operational command of the vessel. Further points noted include: The control system did not incorporate an alarm to warn the operator of an incomplete transfer of control between the consoles; the lights identifying which console was in command were identical and did not readily indicate the status of the control system to the operator; the instructions in the bridge operations manual were at variance with the manufacturer's instructions for the transfer of control procedure.

The third report considers a collision between a tug and a tanker in the Brisbane River in April 1998; Austral Salvor [10]. In handling the 'unilever' to adjust the speed of the tug, the Trainee left on a component of starboard thrust, causing the bow to sheer to starboard. The tug Master corrected the sheer of the bow to starboard. However, as the stern of the tug closed within four metres, interaction forces contributed to the tug's momentum towards the ship causing the stern of the tug to make contact with the ship's side. The training regime, training manual and instructions provided for prospective tug Masters would seem to be comprehensive and were not considered as contributing factors in this incident.

The fourth report considers the contact of a Class V passenger vessel with a bridge on the River Thames in October 1999; Symphony [11]. A mechanical failure [with a feedback drive shaft] caused the vessel to suffered a loss of steering control on the starboard ACD [unit to slew continuously]; with no indication of such from the bridge controls. Contributing factors included the comment that the loss of steering, combined with all instruments reading normal, is not a predictable emergency situation. The proximity of Lambeth Bridge, the effect of the tidal stream and the confused signals as to the condition of the vessel were all significant factors in the accident.

The fifth report considers a malfunction of automatic steering control, in Gabriola Island in April 2002; Bowen Queen [12]. Spontaneous rotation of ACD(s) caused the vessel to back off from the dock (dropping the ramp) and return toward it. While the definite cause of the malfunction was not determined, information points to a defective printed circuit boards in the automatic control systems.

The sixth report considers a collision between a tug and a vessel in the River Mersey in April 2005; Thorngarth [13]. The collision occurred when a mishandled bow tug ended up across the bow of the ship it was assisting. The attributed cause of the accident was the tug Master's lack of familiarity with the tug, and the lack of training in the particular manoeuvre he was required to perform. This was one of a number of similar incidents involving tugs in a period of 4 months; all attributed to the same shortcomings.

The seventh report considered a collision between a ferry and a link-span in Southampton in March 2006; Red Falcon [14]. Following a technical problem the Master chose [justifiably] to desynchronize the two cyclodal units; to operate one at a reduced power. At a changeover of personnel this information was not communicated. Consequently, the Chief Officer, believed he was slowing the ship with two units when in fact the forward unit remained at full power; resulting in the collision. It is noted that, neither the Master nor the Chief Officer had recently undertaken the company specified training in operating with the engines desynchronised. Also, the fact that the Chief Officer, an experienced mariner, did not immediately realise that the units were desynchronised, suggests that the existing indicators are insufficiently clear.

The eighth report considered a contact between a tanker and a jetty in Milford Haven in December 2006; Prospero [15]. A sudden loss of control of the ACD's caused the vessel to make contact with the jetty. When within 100 metres of the jetty, at a speed of 1.2 knots, the control lever moved, with no manual input, to approximately 70% of full power. Even when attempts were made to pull the lever back, the power remained at 70%. After various actions were taken to control the ship (despite the 70% thrust), it stop just as suddenly. However, shortly afterwards it started again; causing a second contact. Only when control was transferred to the engine room and then back to the bridge, was control properly regained.

The root cause of the initial failure of the pod controls has not been found; however, it is suspected that out of range signals in the propulsion control system caused the system to automatically supplant the primary control levers with the back-up buttons. The Master had received no dedicated training in the propulsion system, and was insufficiently familiar with reversionary mode operation and emergency drills.

The ninth report considered a grounding in the River Humber in February 2008; Sea Mirthril [16]. The ship grounded in fog following a lack of support and teamwork; highlighted by a number of factors. The Pilot was the only person monitoring the vessel's position. The Master was the helmsman and was therefore unable to maintain a command oversight of the situation or liaise effectively with the Pilot. Communication between the Pilot and the Master was poor; the Master was not aware of the proximity of moored vessels and the Pilot was not aware of the manoeuvring undertaken by the Master or of a problem with the port ACD. The ship's crew had not adequately planned the passage from the anchorage to the vessel's intended berth. The more detailed, larger scale chart of the area was not made available to the bridge team.

The report commented that, when manoeuvring during mooring or other operations in close proximity to other vessels or dangers, it is not unusual for Masters to steer vessels themselves in hand steering. This is necessary to ensure sufficient control is maintained. However, other situations that require hand steering to be used, such as restricted visibility, also tend to require a Master's undivided attention and skills of command, which is not possible if he is also the helmsman. It is therefore essential that all vessels have sufficient crew, other than the Master, who are competent in the use of the steering and propulsion systems fitted, regardless of their complexity.

The tenth report considered a cruise ship contact with a quay in Valetta Harbour in May 2008; Queen Victoria [17]. A berthing operation required the ship to turn through 180° before mooring port side to. At the start of the turn, the Captain controlled the ACD's and bow thrusters from the bridge's centre console, but once the berth was open on the port side, he moved to the port wing console accompanied by the embarked Harbour Pilot and the Staff Captain. Once on the port bridge wing, the Captain adjusted the main engine controls to arrest movement astern. However, this had no effect because the control of the ACD's had not been transferred to the port console. The vessel continued to move astern until contact was made with the quay.

Although not used in the statics here (because the MAIB report is not yet published), it is also interesting to mention the Nils Holgersson. This pod-driven Ropax collided with a berthed vessel (3 May 2012) after the pod control system had allegedly been left in 'Sea Mode'.

4.1 DISCUSSION OF CONTRIBUTING FACTORS FROM ACCIDENT AND INCIDENT REPORTS

The brief summarisation shows that while no one fault exists in all the incidents there is some commonalty in that manoeuvring error and transfer of control issues are relevant in 60% of the incidents. In the incidents highlighting manoeuvring error as a factor the reports recommend further training and familiarization as being necessary despite the individuals having considerable experience at sea, this has not always been on-board the vessels involved in the incident. In the incidents highlighting transfer of control issues the reports recommend improved the on-board procedures and an improvement in equipment knowledge for the ships officers.

To put this in context, in the same period a total of 239 reports are listed on the Marine Accident Investigation Branch web-site. Of these 117 are related in some way to contacts, collisions and/or groundings. ACD ship account for around 7% of the world fleet and 9% of the reported accidents, which, based on the small sample size, shows no significant difference. Nevertheless, the types of incident reported show far more commonality than in other vessels. Of the non-ACD ship only four cases identified route causes similar to those identified for ACD ships. Two identified 'a lack of appreciation for the manoeuvring characteristics' as a cause; one experienced a loss of steering; one identified confusion with the controls. Resolving these issues for ACD ship may in fact make them measurably safer than conventional ships.

5. DISCUSSION OF OUTCOMES

In reviewing devices and regulation, various embodiments of ACD are identified and described. Also, the relevant operational criteria are identified and details provided. Notably, the IMO manoeuvring criteria are argued to provide a perfectly acceptable operational envelope; within which all ships should perform. In addition, published results indicate that the application of the criteria should yield equitant results as for conventional ships. Nevertheless, results also indicate that manoeuvres not described by IMO are often preferred in practice. Most notably this is apparent with the applications of stopping manoeuvres wherein a 'transverse arrest' appears to be favoured; certainly for tugs and possibly becoming favoured for larger ships. Notwithstanding, evidence indicated that ACD ships tend to be at the less course-stable end of the spectrum; which may present specific problems in confined waters.

Neither SOLAS nor STCW contain items specific to ACD's. However, STCW invites the introduction of specialist training modules; for which an ACD module would be most suitable. When considering the manoeuvring information provided on board ships a review is made of the necessary materials. Most significant is the finding that manoeuvring information provided on board a ship need not be derived from trials, but can instead be obtained from simulation or estimation. As many simulators and estimation methods are extrapolated (lacking as yet fundamental models), little confidence can be place in such results. Further, such concerns seem to be born-out in the review of compliance. In the experience of the authors, model test results do not always match the full-scale trial results. In addition, the simulation of turning circle manoeuvres (needing as it does, many time steps) can diverge substantially if the underlying model is in any way inadequate. It is recommended that the validity of information provided on board ACD ships should be examined in light of outlined uncertainties and the implications of such inaccuracies should be explored.

From the accident and incident reports, it is perhaps inadequate to highlight manoeuvring error, or more specifically human error as a root cause. Human error can be better understood as an error cause by the human being expected to carry out activities without the correct support or training or to perform beyond an achievable capacity. Considering this, it is more appropriate to consider what underlying factors may contribute. To better identify relevant contributing factors Figure 2 give some of the more prominent causes and contributing factors in the considered accidents and incidents. Five common factors appear to be more prevalent, as shown in the figure. Not so much can be said about mechanical failure in this context other than to say that these increasingly complex systems may behave in quite unexpected ways when failures occur. Also, it is perhaps worth considering that better emergency procedures may help elevate risk associated with mechanical failures. A lack of training appears most frequently to have a contribution. In nearly all cases reported, where this was considered a factor, no training was received at all. Poor procedures seem to make a significant contribution. This could well be related to a lack of training but in part at least could be related to the time needed to evolve good procedures in this emerging technology. Communication errors were apparent which again may well be cross-related to both training and procedures. Nevertheless, it is apparent that the almost infinitely variable settings, the various configuration and unstandardized terminology, will not help in this respect. Finally, a transfer of control appeared to present a common problem. Both better system design and more robust procedure may well help to remove these risk factors.

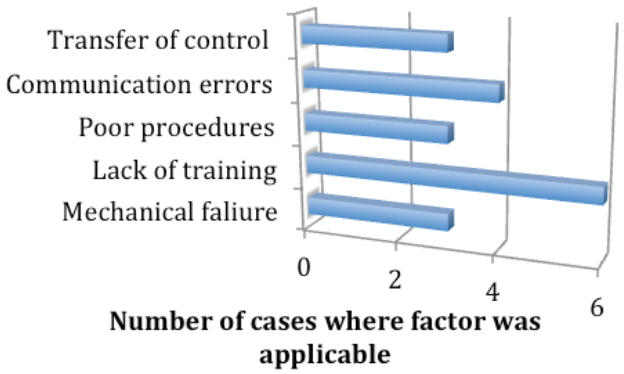

Figure 2. Causes and contributing factors in accident and incidents

One reoccurring theme seems to be related to the ability to communicate what is going on or is trying to be achieved. This is in part seen to be due to the more hands-on intuitive nature of operating ACD's in comparison to conventional ships. This is further compounded by an as yet unstandardized bridge hardware and terminology. For maritime pilots visiting as they do many different vessels, these issues can present a barrier for clear communication. It is the opinion of the authors that, for good progress, research should focus on standardisation of both hardware and terminology. Also, the communication of desired actions may be better communicated by describing the expected outcome; rather than the input action. For example, for a goal-orientated approach, a pilot would be better advised to specify a desired heading rather that an input helm-angle.

Notwithstanding the above, it is also apparent that ACD ships appear to have no measurable increase in accident rates when compared with conventional ship but do show a higher tendency for those accidents to be related to certain route causes; that if addressed may make ACD ships comparatively safer than other ships.

6. CONCLUSION

Existing manoeuvring performance criteria do appear to prevent the building of ships with inadequate or unsafe characteristics. However, requirements for information to be provided on-board ships appear to be lacking and for the most part disregarded by the seafarers using them. The vast majority of maritime pilots seem to have to deal with ACD ships yet only one-in-ten has undertaken training at a dedicated facility. ACD ships do not appear to have any increased accident rate when compared to conventional ships. Nevertheless, problems are apparent with the bridge operations especially when moving between the main console and the bridge wing. This may be improved by better attention in design and by attention to bridge procedural operations. Better and more transparent communication may be achieved between the bridge team and also with the pilot, by considering a standardised terminology and by adopting a goal-orientated command approach.

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