Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title:

Deliverable 2.4:

Review of ability to model bridge systems and human interface

Contents

PUBLISHABLE EXECUTUVE SUMMARY

The objectives of this task were to explore the use of existing bridge systems and review their relevance when operating ships equipped with azimuthing control devices. The task focused on reviewing the capability and validity of the most common bridge systems.

The methodology employed involved interviews with masters experienced in use of ASD propulsion and manoeuvring experts visiting some ASD vessels and examining actual ASD operations on the spot. The conclusions indicated the following:

- ISO 13407 Human Centred Design Process for Interactive Systems should be referenced.
- Consultation with user experts is an absolute requirement even though standardized elements have been identified and documents.
- The ASD system usage will become more widespread in the future, thus education and training is a necessity.
- Aside from the more academic factor of the positioning of bridge equipment, field of viewing is sometimes overlooked and requires attention.
- It is easy for the master while manoeuvring to find him/herself in a cognitive overload situation due to the fact that two levers must be used simultaneously and possibly in very different configurations. Again, education and training in this area not only by simulation but also on-site would be a great advantage, if not a necessity.
- Optimal bridge layout for ASD propulsion varies widely between similar and different types of vessels and the type of ASD arrangement, i.e. Azi-push or Azi-pull. If we confine our discussion to, for example, tug use, an optimal bridge arrangement can be dictated by the type of work performed whether it be Open sea, Confined waters, Anchor areas, Narrow channel / rivers Port basins, Terminal approach, Open sea off shore, Short track ferry or Tug assistance.
- The resultant thrust component is often difficult for the user to calculate/comprehend during operations.
- If a specific arrangement of thrusters is selected, this can present problems if the Conn is now changed to the bridge wing position. The joystick position on the bridge-wing (not yet connected) may not mimic the arrangement originally selected from the central conning position. This may result in confusion or even in accidents.
- When, and if, the Conn position is changed to the bridge wing the necessary information for manoeuvring must also be available.
- Tugs often change the Conn position from central looking forward to central looking aft. This is also an opportunity for confusion for the user.

In conclusion, official standardisation for operating systems must be consulted along with consultation of experienced users. This should then be supported by educating and training at the very least by simulator training and, if possible, supplemented by onsite training.

- Introduction

This task report delineates the ‘Task Analysis’ review of bridge systems and the human interface. The objects are to explore the use of existing bridge systems and review their relevance when operating ships equipped with azimuthing control devices. The task will focus on reviewing the capability and validity most common bridge systems. The contributors and responsibilities are identified below.

BTMS
Review of the ergonomics of various control systems that are commonly used in conjunction with azimuthing control devices.
Discuss Bridge and operational information systems.

FORC
Explore intuitive safety devices.
Review relevance of automation with respect to both over-loaded and under-loaded working conditions.

STC
Review of similarities between different ships and between sister-ships when considering bridge layout and manoeuvring operations.

To date contributions have been received from FORC and STC.

The FORC contribution made use of interview with a Master experienced with ACD use and also incorporated the human element when considering design. Reference has also been made to ISO 13407 which gives guidance on design of types of systems taking into account suggestions from experts in the field of practical use.
The second FORC contribution examined the various levels of automation and the various stages of human processing. In addition an interview was once again utilized to aid in information gathering to finalize the report. The are various conclusions to be drawn from this WP task amongst those are the need to consult experts in the design and layout and the need to consult an establish standard such as ISO 13407.

The STC contribution identified the various handling situations in which the ACD will be used and noted that use of this type of system will become more widespread in the maritime community.
Interviews were conducted with masters having experience with ACD and the observations contributed greatly to the material within the work package. From the interviews insight was gained into optimal arrangements and practicalities when the vessel is in service. Highlighted were the challenges masters and officers face when handling such units. Bridge layouts have been provided to aid in the understanding of the difficulties facing the bridge members, based on actual bridge arrangements. In addition the reader is reminded of the practicalities involved with field of views as constrained by the bridge arrangement and the individual.

1. Item (3) Explore intuitive safety devices.

There exists to our knowledge no intuitive safety devices onboard Svitzer M class tugs or in our state-of-the-art 360 degree tug simulator that has any direct connection to the controllers for the azimuth propellers except from the push buttons for switching from lever control to push button control.

The push buttons for switching from lever to push button control of the azimuth propellers are situation in the bottom right of the photo.

Close up photo of push buttons for taking control from levers to push buttons. Photo taken onboard Svitzer Mars.

Close up photo of the same panel. Photo taken in ASD tug simulator brigde at Force facilities, Lyngby.

In the interview with our expert ASD tug master safety devices are discussed:

I: When we talk about safety devices which could be some kind of combined use of the azimuths. If you think about something that could be of an advantage regarding safe operation of azimuths what do you think of?

B: Well I think training is the one thing that can do the most for the safety. That is the most important. The next is the quick release mechanism on the winch where we can let go the line. And the other is the release hook after if we have something made fast aft. These are the two most important things.

(Interview: 17-18)

What is clear from the interview is that training is considered being the best safety there is. After that comes quick release mechanism on the winch. And then the realease hook if a line or wire from the assisted vessel has been made fast.

Equal to the problems of automatisation (see next chapter), safety devices in this context are quite hard to imagine because the work the tug does for the assisted vessel is often done using the maximum effect possible, or generally what is to the limit and still considered safe. Training is therefore naturally viewed as the most important in connection to safety because with the right knowledge and the right amount of relevant training it is believed, that the master or mate will know what the tug can do and what it can not do within a safe limit.

And as our interviewed capatain tells us:

I: Is it possible to imagine some combination of an automatic mechanism regarding the manoeuver of the tug or adjustment of the controllers (some optimization)?

B: No – not really. What we must keep in mind is that we often have to give the maximum pull on the line that we possibly can. You can in fact say this is the criteria for success. Something that would release it at a certain force that would be completely opposite to what tug operation is all about. Much if the safety is build into the line you choose to fit on your tug. This line is calibrated to fit the effect of the tug and so on. If you are at the limit where the tug is in danger then the line must break. So the dimensions of the line is tailored to the limits of the tug. That may be from an economical perspective but it is some sort of a safety measure. It is generally very important in the tug business that you follow the procedures that exists. That you ensure watertightness and so on. So that the vessel actually can stand lying on its side – as it is supposed to be able to withstand and come back up again. Building in of any automatic measures is hard to imagine because the kind of work you have to do with the tug is about operating on the "crazy" side of what many would consider right. But that is what tugs are for.

(op.cit.)

But of course, if safety devices exists on tugs in real life it makes perfect sense that such devices are also found in the simulator bridge tug masters or mates are training on. No doubt about that.

Intuitive as usability and utility

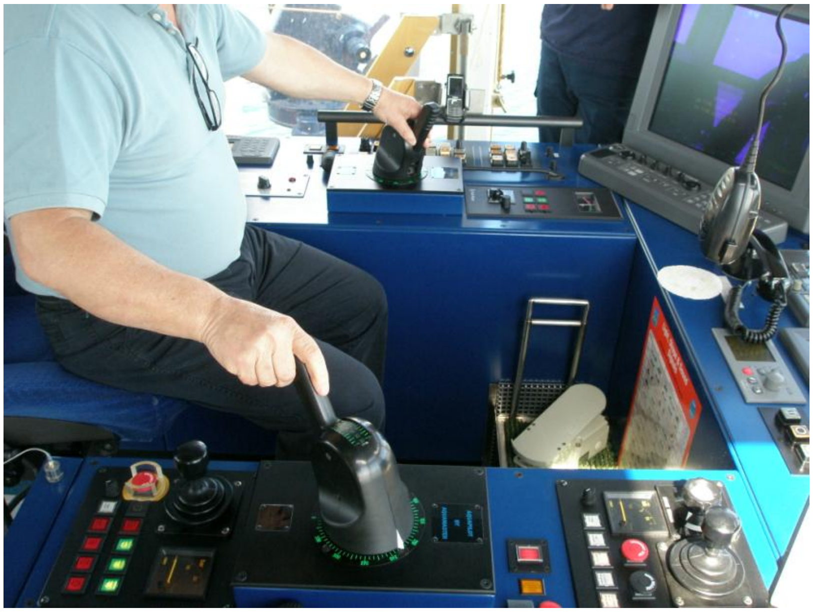
If one is to think about demands for future safety devices it is relevant to look at demands for usability. Designing any "safety device" should be carefully carried out while making sure that any human factor issue is dealt with accordingly. As further described in the next chapter the ISO 13407 standard can be proposed as a kind of checklist for ensuring that the user, their knowledge and the knowledge of the users, their behaviour and context (captain or mate) is incorporated sufficiently in the design processes. And it is important to keep in mind that usability is not just a demand for some feature to be "easy to operate" or "easy to understand". That would be a great misunderstanding.

Usability is much more than that. And "intuitive" is just one aspect of many factors that all in connection in a certain system, situation and context makes a certain function or piece of equipment intuitive to use. In other words designing from a human-centred perspective increases the chances of ending up with a function or piece of equipment that has a high degree of usability, utility and is also straightforward to take advantage of or get assistance from by the user.

2. Review relevance of automation with respect to both over-loaded and under-loaded situations.

In answering this task the focus is on ASD tugs. The operation, handling of them (through the controllers for the azimuthing propulsion system) is seen as an overload situation because it needs constant vigilance and manual adjustments by the operator.

In most tug handling and tug assisting manoeuvring the mate or captain handling the tug is constantly operating the two controllers (one for each azimuth). This means that he must always handle the vessel. This is his primary task, while for instance communication with pilot and captain on the assisted vessel, harbour authorities or own crew, is secondary.



As described in the answer to WP 3.3 the work done by Force in this report focuses on operating and handling of an ASD tug. This handling is defined as an over-load situation. The reason for this is thoroughly explained in chapter 3.3.2.

Any automation can be defined as

"…the circumstances when a machine (nowadays often computer controlled) assumes a task that is otherwise performed by the human operator."

(Wickens, 2004:418)

Before deciding to design any automation there is usually a wish that a machine (computer) controls and performs tasks that a human operator should have done. The task performed automatically typically has to be monitored for its correct execution by a human.

When deciding what functions to automate it is important to ask the question: "Why automate". This is important because automation is not just the successful solution to any problem of handling tasks or functions assisting the human operator. There are several pitfalls with automation. This is also true for any automation regarding the handling controlling of azimuthing propulsion systems.

Roughly four categories of reasons for automation can be identified (Wickens, 2004):

Impossible or hazardous processes which proposes a danger to the human operator. An example is handling of poisonous chemicals. It can also be processes that the human operator for some reason is not able to do without some kind of system assistance. An example is automatic readers for visually impaired. Clearly this category does not characterize the handling of controllers on an ASD tug.

Difficult or unpleasant processes are another reason to automate. These are processes which are very challenging for the human operator to perform to perfection. The restriction making the process difficult to perform correctly for the human operator can for instance be time. Calculating huge numbers can of course be trained and done well and correctly by a human operator but a calculator can do this much faster and with a lower degree of error than most humans. It can also be processes that are tiresome, repetitive or fatiguing. This category is somewhat relevant to handling an ASD tug. The handling can be both difficult to perform correctly, swiftly, repetitive and without making any errors (non optimal use of the thrusters). It is therefore relevant to speculate about "emergency procedures" which the controlling system in some way could be set to perform when the entire "system" was in danger (the tug being in danger of capsizing, running aground, colliding with obstacles such as dub´albes, buoys quay or the assisted vessel). The problem here is that the "system" than should have access to information and data telling it that there was a dangerous situation. This could be range measurements from the speed log, the radar, under keel clearance alarms form the echo sounder, overload on tow rope, alarms of insufficient reserve engine power (thrust) to escape from a dangerous situation (for instance when attached to the assisted vessel bow to bow that accelerates rapidly) etc.

But as these different electronic aids onboard the tug measuring these different values are not even all connected today it is hard to imagine that a computer could be successfully programmed to decide within a reasonable margin when a situation is dangerous.

As it is today this evaluation of system parameters is an always ongoing process within the head and actions of the human controller – the captain or mate operating the tug. It is his knowledge, abilities and experience (the human factor) that does this job. His decisions and actions are based on his perceptions, different levels of situational awareness (Endsley, 2000) , short and long term memory, input and stimuli from the real world (looking out the window), listening to the sound of the engines and "hearing" the load on them, stimuli from the instruments and there readouts on the bridge, internal communication with the crew, external communication with assisted vessel, pilot, harbor, VTS[1] etc. It is therefore somewhat unrealistic to image that a computer in the nearest future could be set up and programmed to fulfill these very complex situational evaluations and give "engine orders" automatically in order to make the situation safer. The possibility that the chosen action of the automation system in such a complex and dynamic situation could make the situation more dangerous than safe seems to be rather big.

Another reason for a wish for automation is *extension of the human capability.* This can be automated functions that do not replace but simply aid humans in difficult situations. It is a well known fact that human memory is not perfect and especially the short term memory is very sensitive to disruptions, simultaneous tasks, high workload or plain stressful situations. This kind of automation is especially useful in extending the human operators multitasking capabilities.

An example relevant for the tug captain or mate is to be able to set up the autopilot (automatic steering – keeping a set course over ground) when the actual steering of the tug is not the primary task. This could be the situation when he has to communicate externally about, ETA and meeting positions with vessels in need of assistance or when he has to follow the rules of the road and therefore determine if other vessels should give way or he should give way for them.

Alarms from different parts of the system, are examples of such automation. They are aids to the human operator's decision making.

Another reason for automation is *"because it is technically possible"* . This reason should be considered with great caution. Simply deciding to automize because you can and because it is inexpensive is a dangerous business. The problem is that all pros and cons needs to be considering and compared to see what is gained by the automatic function. Automation of a task can easily make it more difficult, cumbersome or complex to perform than simply doing it manually. Automation just to show technical sophistication should be avoided altogether.

[1] VTS = Vessel Traffic management Systems which monitors, guides and to some degree control the traffic within the defined area of VTS area.

Levels of automation – stages of human processing

To understand which automation systems that seems relevant to the handling of an ASD tug we need to firstly briefly touch the subject of automation level – or human processing stage.
In this way of looking at automation it is compared to the human information processes it replaces. It is compared to cognitive work or load it replaces – defined by level of automation. Parasuraman (2000) defines four stages, each with sub levels:

1. *Information acquisition*, selection and filtering. Automation in this level assist the human operator with his selective attention, sorting of important data and information from his environment. A good example is the ARPA radar giving the navigator an alarm when it "observes" and plots a target in a set guard zone. It can be further developed, filtering (or cuing) targets for time to closets point of approach (CPA) or even "aggressive" and hiding irrelevant targets and information assumed to be unworthy of the operators attention.
2. *Information integration*, where automation provides the operator with situation assessment, inference, diagnosis and a "picture" of task relevant information which is easy for the operator to interpret. Known examples of such information integration can be the simple feedback instruments showing the angle of thrust, the pitch of the propellers and/revs on the engines. It can also be more advanced displays showing for instance predictions of the vessel movement (where will the vessel be in 2 minutes with these engine setting, present wind forces, current, etc.) It can also be advanced warning systems.
3. *Action selection and choice*. At this stage actions are chosen on the basis of information acquisition, integration and a lot more. An example of stage 3 automation is the is the airborne traffic alert and collision avoidance system (TCAS) which very strongly advices the pilot to take actions in case of acute danger of collision between two aircraft.
4. *Control and action execution*. At this level the automation actually carries out and action of some kind. Cruise control in a car or autopilot on a tug are examples.

(Wickens, 2004)

Considering levels of automation in relation to stages of human processing makes is clear that the higher the level the more "work" is required. Either by the human operator or the system behind the automation. Amount of work is related to workload for the human operator. Considering any kind of automation on an ASD tug in real life or in the simulator should therefore include an assessment of the workload it relieves the human operator (mate or captain) of.

Levels of automation

Set up in a matrix the different levels of automation can be sorted in 8 stages.

Level	Human or system control and actions performed
1	No aid from automation – human is in complete control.
2	Suggestion of multiple alternatives, filtering and highlighting of considered best alternatives by the automation system.
3	Automation selects alternatives, information sets, or ways to perform the task and suggest it to the human.
4	Automation carries out the suggested action if the human approves.
5	Automation gives the human limited time to veto the automatic actions before carrying it out.
6	Automation carries out tasks and informs the human afterward.
7	Automation carries out an action and informs the human only if asked.

8	Automation selects method, executes tasks, and ignores the human (no veto).

(Wickens, 2004: 422)

Problems with automation

The literature on automation identifies 7 primary "problems" with automation (Salvendy, 1997)[2]:

1. *Operators "out of the control loop"* is the problem caused by the operator loosing skills and long term knowledge of how the system works in details because these functions have been "taken over" by the system. This means that they have less knowledge of how to operate the system in case of emergency than they would have had if they where trained every day by continually operating the system manually.

2. *Insufficient or outdated "mental picture".* The inner representation is reduced compared to its quality before automation was introduced. This makes necessary intervention from the human operator slower and less optimal.

3. *Disappearing generation of skills* because new operators have not learned to operate the system manually since their predecessors were introduced to the automation. This can result in lower detailed knowledge of the system and how it works making the new generation of operator less able to exercise effective control if needed.

4. *Authority of automatics* is the problem of deciding if the human operator or the system is actually best to perform the required tasks. If the computerized system can actually do the tasks better than the human operator (faster, more accurate etc.) then the problem arises when the operator must decide if the decisions made and actions carried out by the system is correct or incorrect (optimal or sub- optimal).

5. *New type of errors due to automation.* Introduction of automatic systems can introduce new sorts of errors that are not formerly known to be a problem. A good example is ARPA assisted collisions.[3] This kind of automation induced errors and accidents are hard to analyze and understand until several of them has happened and a pattern arises. They do not fit into the framework of tradition human operated techniques or procedures.

[2] Salvendy (1997: p 1873) actually mentions a total of 7 "Ironies of Automation" but only the mentioned 5 points are relevant in this context.

[3] ARPA = Automatic radar Plotting Aid . ARPA assisted collisions occur because the operator (navigator) trusts this system more than visual judgment gradually accustoming him to pass other vessels at closer and closer distances. Visually the bearing to another vessel can look the same even though it is actually changing very slowly. Trusting the ARPA more than his sight can falsely reassure him that no danger of collision exists because even though the visual bearing to the ither vessel does not chance he trusts in the ARPA when it tells him that the passing clearance (CPA = Closest Point og Approach) is safe. In some situations and conditions the ARPA system can easily calculate quite large inaccuracies in its calculation of CPA.

In order to avoid or reduce the effect of these mentioned problems (negative aspects of automation) it is recommended to look at the interaction between human, any technical solution, system or aid from a user centered and systemic view point. Doing this means among other things that one has to formulate the requirements for the automation design.
Any automation system designed to assist the human operator operating the controllers of the azimuthing propulsion system should therefore ensure:

- *Compatibility*. No handling of the automation system should force the human operator to learn skills that is unrelated to the skills he already have for operating the system manually. It is the point that the operator should input and receive information from the system that is totally compatible with prior practice and conform to user's prior knowledge and skills.

- *Transparency*. The operator must somehow all the time be able to "see" what the automation does (how individual thrusters are turned, revolutions and pitch applied etc). He cannot control a system if he does not understand it. If the system I transparent the handler of the tug can build up "an internal model" of the decision making and control functions the system performs, is able to perform and unable to perform to satisfaction.

- *Minimum shock*. The automation should never do anything that the navigator finds unexpected in relation to the information of variables the system operates from and the present state of the system the user has.

- *Disturbance control*. The automation should not execute "uncertain" tasks (task which are on its functional limits). At least not without warning the user that it is doing so. In such a case the system should advice the user to take manual control or change parameters in other ways.

- *Fallibility*. It must always be possible to take command of the system manually. The user should never be put in a situation where his tacit skills and knowledge is designed out of the system and where he can only helplessly watch the system making a wrong decision and possibly dangerous actions.

- *Error reversibility*. The software and indicators/displays/readouts should supply the operator with sufficient feed forward of information of the likely consequences of a particular operation or strategy.

- *Operating flexibility*. The system should offer operators the freedom to trade of requirements and resource limits by shifting operation strategies, preferably without losing support from the automation.

(Corbet, 1989)

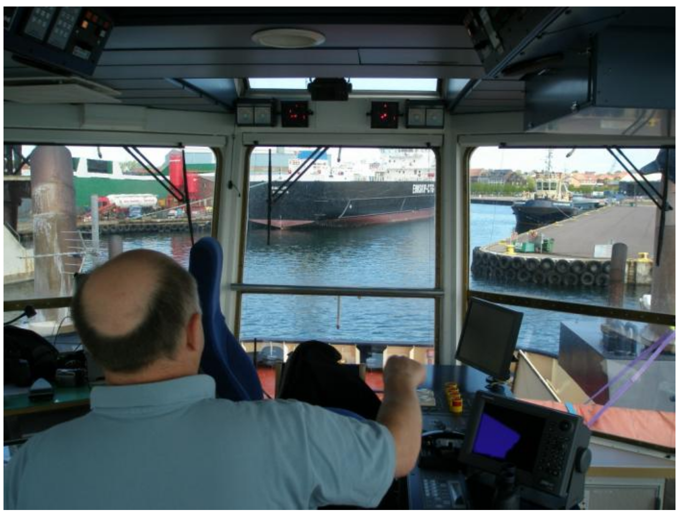
ISO 13407 – a standard about human-centered design processes for interactive systems.
Founded on the knowledge of the importance of usability and utility of any interface between a human operator and the system he is supposed to operate, in this case the controllers for the azimuthing propulsion machinery on an ASD tug, standards have been made by different organizations. The ISO 13407 standard is a good example of such a standard. Originally it is a

standard which is born out of the HCI Human Computer Interaction paradigm, but it can logically be applied successfully in the design and evaluation of all products and systems that needs an interface which lives up to a certain degree of usability and utility. Therefore it can be considered when evaluating an automation feature related to the control of azimuth propulsion.

The main points in the standard that is relevant in relation to any consideration of automation of the handling of an ASD tug is:

- Knowledge of context
- Tasks that the navigator has to perform to handle the vessel
- The total "system" in which these tasks are performed

What we have done in this project is actually a little part of such work aimed at understanding the users context. The standard proposes observations of users in the real context. We have done that by observing and interviewing crew on their tug in operation. We have also taken photos of them while they were handling their tug.



Example of captain handling his tug – maneuvering back towards the dock after a successful assisting was carried out.

The standard also mentions the possibility of applying tasks analysis like methods. This we have also done for three different classic ASD tug assisting methods (please se chapter xxx for reference) Knowledge of how the navigator thinks before, while and after he is performing each sub task underlying the bigger operations gives an understanding of what tasks he could need support from any kind of automation system the most. It also informs us about what kind of assistance that is useful and at what level the automation should operate (refer to table above describing levels of automation). Knowledge of possible pitfalls applying automation to some or more of the tasks can also be deducted.

Overall the context analysis can incorporate many methods (for instance recording of pieces of video for later analysis). This we have also done to broadening our understanding of the navigators task, working environment and the whole "system" in which he works including factors such as lighting, noise, vibration, distractions, disturbances etc.

One of the main considerations before proposing any kind or sort of automation has to do with the question of were tasks, functions and decisions should be placed – at the human or system level?

The ISO standard 13407 recommends these considerations includes at least the following factors (which gives the most: the human or the system?):

- Reliability of performance
- Speed of performance
- Accuracy of performance
- Strength needed to perform
- Flexibility in choice of methods an making decisions
- Economy
- Importance of timing of performance

Finally considerations about utility and usability must be made.

Types of automation systems mentioned in the questionnaires

In the questionnaires (see questionnaire in annex xxx) which where returned from 42 navigators (pilots, captains and mates) training the handling of ASD tugs at our 360 degree state-of-the-art full mission simulator at Lyngby, Denmark, answers about automation have been given.

The question given to the informants answering the questionnaire on automation are as follows:

Q 47: Does your vessel(s) have any kind of automation for the steering or propulsion controls of the pods?

Q 48: If so – which?

Q 49: What is your opinion of the safety and usability of these automation systems (answer only if you have experience with such system)?

Safety:
Safe Unsafe

1 2 3 4 5 6 7

Q 50: Usability:

Highly usable Useless
1 2 3 4 5 6 7

Q 51:
-please explain further in a few words:

Q 52: Can you think of an automation feature (ex. Coupling of pods, regulation of relative angle between pods) that could be beneficial to your specific vessels/operating conditions/situations?

Q 53: If so – which?

(Questionnaire: 48-49)
The questions are aimed at respondents reporting on their experiences of any automation systems on their "real" vessels, meaning the vessels they normally handle and not the "vessel" they are training on in the simulator. The included answers here did all live up to that criteria.

21 of the 42 answered Q 47. 7 or 33 % (valid) of these said no, 14 or 67% yes. It is not possible to investigate if the remaining respondents do not have any kind of automation on their vessels, did not understand the question, chose not to answer it, forgot it or did not answer it for any other reason.

Q 48 about type of automation was answered in text string. 14 respondents answered this question. 12 gave the answer autopilot[4] while 2 answered joystick.

In Q 49 the respondents were asked to give their opinion of the safety of the automation systems. Joystick was rated 3 on the 1 to 7 scale, while autopilot ratings had a mean of 2, 4, clearly more safe than unsafe.

In Q 50 about experienced usability with the automation system shows rating of usability of joystick 4 (close to useless), while the question was answered by 11 persons rating autopilot average 2,45 on the scale, indicating that they think they are clearly more safe to use than unsafe.

In Q 51 respondents where asked to put more words on their rating of usability one of the to persons describing joystick mentions a personal experience: *"…on a bouy laying operation the joystick was put to neutral and wash from the propellers pushed bouy and work away."* Other answers related to autopilot was:

"Switching over to autopilot is not simple enough."

"The autopilot has worked well even in poor weather."

"There are that many systems!"

It is important to beware that only 2 persons have mentioned joystick and therefore only 2 persons ratings are calculated.

Q 52 was slightly misunderstood by most respondents and is therefore not considered.

Q 53 gave only three replies. One responder proposed that pods could be coupled on longer sailings (distances). Another reply was interesting but vague: "Every type of automation is very important". The last was a wish for "slow side step". It is a difficult to learn manoeuvre where the tug is moved straight towards either starboard or port side by the combined forces of the to thrusters aft without changing the heading (without turning).

[4] A marine autopilot is fitted on most vessels. It frees the navigator (or helmsman) on the bridge of constantly manually operating the wheel, thruster , or other kind of propulsion system controllers in order to maintain a preset course over the ground.

Item (5) – "Review of similarities between different (sister)ships when considering bridge lay out and manoeuvring operations"

Approach

Optimal bridge layout with the ACD propulsion system will vary and is dependant upon the task type. We have taken the approach to review optimum layout for each expected task, whether it be working in confined waters, open sea, terminal work etc. Aside from discussion about optimal layout we have included interviews from users and some of their concerns.

Requirements based on tasks to perform

Type of manoeuvres

A voyage consist of more distinctive phases where the navigation and ship handling is significantly different. The following manoeuvring situations have been identified;

- Open sea
- Confined waters
- Anchor areas
- Narrow channel / rivers Port basins
- Terminal approach
- Open sea off shore
- Short track ferry
- Tug assistance

It should be considered that depending upon the manoeuvring situation the workload and requirement for "active handling" will vary. A summary is provided below elaborating on each manoeuvring situation.

Open sea navigation

Ships are on fixed courses with service speed and only change the course to give way for other vessels and/ or alter course in way points. The heading is maintained with an auto pilot system. To alter course the autopilot is set to another heading. Only in rare cases the autopilot is changed to manual steering. The vessel will in most cases cruise at the established, best economical sea speed. In restricted visibility the vessel may be required to operate on manual steering and will most certainly operate at a reduced speed.
The manual handling of the ACD system is limited and can be done from a location near the other main navigation instruments. This is the position where the navigator will stay most of the time during the watch.

Open sea navigation off shore

In this situation ships will approach rigs and other off shore objects. The manoeuvres will be executed by handling the ACDS manually and possibly in combination, with other means, like bow thrusters.. The navigator will handle the ship based on RADAR/ARPA information for objects at distance and during periods of restricted visibility. Manoeuvring will be assisted by visual cues if and when possible. In the first situation a central location to handle the ACD near the other navigation instruments can be used. When in position near objects such as an offshore platform, the navigator may require positioning in a more optimal location which may be the bridge wings or a position where a full astern view is necessary.

Confined waters

The ship will have to give way more often as well as execute course alterations. This can be executed from the main console by using the auto pilot system. If course or speed alterations are needed by manual setting of the ACD system, this can be done at the central navigation location. Because of the possible frequency of course alterations extra bridge equipment such as communication equipment should also be made available at this location.

Anchor areas

For anchoring situations a speed reduction is required as is an eventual heading into wind and or current prior to letting go of the anchor. The typical tools for this manoeuvre are RADAR/ARPA, speed control and communications (internal and external). Providing the necessary equipment is available this manoeuvre can be performed at the central con position or on a bridge wing.

Narrow channel / rivers

The navigator will keep the ship on a track as accurate as possible.
A helmsman will steer the vessel manually at the steering console.
Speed is controlled by manual ACD settings. This can be done at the central navigation location. The navigator is positioned at the central navigation location with ARPR/RADAR, communication and speed information. The observation of the environment is preliminary from dead ahead to 90º on both sides, though good seamanship dictates that an all around watch must be maintained.

Port basins

The ship will slow down, stop, turn or make stern way in this area.
Steering is done by the helmsman behind the steering console. The navigator will choose a position where visual information received can be combined with RADAR and the operation of engines, thrusters and communication can be accessed. In addition, propulsion and steering alarms must be heard and observable from these locations.

Terminal approach

The ship will approach the terminal with slow speed and appropriate angle taking into account the external effects of wind and current. With this manoeuvre lateral movement (crabbing) of the ship may be necessary. This requires uncoupled ACDS with frequent changing of the ACDS settings. In this type of operation it is typical that the navigator is absorbed monitoring the visual situation. The control settings for thrusters and ACD are monitored by “feel” rather than by visual sighting of individual settings.
Speed and communication information should be available on location.

Open sea navigation off shore

In this situation ships will approach rigs and other off shore objects. The manoeuvres will be executed by handling the ACDS manually, possibly in combination with other means like bow thrusters. The navigator will handle the ship based on RADAR/ARPA information at longer distance and restricted visibility and by observing the environment when near the off shore object. Initially, a central location will be selected to handle the ACD. In the position near the off shore object the navigator may need another position for the ACD handling to be able to fully observe the environment by sight. This may require extra consoles in the ship side or in a location with a full view in the direction of the ship stern.

Tug operation

During the approach of the vessel to be assisted RADAR will be used during restricted visibility. For steering an autopilot can be used during the approach at larger distances but near the vessel the tug is manoeuvred manually.
While picking up the tow and assisting, the tug is constantly holding position relative to the ship to be assisted. Changes in ACD's settings must be executed without any delay to avoid high tension in towing lines, fall off towing position or coming too close to ships hull.
There will be frequent communications between the tug master and the pilot on board of the vessel to be assisted.
The navigator will operate the ACD's from a central location with full view over the fore and aft part of the ship, with view on RADAR and ECDIS monitors, wind information, tension in the tow line and the communication.
Also alarms of the propulsion system must be in audible and visual range of the navigator position.
All necessary instruments must be accessible to the navigator while at the con of the ACD's.
As an example the VHF is operated by foot pedal for transmission together with a fixed microphone located above the navigator position.

Short track ferry

Ferries on short run voyages forgo the time consuming turning procedures and have a special bridge design suited for operating effectively in two directions. The entire navigation console is doubled including the propulsion system. The orientation of the ACD's is relative to the ship which means that the starboard thrusters on the front console are on starboard and on the rear console on starboard as well.

Type of ship

As mentioned before, the requirements of the ACD lay out should be based on the manoeuvring circumstances in the different phases of a voyage. The type of voyage is dependant of the type of ship. The following table indicates the relation between the type of ship and the various phases of a voyage.

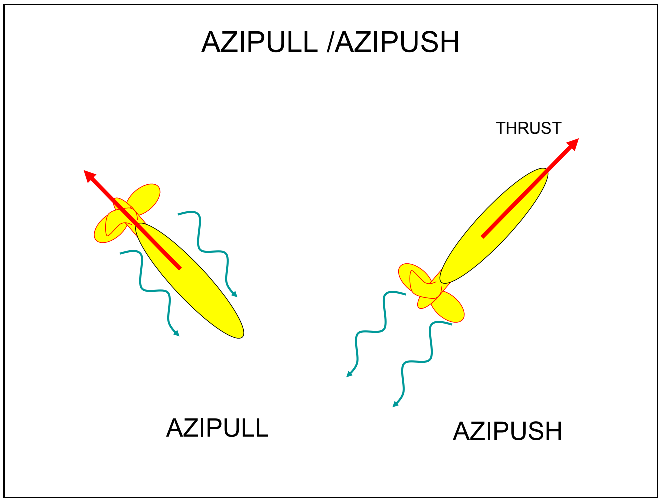
	TYPE OF SHIP									
	Merchant marine	Navy	Harbour tugs	Inland ferry	Offshore supply vessels	Pipelayers	Heavylift vessels	Icebreakers	Ice going tankers	Drilling rigs
Open sea	X	X				X	X	X	X	
Open sea off shore					X					X
Confined waters	X	X								
Anchor areas	X	X			X	X	X	X	X	
Narrow channel / rivers	X	X	X	X	X	X	X	X	X	
Port basins	X	X	X	X	X	X	X	X	X	
Terminal approach	X	X	X	X	X	X	X	X	X	
Tug operation			X							
Short track ferry				X						

Within the merchant marine group the following type of vessels are equipped with ACD systems as mentioned by the manufacturers;

- Container vessels up to the largest ones
- Smaller and middle class Tankers including ice going tankers
- Heavy lift vessels
- Ice breakers

For the future we can expect use of this type of propulsion on a greater variety of ship, type and size.

AZIPULL / AZIPUSH
ACD systems can be divided into 2 different types ;
AZIPULL with the propeller in front of the ACD body
AZIPUSH with the propeller behind the ACD body.



Ergonomic aspects affecting Bridge lay out design.

For similarities in bridge layout also the requirements regarding the ergonomic aspects play a role.
In accordance with the IMO MSC circular 982 of December 2002 the navigation bridge has a number of different work stations, listed below:

- Navigation, communication and manoeuvring
- Monitoring instruments and environment
- Manual steering
- Docking from bridge wing
- Planning and documentation
- Safety

In relation to the ACD handling the navigation and manoeuvring, the monitoring, the manual steering and the docking workstations should be taken into account.
The following relevant details in the IMO guideline are considered in relation to ACD's within a bridge layout.

Is must be emphasised that these are guidelines only and are non-compulsory. Ship owners may use them for new ship building or (partly) have their own concepts. Also classification societies may affect the bridge lay out by their own rules.

Minimum field of view.

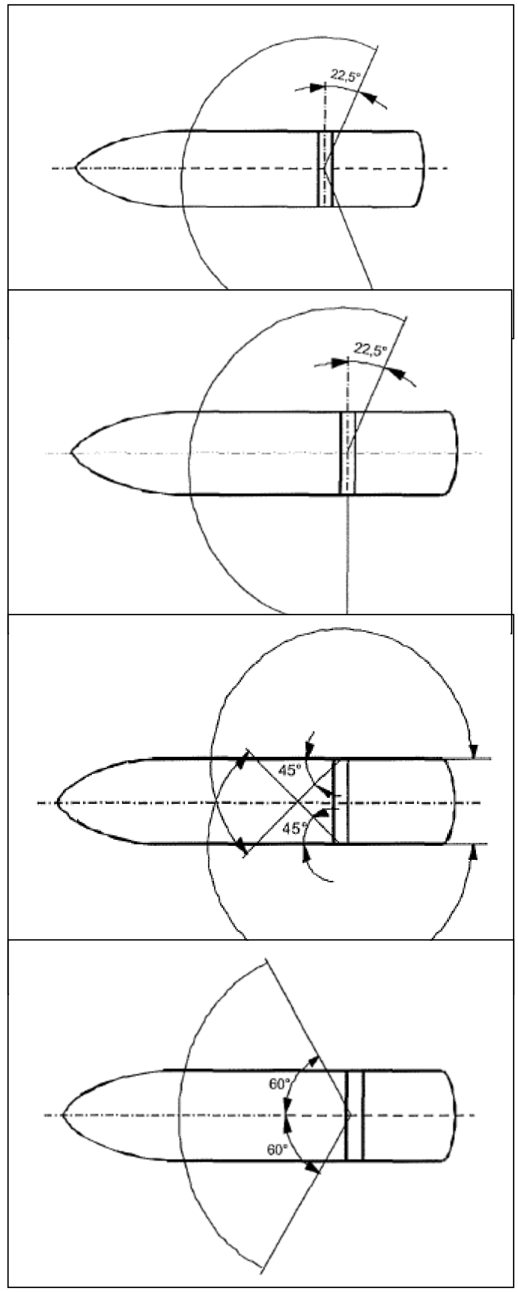
The view of the sea surface from the navigating and manoeuvring workstation should not be obscured by more than two ship lengths or 500 m, whichever is less, forward of the bow to 10° on either side under all conditions of draught, trim and deck cargo.

There should be a field of vision around the vessel of 360° obtained by an observer moving within the confines of the wheelhouse.

The horizontal field of vision from the navigating and manoeuvring workstation should extend over an arc of not less than 225°, that is from right ahead to not less than 22.5°, abaft the beam on either side of the ship.
If the view in the centre-line is obstructed by large masts, cranes, etc., two additional positions giving a clear view ahead should be provided, one on the port side and one on the starboard side of the centre-line, no more than 5m. apart.
From the monitoring workstation, the field of vision shou1d extend at least over an arc from 90° on the port bow, through forward, to 22.5° abaft the beam on starboard.

From each bridge wing the horizontal field of vision shou1d extend over an arc at least 225°, that is at least 45° on the opposite bow through right ahead and then from right ahead to light astern through 180° on the same side of the ship.
The ship's side should be visible from the bridge wing. Bridge wings should be provided out to the maximum beam of the ship. The view over the ship's side should not be obstructed.

From the main steering position (workstation for manual steering) the horizontal field of vision should extend over an arc from right ahead to at least 60° on each side of the ship.



An internal communication system between the workstation for docking and the workstation for navigating and manoeuvring should be provided when the distance between the workstations is greater than l0m. An internal communication system should always be provided between the workstation for navigating and manoeuvring and open bridge wings. Where workstations are widely spread, internal communication systems should be provided so that unhampered communications can be achieved under all operating conditions. It is important that all order/action communication systems be two-way. In practice a portofoon will be used in these circumstances.

The distance between adjacent workstations should be sufficient to allow unobstructed passage to persons not working at the stations. The free passage in passageways between different

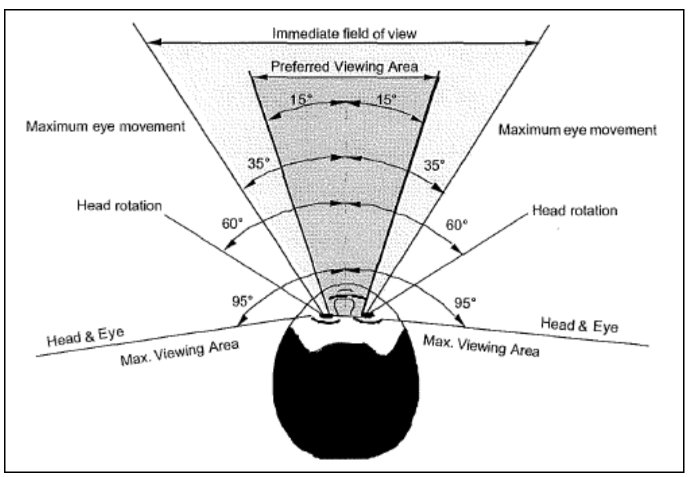
workstation areas should be at least 700 mm. The workstation operating area should be pmt of the workstation not of the passageway.
The distance of a passageway between the front bulkhead and any consoles should preferably be at least 1000 mm, and not less than 800 mm.

The workstations for navigating and manoeuvring, monitoring and for the bridge wings should be planned, designed and placed within an area spacious enough for not less than two operators, but close enough for the workstations to be operated by one person.

Displays providing visual information to more than one person on duty should be located for easy viewing by all users concurrently, or if this is not possible, the displays should be duplicated.
Controls and their associated displays should be located that the information on the displays can be easily read, during the operation of the controls.
Controls or combined controls/indicators should be visually and tactually distinguishable from elements which only indicate.

Controls should be located so that simultaneous operation of two controls will not necessitate a crossing or interchanging of hands.

The most important and frequently used controls should have the most favourable position with respect to ease of reaching and grasping should have a prominent position.
The most important and /or frequently used displays should be located within the operator's immediate field of view (viewing area with eye rotation only)



Controls and displays should be labelled clearly and unequivocally according to their function, possibly by using standardized symbols.
Adjustable lighting (dimming control) should be provided for controls and visual displays, including display, control, and panel labels and critical markings, which must be read at night or under darkened conditions. The range of the dimming control should permit the displays to be legible under all ambient illumination conditions.

Alarms should be provided to indicate sensor input failure or absence.
Alarms and acknowledged alarm should only be capable of being cancelled if the alarm condition is rectified. This cancellation should only be possible at the individual equipment
The number of alarms should be minimized.
Visual alarms should clearly differ from routine information on displays
Audible alarms should be used simultaneously with visual alarms.

Controls should be selected so that the direction of movement of the control will be consistent with the related movement of an equipment component, or vessel. The direction of motion of operating elements for manoeuvring equipment should correspond with the direction of the effect on the ship caused by the installations controlled.
Controls should be easy to identify and operate.
When precise reading of a graphic display is required, the display should be annotated with actual data values to supplement their graphic representation.

Experiences with use of ACD systems on the navigation bridge

It can occur that a sister ship may have a bridge layout which differs from the original. This can be due to input from the users or may be a change in legislative requirement.
Interviews with experienced ACD navigators have been executed, the results of which are reproduced on the following pages.

The following interviews were held;
Interview with Captain J. Bayens, experience as master on board of Cruise liners of the Holland America Line and equipped with AZIPULL systems.
Interview with Captain L. Toly, experience as master on board of gas carriers of Antony Veder and equipped with AZIPULL systems.

The information gathered in interviews has been summarized in the observations noted in sections 1.5.1, 1.5.2 and 1.5.3.

Bridge lay out and ACD console design,

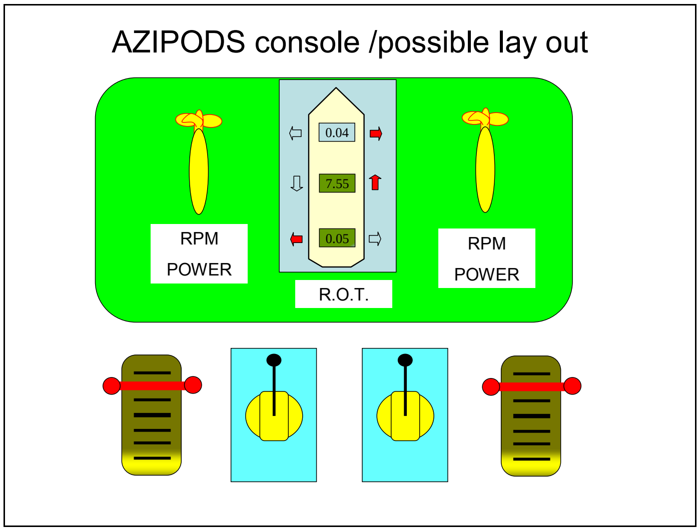
Closed bridge wings have the advantage to install instruments vulnerable to weather influence. Then navigational aids like a RADAR or ECDIS slave can be installed on this location. One disadvantage is the navigator must rely on instrumentation to a greater degree. As an example, the navigator looses the tactile sensation of wind shifts or increments as a result of being in a closed compartment.

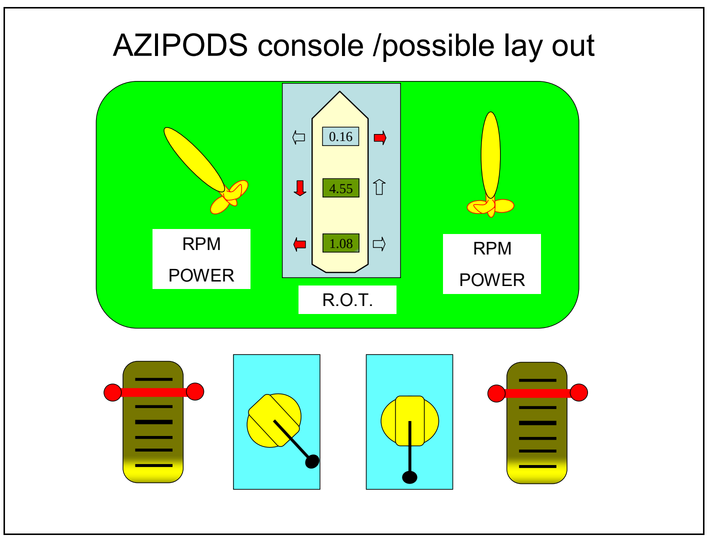
The central bridge console is equipped with an auto pilot, steering option, telegraphs for both thruster and the ACD handles. With closed bridge wings these elements are duplicated on each wing.

Some confusion can arise when changing from telegraph control to manual control of the engines and visa versa. What may appear as an ahead thrust on an AZIPULL can be interpreted incorrectly since the drive can be rotated, thus when switching to telegraph controls great care must be taken. Additionally changing from a central conning position to a bridge wing also presents opportunities. The bridge wing controls do not mimic the central controls but rather remain in the position when previously stopped. To maintain the exact engine forces when changing from the main console to the bridge wing requires precise setting of the controls before the wing console is activated.

Propulsion monitor

The presentation of the ACD’s direction should not confuse the navigator w.r.t. the direction of the thruster force and the water wash. As an example an AZIPULL figure may be displayed correctly but no indication of thrust force or direction is provided. Ideally, direction and force should be indicated which relates directly in magnitude and direction to the engine order.





Steering with the ACD handles may create confusions. The navigator should consider the turning effect of a force on the stern on the starboard or port side. A force to port means a turn to starboard. Thus a turn to starboard means a setting of the force of the thruster to port and vice versa. Compared to steering with a wheel this action can be considered opposite and incorrect. This may confuse navigators not familiar with this system.
A clear indication on the thrusters may improve the clarification.

Similarities in lay-out

The following table is a compilation of the separate requirements in the various manoeuvring phases.
With this overview a general lay out based on the ship types can be established and is presented in the table below.

	TYPE OF SHIP								FEATURES											
	Merchant marine	Navy	Harbour tugs	Inland ferry	Offshore supply vessels	Pipelayers	Icebreakers	sea going tugs	automatic / manual	coupled (C) / uncoupled (UC)	change to other console	in combi with other thrusters	position shiphandler relative to azipod console	ENVIRONMENTAL VIEW at azipod console	Observation of RADAR/ARPA from Azipod console	Observation of ECDIS from Azipod console	Observation of COURSE&SPEED from Azipod console	VHF at the AZIPOD console	Depth information at the AZIPOD console	Intensity of manoeuvring
Open sea	X	X				X	X	X	auto	C	No	No	A	A	Yes	Yes	No	No	No	
Confined waters	X	X				X	X	X	auto/man	C	No	No	A	A	Yes	Yes	Yes	No	No	
Anchor areas	X	X			X	X	X	X	man	C / UC	N							No	No	
Narrow channel / rivers	X	X	X	X	X	X	X	X	man	C/UC	No	No	A	A	Yes	Yes	Yes	Yes	Yes	
Open sea off shore					X				auto/ man	C / UC	Yes	Yes	A/B/C/D	A/B/C/D	Yes	Yes	Yes	Yes	No	
Port basins	X	X	X	X	X	X	X	X	man	UC	Yes	No / Yes	B/ C	A/B/C/D	Yes	Yes	Yes	Yes	Yes	
Terminal approach	X	X	X	X	X	X	X	X	man	UC	Yes	No/ Yes	B / C	A/B/C/D	No	No	Yes	Yes	No	
Short track ferry				X					man	UC	No/Yes	No	A/D/E	A/B/C/D or E	Yes	No	Yes	Yes	No	
Tug operation			X						man	UC	No	No	E	E	Yes	Yes	Yes	Yes	No	

Merchant marine and Navy vessels , Ice breakers, pipe layers

These vessels will have an ACD handling console in the centre navigation location on the bridge. The handles of both ACDs are placed aside of each other and can be reached from the command location. The handles can be in front or aside of the command location. A central console aside of the command location has the advantage that also an assisting navigator can handle the ACD from his/her own location.
Although icebreakers and pipe layers will frequently manoeuvre in open sea areas, a manual handling of the ACDS can be done from the central bridge location. On this type of vessel the VHF system must be handled without leaving the ACD consoles.
During manoeuvres in port basins and terminal approach areas the captain or commanding officer will change to a wing position on the terminal side. The lay out of the ACD console can be similar to the one in the central navigation console where the navigator stands behind the console but has full view of ship side and quay or jetty side. The following navigation information must be available at that location;

- Course / Speed (dual axis Doppler log)
- Wind
- Actual propulsion status (direction and force)
- Propulsion alarms / console in command alarms
- VHF
- Depth indicator

It would be an advantage to have a RADAR/ARPA or ECDIS slave available at this location.
Due to the delay between ACD order and ACD settings the actual propulsion status is relevant information for the navigator(s).

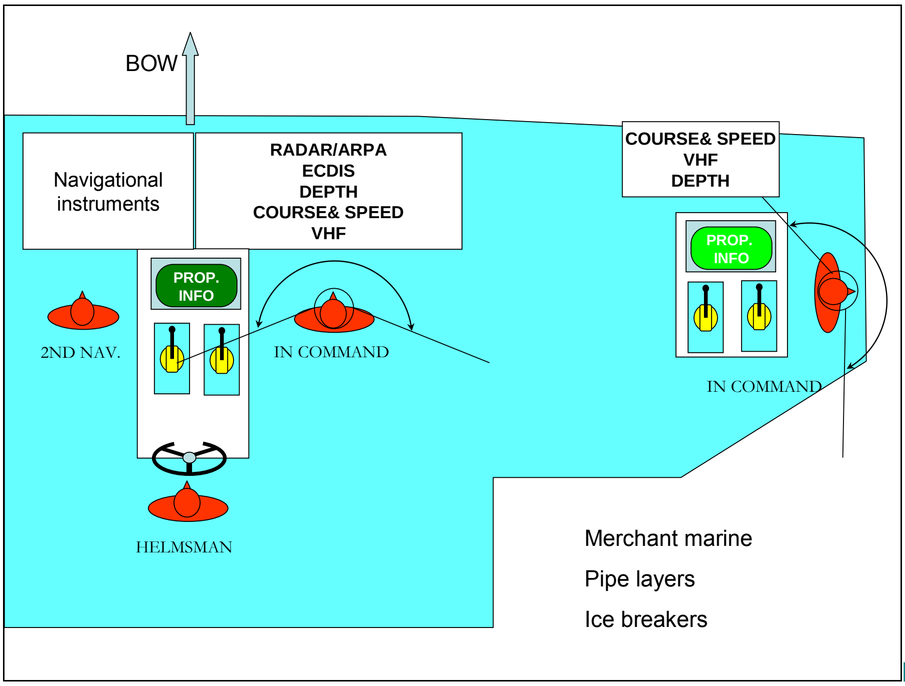


Fig ...

Off shore supply vessels

For the open sea, harbour approach and port manoeuvres similar lay out requirements as for the merchant marine are needed. For the off shore activities, including anchor handling, the vessel will frequently manoeuvre with a stern first approach. Then the navigator will stand behind a console facing the stern. A central bridge location with full view over the stern is in most circumstances not possible. In this case a wing location will be chosen, however the

view over the other side will be limited. A separate console at the stern of the bridge behind the engine room funnels is a better option for off-shore ship handling.
The following navigation information must be available at that location, both when facing the bow or the stern.

- Course / Speed (dual axis Doppler log)
- Wind
- Actual propulsion status (direction and force)
- Propulsion alarms / console in command alarms
- VHF

Since both manoeuvres with bow and stern first approach do occur, the navigator must stand in front or behind the ACD console without confusing him/herself about the orientation of the thrusters. A position between the thrusters could be a better option, similar to the lay-out on tugs.

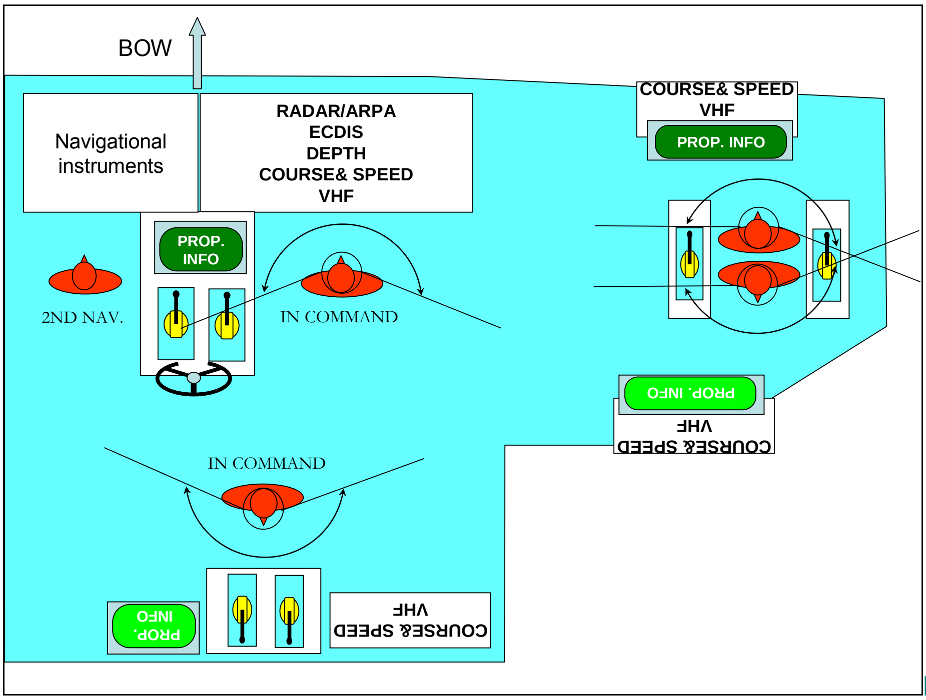
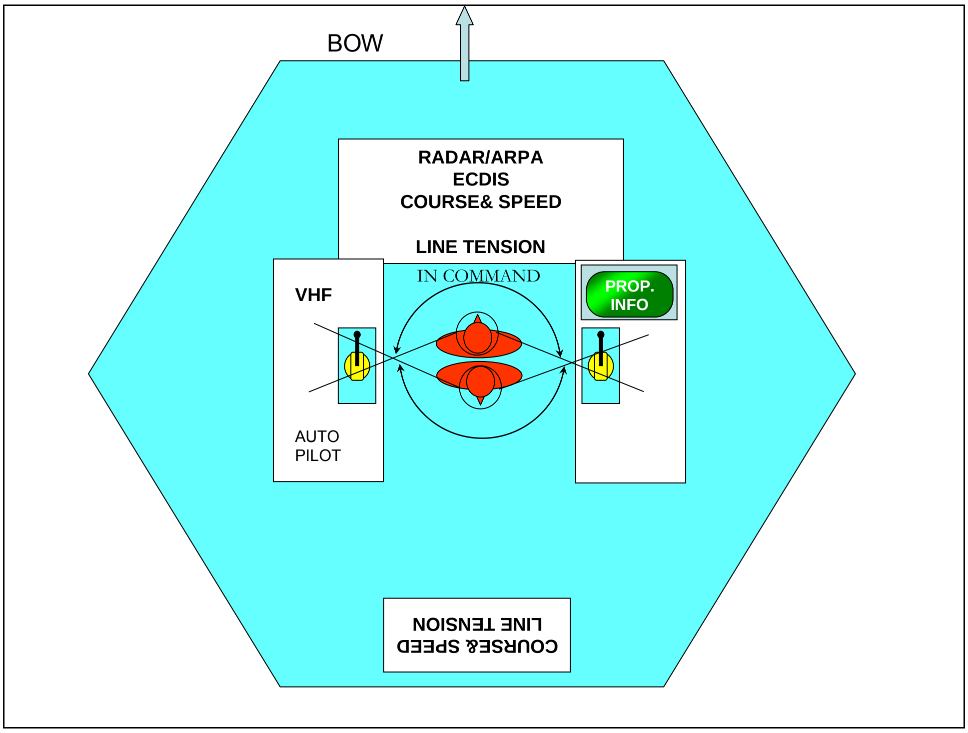


Fig ….

Harbour tugs, escort tugs.

Due to the constant handling of the AZIPOD thrusters by the navigator, the lay out of the navigation bridge is build up around the thruster handless.
In this position the navigator can operate the controls by touch while visually observing the surrounding relative motion. Other navigation, communication and propulsion systems and monitors can be placed on both sides reachable for the navigator while maintaining contact with the console handles.
For tugs with ACD propulsion the navigator must constantly to face the bow or stern of the tug during assistance. This can be done by turning around between both consoles and without a confusion about the orientation and handling of the starboard and port thrusters.


BOW
RADAR/ARPA
ECDIS
COURSE& SPEED
LINE TENSION
IN COMMAND
VHF
PROP.
INFO
AUTO
PILOT
LINE TENSION
COURSE& SPEED

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Annex

Questionnaire

Transcription of interview with expert ASD tug master and instructor

(These documents are attached to WP 3.3 report)

INDEX

Item (1) – "Review of the ergonomics of various control systems that are commonly used in conjunction with Azimuthing Control Drive systems"

Item (2) - "Discuss bridge and operational information systems"

ABSTRACT

The review of the manoeuvring processes executed by the ship handler with ACD systems in various manoeuvring circumstances clarify the need of optimal ergonomic lay- out and design of the equipment.
Specific ACD control lay out is required for the different type of manoeuvres and positions on the navigation bridge.
Particular attention is given to the lay out of the ACD handling controls, display of ACD status information and take-over command features.
Also the intuitive control, degree of automation and stress aspects play a role in the optimizing of the ACD control systems.
Finally the ergonomic requirements of the IMO guidelines on bridge lay out affects the ACD systems.
The review of a number of existing ACD control systems lead to the following conclusions;

- Existing products differ in great extend from each other and are rather representing the individual view of the manufacturer than based on a general philosophy regarding implementation of relevant ergonomic rules.
- Each observed system has in one way or another a less optimal element in the design or layout of the ACD control components.
- For the future more work has to be done to get more harmonized and optimal designed ACD control systems fully fit for the use by the ship handler in various manoeuvring circumstances.

1 Abbreviations

ACD pod –	Propeller system under ship’s hull.
ACD HD -	Combined thrust and azimuth device to control the ACD pod from the navigation bridge.
ACD CD -	Control device including ACD HD, information instruments and take over commands.
ACD console -	Console with all relevant ACD instruments and commands.
Azimuth angle-	The direction of ACD pod relative to ship heading.
Thrust-	The force created by the ACD pod
Water wash-	The water wash created by the ACD pod opposite to the thrust.
ROT-	Rate of turn of the ship
ECDIS-	Electronic Chart Display
Ship handler-	Person who takes care of the manoeuvre
ECR-	Engine Control Room

2 Approach

In order to say something about ergonomic aspects, the first step is to study the way the ship handler will use the ACD system in various manoeuvring situations. This work has already been written under the WP 3.3 (Maritime training Review of the human and physical and behavioural components) and has been taken into account within the specific chapters of this item.
Apart from the availability of ACD HD needed to executed the manoeuvre, the primary information of the status of the ACD pods (in command, rpm, pitch and azimuth angle) should be available in an easy observable way. A few comments are presented in the chapter “Technical requirements”.
The basic regarding ergonomic aspects is the man-machine interface as elaborated in chapter 4 to 9.
Apart from the men- machine interface the IMO guidelines regarding the bridge layout also show elements related to the ACD control equipment. Relevant requirements from this IMO document are mentioned in chapter 10 together with added specific comments from ACD control point of view.
In the chapter 11 a number of existing ACD control systems have been reviewed and comments are made based on the ergonomic aspects mentioned in the previous chapters.

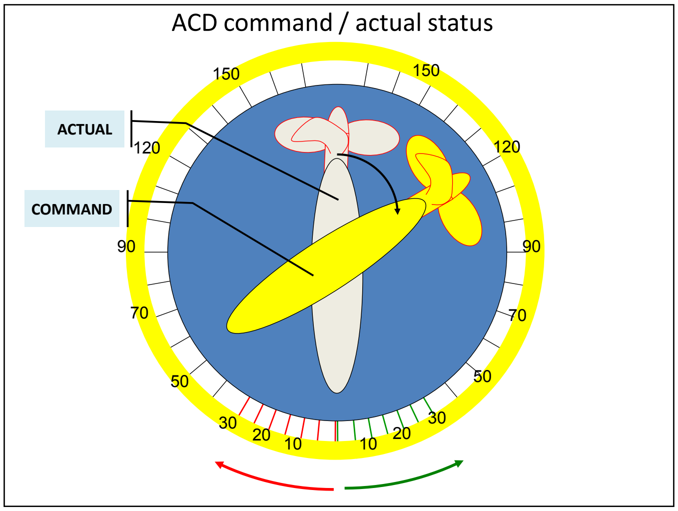
3 Technical requirements of ACD CD.

The requirements of the ACD CD from a technical point of view are rather simple.
ACD with a fixed pitch propeller the r.p.m. and azimuth angle are the variables controlled from the navigation bridge.
ACD with a variable pitch propeller the r.p.m., pitch and horizontal direction are the variables to be controlled. The pitch / r.p.m. relation is regulated by a separated automatic control system in the engine room, the ship handler only controls the thrust magnitude.
In general the information of the ACD status on the navigation bridge depends on the propeller type and should preferably be as indicated in the table below;

Propeller type	RPM	Pitch setting	Thrust magnitude	Azimuth angle
Fixed pitch	X	(Constant)	X % of max.	X (0º-360º)
Variable pitch	X	Variable (% of max)	X (% of max.)	X (0º-360º)

Regarding the ACD HD two types of information must be available;

- The command set by the ship handler
- The actual performed thrust and direction of the ACD.



The ACD CD information in the first place must be easily available for ship handler, but also some relevant information can be presented on a monitor observable by others involved in the navigation.

The actual ACD performance such as “in command”, rpm, pitch, azimuth angle and alarms will be presented on separate instruments or combined on monitors. The layout of this information is important in relation to a quick scan by the ship handler. This should be such that the ship handler in a glance is aware of the ACD actual status.

There are several options to present the lay-out of the controls as separate or combined information as later on dealt with. The actual design of the controls and information particularly dependant on;

- The man-machine interface.
- Type of ship
- Type of manoeuvre

They determine how the ACD CD should be presented to the ship handler.

The following chapter will discuss these aspects in detail.

4 Man- machine interface

Amongst the aspects when designing a man-machine interface, many human factors play a role as well.
In order to get an overall view of these aspects one should review the following elements separately;

- Mental process to translate the required behaviour of the ship into ACD settings
- Optimal presentation of the information to the ship handler and other navigators on the bridge.
- Lay-out aspects in relation to intuitive control and automation
- Change in performance of the ship handler due to stress.

4.1 Mental process

The ship handler analyses the behaviour of the ship by observing the environment and available instruments i.e. speed and rate of turn.
The information regarding movement of the ship, by observing the outside view, is instantly available and is considered a reliable source. The ship handler will interpret this kind of information into the actual position and movement of the vessel.
The type and amount of required information depends on the navigational circumstances as shown in the table below.

	FEATURES											
	automatic / manual	coupled (C) / uncoupled (UC)	change to other console	in combi with other thrusters	position shiphandler relative to azipod console	ENVIRONMENTAL VIEW at azipod console	Observation of RADAR/ARPA from Azipod console	Observation of ECDIS from Azipod console	Observation of COURSE&SPEED from Azipod console	VHF at the AZIPOD console	Depth information at the AZIPOD console	Intensity of manoeuvring
Open sea	auto	C	No	No	A	A	Yes	Yes	No	No	No	■
Confined waters	auto/man	C	No	No	A	A	Yes	Yes	Yes	No	No	■■
Anchor areas	man	C / UC	N							No	No	■■■
Narrow channel / rivers	man	C/UC	No	No	A	A	Yes	Yes	Yes	Yes	Yes	■■■
Open sea off shore	auto/ man	C / UC	Yes	Yes	A/B/C/D	A/B/C/D	Yes	Yes	Yes	Yes	No	■■■■
Port basins	man	UC	Yes	No / Yes	B/ C	A/B/C/D	Yes	Yes	Yes	Yes	Yes	■■■■
Terminal approach	man	UC	Yes	No/ Yes	B / C	A/B/C/D	No	No	Yes	Yes	No	■■■■■
Short track ferry	man	UC	No/Yes	No	A/D/E	A/B/C/D or E	Yes	No	Yes	Yes	No	■■■■■
Tug operation	man	UC	No	No	E	E	Yes	Yes	Yes	Yes	No	■■■■■■

The observation of the environment plays the most important role when manoeuvring in areas where change in position or movement of the vessel demands instant change in ACD HD settings. This is the case in the following circumstances ;

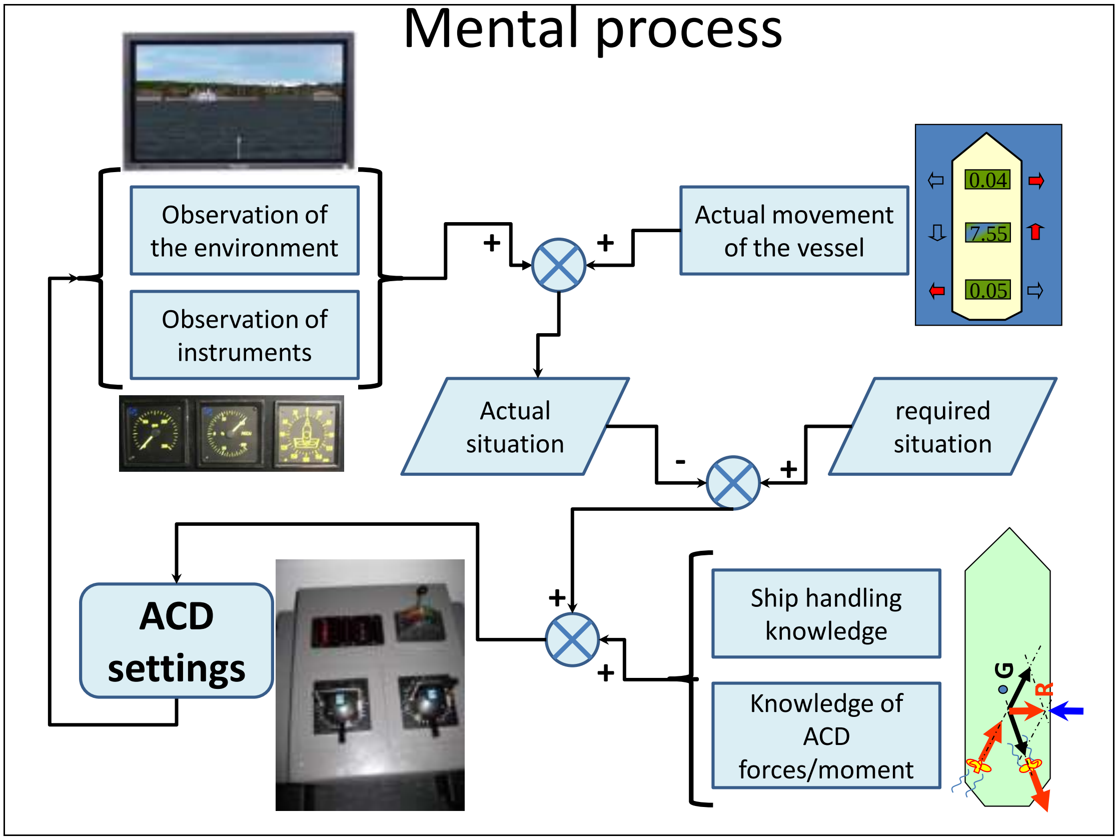
- Ship handling in congested waters to give way to other vessels
- Ship handling in areas with restricted manoeuvrability such as traffic separation zones, anchor areas, port approach, rivers, terminals , locks and bridge passages.

In open water with limited traffic and during restricted visibility other sources of information shall be observed to ascertain ship position and movement, to mention ;

- Radar (RADAR/ARPA)
- Fixed positions in paper chart or electronic chart displays (ECDIS).
- Speed information from SALLOG, Dual Axis Doppler log, GPS or DGPS

In the case of manoeuvres whereby the ship handler will more frequently change the settings of the ACD HD the more the ship position and movement will be observed by outside view or instruments. This implicates that the time available to observe the settings of the ACD HD will be less to almost zero. The ergonomics of the ACD HD's should take this into account. This aspect is further elaborated in following chapters.

The information regarding the position and movement of the ship will be in the mind of the ship handler combined with the required behaviour of the vessel. If this is to the satisfaction of the ship handler than the setting of the ACD's will not change, if not a next mental step takes place.
The ship handler will ascertain (in his mind) how to set the ACD's to change the vessel's position or movement as required.
For instance if the speed of a vessel is too high, the ship handler will reduce the thrust on the ACD pod's but it is also possible to reduce speed by changing the directions of the ACD's or reduce thrust on only one ACD. The latter depends on the foreseen situation in the future after the speed reduction.
If the vessel requires lateral movement than the ship handler has more options to do so. In many circumstances this will be a combination of the settings of the ACD together with a bow thruster.
The settings of the ADC's itself is a complex matter due to more than one possibility to obtain the same results. The experience and ship handling knowledge affect the time needed to take the right decision regarding ACD HD settings but also the lay out of the ACD HD and the relevant information at the ACD console is of vital importance to improve this decision making phase.
In general, it can be stated that the ship handler acts not purely in an intuitive way but also a conscious decision moment may occur. The degree of intuitive control depends on the experience in ship handling with ACD systems . For instance a tug master constantly handling the ACD HD's will act much more on intuitive control than a master on a cruise liner or tanker with larger intervals between manoeuvring actions.

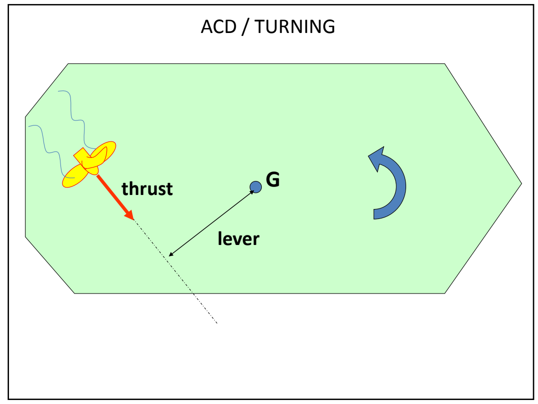


As a next step the ship handler shall observe the results of the new ACD HD settings and find out whether this is in accordance with the expectations. The delay of the change in thrust and azimuth angle of the ACD pod's is an important element in this phase. The ship handler cannot change these delays but must be able to observe it in order to realize when changes in settings become effective. For instance the time needed to change the ACD pod's from dead ahead to dead astern in order to slow down ship speed before turning the thrust to dead astern may for example last 60 sec. and during this period the ship handler should not expect much of a slowdown of the ship speed, but as soon as he sees that the ACD pod is in position he/she can increase the thrust and the speed drop will start. .
In general the difference in command settings and the actual situation of the ACD is a vital source of information and should be presented in an easy observable way to the ship handle (see figure in chapter 3).

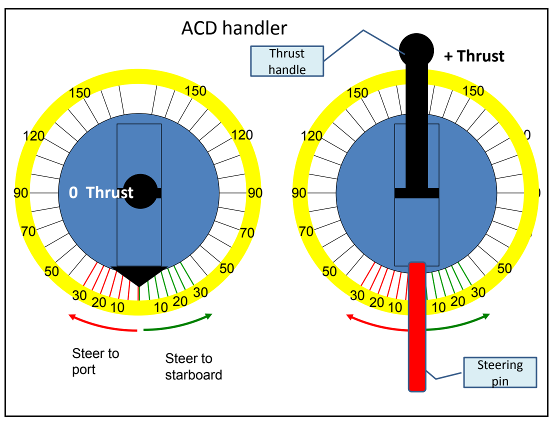
4.2 ACD HD lay out.

To understand the correct lay out of an ACD HD first of all the relation ACD thrust and ship movement should be reviewed.

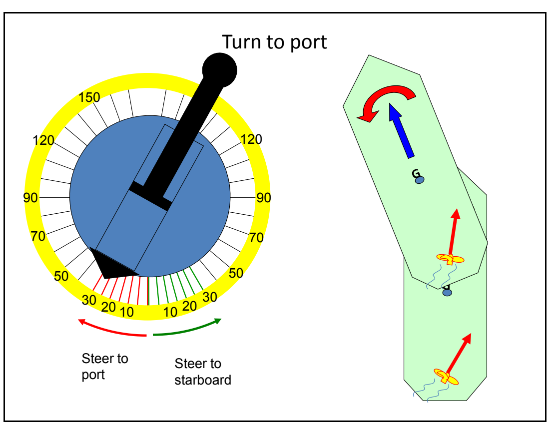
The movement of a ship depends on the magnitude and direction of the produced thrust. The ship speed is dependent on the magnitude of the thrust. The ship turning rate is dependent on the moment created by the thrust and depends of the magnitude of the thrust and the lever relative to the centre of gravity of the ship. The same turning can be attained by a larger thrust and a small lever (azimuth angle) or a small thrust and a larger lever. This is one of the reasons to combine thrust and azimuth setting in one handler.

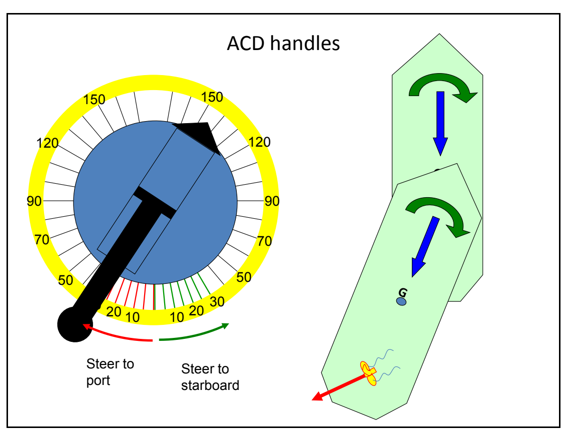


To turn a ship to starboard the thrust is set to port similar to a helm stick but opposite to the common wheel handling on board of ships. The ACD handler must clearly indicate direction of the thrust (and not the water wash) and the turning direction of the ship by setting the handler. And good ergonomic option is the steering pin on the backside of the handler. This pin will be placed in the same direction as the turning of the ship (pin to starboard means ship turns to starboard).



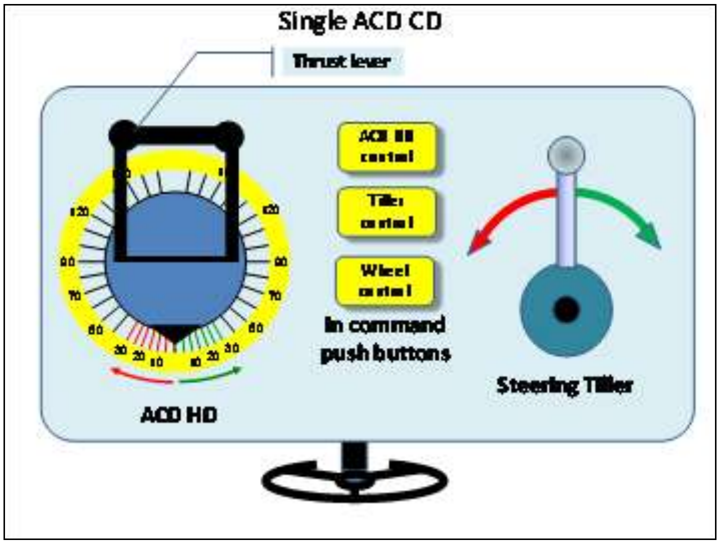
However in manoeuvring modes where the ACD is set in directions more than 90º the steering pin may cause confusions as shown in the right figure below.





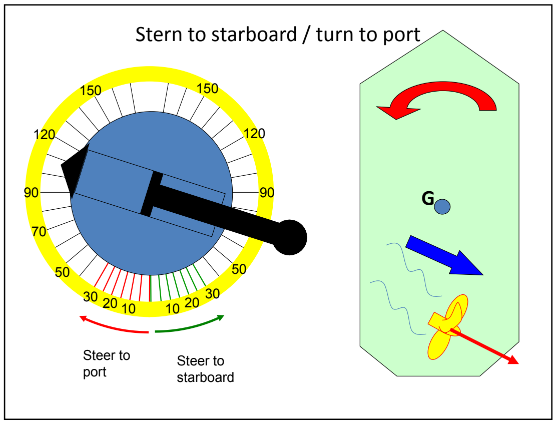
5 ACD HD lay out in relation to type of propulsion

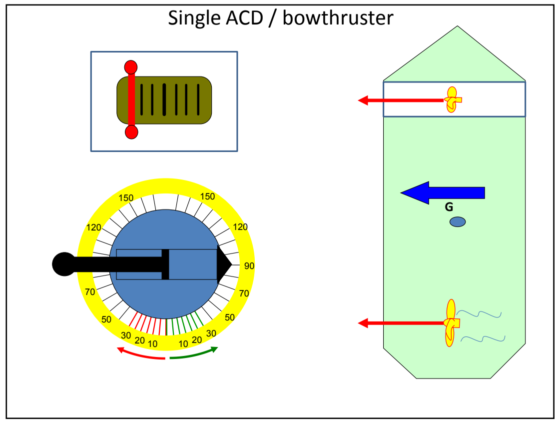
5.1 Single ACD pod



<u>Sea condition</u>
Ships will be handled during course keeping and course alterations while having a service speed. This lay out on a ship acts in a similar way as a combination of a fixed propeller and a rudder. The azimuth angle of the ACD pod will be limited in order to limit forces and vibrations on the vessel. The ship is manually steered or the system is coupled to an auto pilot. Manual steering can best be done with a normal steering wheel since azimuth angles up to 30º are sufficient to change the heading. Some lay outs have a tiller control in the central ACD console to take over the steering by the officer of watch. A lay out of the tiller as shown below has a similar orientation to the steering wheel (pin pointing ahead).

<u>Manoeuvring condition</u>
In the manoeuvring mode an ACD HD will be set in any thruster force and direction. Then, the ship handler will think more in forces and moments than in turning directions. The thrust lever position of the ACD HD informs the ship handler about the actual ACD thrust force. The thrust direction is observed on the azimuth angle scale but the orientation should be observed by the direction of the thrust lever and not by the red or green colours.





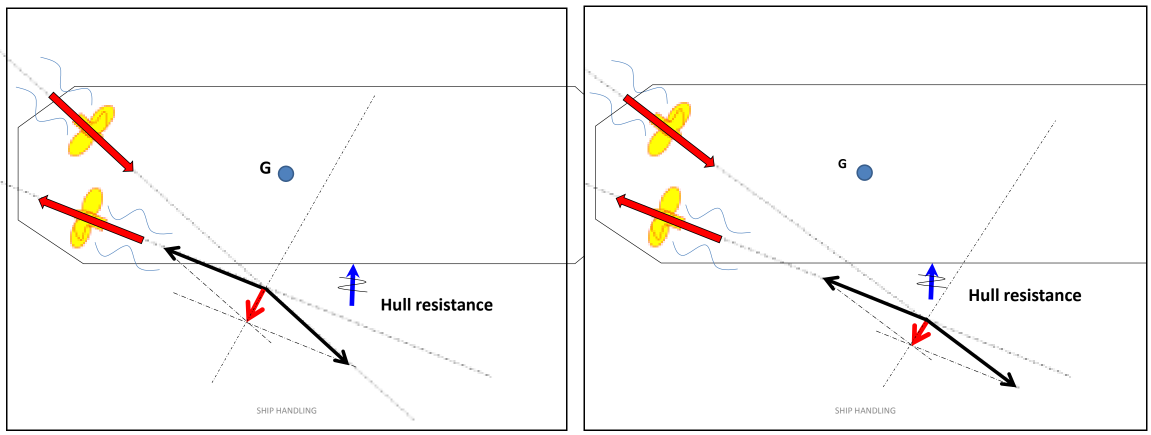
<u>Change over from sea condition to manoeuvre condition</u>
At any time the ship handler must be aware whether the ACD control is wheel, tiller or ACD HD control. In more critical ship handling situations a fast switch from sea to manoeuvring mode or from wheel steering to tiller steering may be necessary. Therefore, the change over method should be simple and clear with minimum chance of using accidently other switches like a shut down command.
A clear indication of the status of the ACD control should be available on each ACD console. An audible alarm (for a short period) can inform the ship handlers about the take- over status without actually observing the instruments.

5.2 Twin ACD pod's

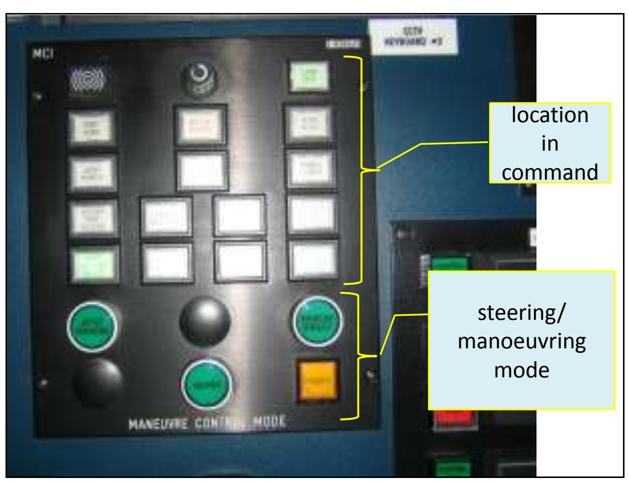
<u>Sea condition</u>
In service speed the ACD's are coupled and course keeping or course alteration will be done with small azimuth angles either by hand steering or by the auto pilot. The azimuth angle is limited up to 30º in this mode.
Manual steering can best be done with a normal steering wheel since only small azimuth angles are sufficient to change the heading. For faster course alterations a tiller control can be used .
Steering can be done by one or two ACD's. A clear indication whether the system is coupled or not must be available for the ship handler at each control location. The change over method should be simple and clear with minimum chance of using accidently other command functions.

<u>Manoeuvring condition</u>.
The ACD pod's are used in coupled or uncoupled mode. Many different settings of the ACD pod's may lead to required ships movement.
A few limitations in setting may occur. For instance the setting of an ACD with full power in a direction with the water wash towards the ship hull to avoid hull vibrations. This reduction may also be arranged as an automatic setting by the system.
Setting the ACD's in different directions and with different thrust forces, the actual effect on the ship is a resulting force derived from the 2 force vectors as shown in the figure below. The ship handler should try to estimate the direction and position of this resulting

force to find out which movement of the vessel will probably occur. The accuracy of this estimation is limited and will only improve by more experience.
As an example, the crabbing (side stepping) of a ship can be done by the ACD azimuth setting with less than 20º off the ship centreline. See figure below This manoeuvre has to be executed with high thrust power. Any change in power or direction may significantly change the movement of the ship. The reason is a fast change in position of the resulting force relative to the centre of gravity with only small changes in ACD forces or directions.
In this respect it would help the navigator if the actual resulting force based on the individual ACD settings is shown on a display in a ship contour.



<u>Change over from sea condition to manoeuvre condition</u>
At any time the ship handler must be aware whether the ACD control is in “Sea” or in “Manoeuvring” mode. In more critical ship handling situations a quick switch from sea to manoeuvring mode or from wheel steering to tiller steering may be necessary. Therefore, the change over method should be simple and clear with minimum chance of accidently using other switches like other take buttons or a ACD shut down command. Also the indicated command terminology should be unambiguous.
A clear indication of the status of the ACD control should be available on each control location.



6 Lay out of ACD CD in relation to Intuitive control

There is also a significant relation between the design of the ACD CD and the degree of intuitive control by the ship handler. As mentioned before the intuitive control of ship handlers in high frequent manoeuvring conditions will be more than for persons executing manoeuvres with larger intervals.
The following statements regarding intuitive control as elaborated in WP3.3 are considered to be relevant with respect to the layout of a ACD CD.

- *The human machine interface is called intuitive and refers to intuitive use that should not demand high cognitive resources.*
- *A technical system is, in the context of a certain task, intuitively usable while the particular user is able to interact effectively, not-consciously using previous knowledge"*
- *If the user does not perceive objects and signs as attractive and usable, or at least familiar, then the application or product has almost no chance of being used intuitively.*
- *In most cases usability is a complementary goal in that a highly usable interface will make the operator more comfortable and reduce anxiety*
- *The human machine interface should be easy and intuitive for operators to use, but not so simple that it provokes a state of complacency and lowers the operator's responsiveness to emergency situations.*

As indicated in the preceding chapters the ACD control can be complex requiring higher cognitive capabilities.
The less the ship handler has to conscious review the process to change the actual situation into a required situation and consequently how to handle the ACD HD, the faster more reliable and more relaxed performance will occur.
A more intuitive control approach can be reached by the following aspects;

- More engraved knowledge how the ACD thrust is translated to ship movement
- More practical experience in handling the ship with ACD's
- An optimal lay out from an ergonomic point of view by clear, simple and unambiguous presentation of the information.

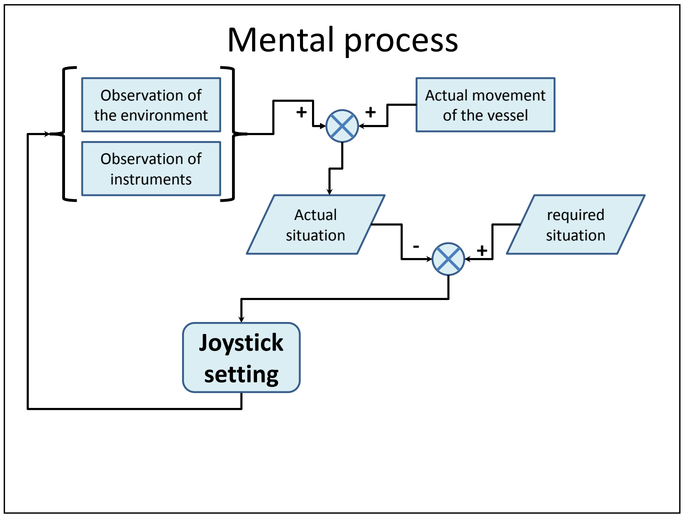
7 ACD CD Lay out in relation to Automation

The following statements regarding automation as elaborated in WP3.3 are considered to be relevant with respect to the layout of ACD controls.

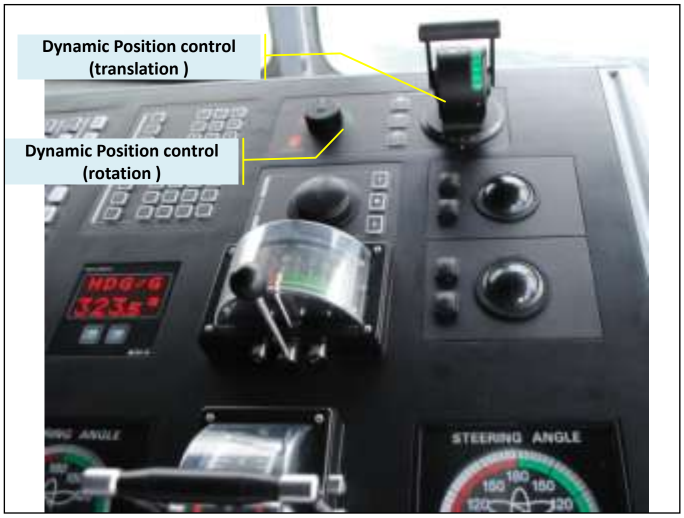
The goal of progressive automation is to maximize system safety and efficiency by reducing human workload and error. However, it can also increase some problems related to both cognitive processes and operative procedures. There is a concern for increased human boredom, decreased motivation, loss of situational awareness, over-reliance on and misuse of automated systems, and deterioration of skills

The development of highly complex systems frequently means that no one person understands the whole system or has complete control of it. Furthermore, the circumstances of their use can never be completely specified and the resulting variability of performance is unavoidable.[1]

In this respect the handling of the twin ACD's (possibly in combination with bow thrusters) by an indirect joystick control system would simplify the operation. Then the ship handler ascertains the required movement based on the actual situation without the need to translate the required movement into the combined setting of the ACD HD's together with the bow thrusters. In principle the simplification of the ship handling process is so clear that , errors in ACD HD settings, interpretation of ACD information and stress levels will significantly be reduced.



However, the ship handler is less aware of the actual use of the ACD thrusters in combination with the bow thruster. If the ship handler has to change to manual ACD control he/she might need more time to understand how to react on the actual movement of the ship, possibly creating more critical situations. In practice this appeared to be a restrictive factor that hold back many ship handlers to work with an indirect joystick



[1] The Human Element a guide to human behaviour in the shipping industry MCA report

control system. This is in particular the case in situation where maneuvering with high frequency ACD HD settings occur, such as with tugs and ships maneuvering in ports. There also is a general feeling that the maximum capacity of combining the ACD with bow thrusters is not available when using this automated control. Then in more extreme weather conditions ship handlers tends to change over to manual ACD and thruster settings.
Use of Dynamic Position (DP) control systems, as common on supply vessels, if not stationary a joystick option is available and will be used to control the ship movement. This confirms at least for specific maneuvering situations that joystick control can be a good ship handling option.

8 Lay out in relation to Stress of ship handler

The following statements regarding stress as elaborated in WP3.3 are considered to be relevant with respect to the layout of ACD controls.
Events that involve very strong demands and are imminent will cause stress with the ship handler.
Ambiguity –a lack of clarity in a situation- can have an effect on stress appraisals.
Emergency situations are examples of high stress situations. Especially in these kinds of situations making use of intuitive interfaces could be beneficial.

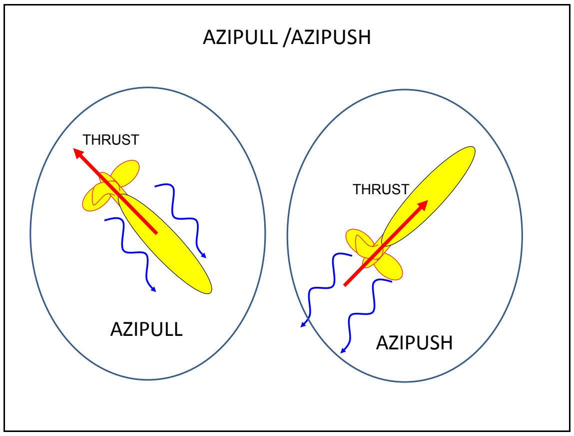
To minimize stress the lay out of the ACD control and monitor system can play an important role. A simple and clear presentation of the required information and well separated between primary and secondary sources will decrease the stress level of the ship handler. Also the reduced need to seek for information by switching from the observation of the environment to instruments will reduce stress levels. In particular the prime information sources such as the actual position of the ACD direction and force should be clarified by just a split second of observation. Also the setting of the ACD handlers by “feeling” instead of observing may decrease the amount of stress during manoeuvring situations with a high frequency of setting alterations.

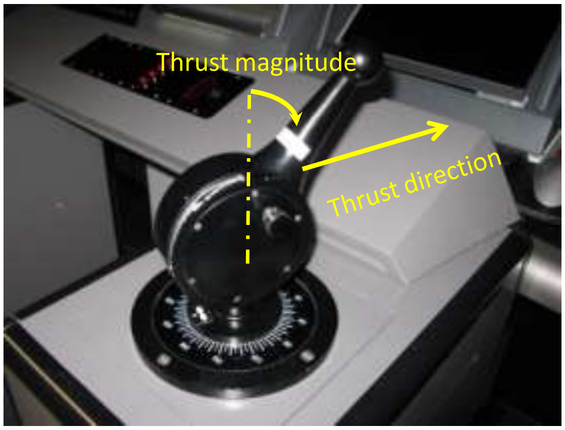
9 Points of attention for ACD CD equipment

There are some doubts that the arguments used by the manufacturers regarding the design of the ACD HD and the ACD related displays as well as the console dimensions are not fully taken the ergonomic laws into account.
Comments regarding the dimensions of ACD consoles are mentioned in chapter 10.
With respect to the optimal design of the elements if the ACD CD the following points of attention can be mentioned.

9.1 ACD HD

A clear indication that the ship is equipped with an azipull or azipush system.
An ACD handler without confusing the ship handler about the magnitude and direction of the thrust (opposite to the water wash).



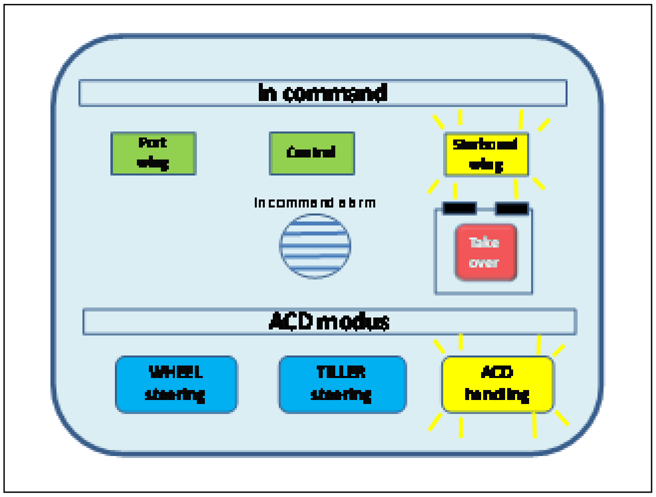


Manoeuvres whereby the ship handler must change the settings frequently and observe the environment almost constantly, the actual setting must be known by feeling rather than observing. This requirement ascertains the shape and size of the ACD HD as well as a notch for the 0 thrust and 0º azimuth setting is needed to feel the default settings. Preferably a notch is also placed for 90º and 180º azimuth angles.

<u>ACD status display</u>
The ACD command and actual status (azimuth, thrust or rpm) should be displayed in a clear and simple way. Only a glance of less than 1 second is enough to overview the actual situation. Additional information such as load, power plant status, should be a bid separated from the basic manoeuvring information.
In particular for the intuitive control while the ACD's have a different direction and thrust, a resulting force and location of the force presented as a vector in a ship contour would significantly help the ship handler.

Switch over to other ACD console location

A simple, clear and unambiguous procedure to change to another ACD control location is required. On each console a clear indication of its status must be shown in order to minimize the procedure and status observation.



A critical element in the take over process is the setting of the ACD HD between the actual and the new ACD CD. A difference in settings will change the movement of the vessel after a take -over with possibly creating a critical situation. It is common practice that the ACD handlers are set in a default setting (0 thrust and dead ahead) on both stations before a “take over” command. In extreme weather conditions this intermediate stop of the ACD thrusters should be limited in time as much as possible by a fast take over procedure. The ship handler must work in an adaptive manner to take over in advance of more critical ship handling situations.

An continuous synchronize of the settings on all ACD control stations would overcome this problem but then the ACD handlers at the stations not in control should be untouchable for instance by a Plexiglas cover.

10 Other navigational information

As further explained in this work package (2.4 item 5) , the ship handler needs additional navigation information to fulfil the ship handler task, to mention;

- Ship Course and speed (longitudinal / lateral) and rate of turn .
- RADAR/ARPA or ECDIS monitor.
- Wind direction and speed.
- VHF communication.
- Automatic Identification System (AIS).
- Depth indicator .

<u>Ship Course and speed (longitudinal / lateral) and rate of turn</u>
Apart from the observation of the environment to ascertain the ship movement , the ship speed in longitudinal and lateral direction, the pivot point and the rate of turn can be and will be observed by Doppler dual axis log or dual sensor DGPS instrument. Speed and rate of turn information should be easily observable from the ACD HD location, preferable in the immediate field of the view sector. (see 2.4 /item 5) .

<u>RADAR/ARPA or ECDIS slave</u>
Apart from the observation of the environment to ascertain the ship position, and in particular during restricted visibility, the ship handler will observe the RADAR/ARPA or ECDIS monitor. With the modern high accurate sytems judgement of distances to other objects observed on this equipment can be more accurate the by observing the environment. The monitor should be observed without leaving the ACD control station and preferably within the immediate field of view sector. (see 2.4 /item 5) . Since the ECDIS gives the most comprehensive information of the ship in its environment and if reliable, this instrument is in favour of the RADAR/ECDIS as long as ship target information is superseded on this monitor.

<u>Wind direction and speed.</u>
To ascertain the correct settings of the ACD and bow thrusters, the ship handler must also take into account the existing wind condition. A regular observation of this instrument is needed, in particular on bridges with enclosed wings. Without leaving the ACD control station the ship handler should be able to observe the wind meters.

<u>Communication</u>
During manoeuvres also communication for instance between ships and tugs is needed. If the ship handler also takes care of the communication a VHF must be handled without leaving the ACD CD station.
On tugs and inland water vessels, where a constant hands-on of ACD HD is necessary, the VHF is controlled by foot pedals with a microphone hanging from the ceiling near the ship handler. Also communication between the ship handler and other ship locations should be available nearby the ACD consoles.

AIS
To reduce the time of communication with other ships the AIS is a relevant source of information. Preferably the name of each target from the AIS system is presented on the RADAR/ARPA or ECDIS.

Depth indicator
In a number of ship handling situations a regular control of the available depth is needed. Then also the depth indicator should be available in the neighbourhood of the ACD control station.

The following table summarizes the relation between required information and the related instruments in the vicinity of the ACD consoles

	Information required nearby the ACD CD						
	Course	Speed	ROT	Position	Wind	Commu nication	Depth
Gyro compass	X		X				
Doppler log		X					
DGPS	X	X	X				
RADAR/ARPA				X			
ECDIS				X			
VHF						X	
AIS						X	
Echo sounder							X
Wind meter					X		
Intercom						X	

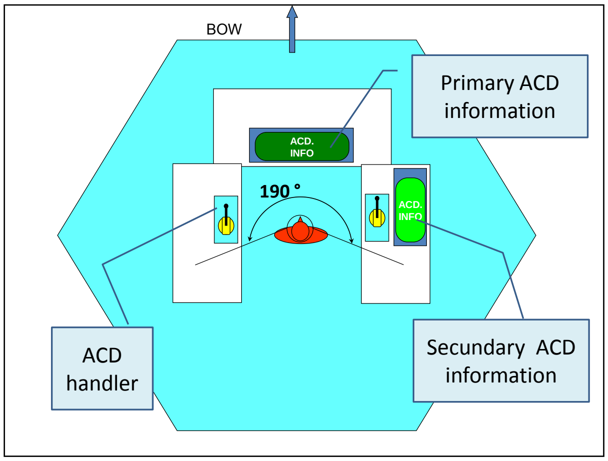
11 IMO guidelines affecting ACD CD lay out

A number of general aspects concerning bridge lay out are mentioned under WP 2.4 item 5 (Review of similarities between different (sister) ships).
The following additional items from the IMO document MSC circ. 982 are relevant with respect to the layout of ACD CD and consoles.

11.1 Viewing Angle on consoles

The console should be designed that from the normal working position the total required left-to-right viewing angle should not exceed 190º. This angle shall be reduced whenever possible through appropriate control-display layout.

With common bridge lay out this requirement can be met. For console lay out like installed on tugs, the ACD instruments should not be placed in locations aft of the ship handler position.



11.2 Displays

Controls and their associated displays should be located that the information on the displays can be easily read, during the operation of the controls.
Displays providing visual information to more than one person on duty should be located for easy viewing by all users concurrently, or if this is not possible, the displays should be duplicated.
Controls or combined controls/indicators should be visually and tactually distinguishable from elements which only indicate.
Displays should present the simplest information consistent with their function; information irrelevant to the task should not be displayed, and extraneous text and graphics should not be present.

For a central bridge console, with a command and assistant location, the ACD HD and primary ACD displays should also be observable by the assistant navigator. A good solution is to place the primary ACD displays in an overhead location.

11.3 Location of Primary and Frequently Used Controls

The most important and frequently used controls should have the most favourable position with respect to ease of reaching and grasping (particularly rotary controls and those requiring fine settings), e.g., keys for emergency functions should have a prominent position.

Apart from the location of the ACD HD, ACD take-over and the emergency stop buttons should also be in an easily reachable position, however, not in such a place that accidental activation during ACD HD handling should occur.

11.4 Consistent Arrangement

The arrangement of functionally similar or identical controls should be consistent from work station to workstation, panel to panel throughout the bridge.

ACD control and displays should have such a uniform lay out on the different locations that misjudgment in how to handle the ACD controls or how to interpret the displays should not take place in even more stressful situations. In particular the ACD HD design should be similar at each location as well as the display of the command and actual status of the ACD pod's.

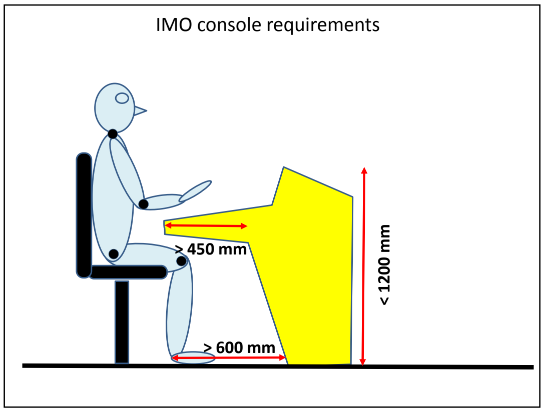
11.5 Alarm Acknowledgement

Alarm systems should clearly distinguish between alarm, acknowledged alarm, and no alarm (normal condition).
A method of acknowledging all alarms (silence audible alarms and set visual alarms to steady state), including the indication of the source of the alarm, should be provided at the navigating and manoeuvring workstation, to avoid distraction by alarms which require attention but have no direct influence on the safe navigation of the ship and which do not require immediate action to restore or maintain the safe navigation of the ship.

11.6 Console dimensions.

The top of the consoles should not exceed a height of 1200 mm.
The upper leg room of the console should have a minimum of 450 mm in depth and the lower leg room a minimum of 600 mm in depth.
The console should be dimensioned and configured so that all relevant controls can be reached from a sitting position.

For an ACD console on the bridge wing the ship handler will stand and consequently the dimensions should be adapted accordingly.



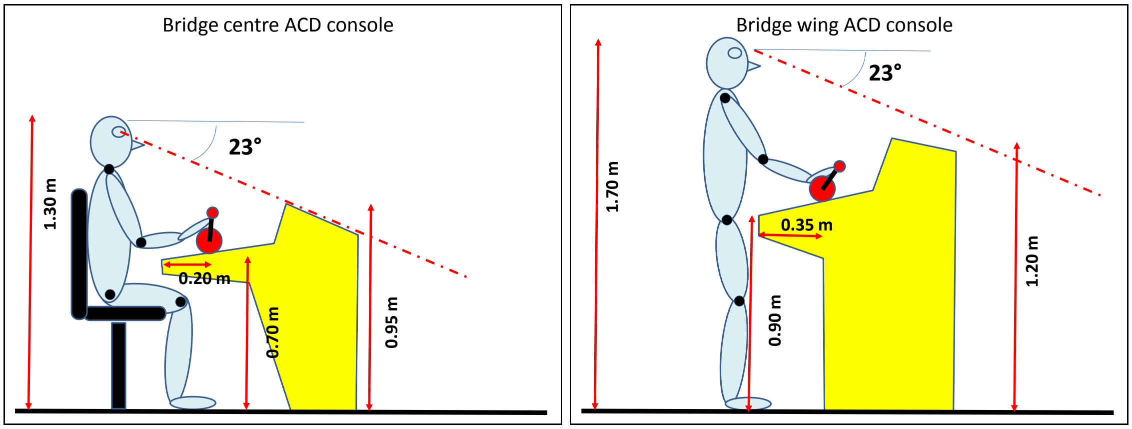
The design as shown is from an ergonomic point of view acceptable but also should take into account the proper observation of the environment.

11.7 Control location in consoles

Controls requiring frequent or accurate settings should not be placed more than 675 mm. from the front edge of the console.

For ACD HD this can already be too far away for a relaxed way of operation by the ship handler.
Controls should be located so that simultaneous operation of two controls will not necessitate a crossing or interchanging of hands.

To comply with the IMO guidelines the ACD controls should not be placed more than 675 mm. from the front edge of the console. For the consoles with the ship handler in a sitting position the ACD HD preferably have a distance of about 0.20 m. from the edge. For the standing position like on the bridge wings the ACD HD should preferably be placed not more than 350 mm. from the edge.



To maintain a vertical angle of view of about 25° the height of the console should not exceed about 1200 mm. for a standing position and 950 mm. for a sitting position.

12 Ergonomic remarks on existing ACD systems.

Based on observation of a number of ACD control systems in practice and the ergonomic arguments mentioned before, the following remarks can be made.

12.1 ACD HD.

As mentioned before the design of the ACD HD is of paramount importance since the actual setting should not be observed but sensed by the ship handler.
To set the thrust lever from stop to full power (90º) the hand is placed on the lever. To turn the ACD HD the hand is moved to the lower body, then a continuous sense of the actual setting is partly lost.
From that point of view the size of the shown ACD HD is too large.

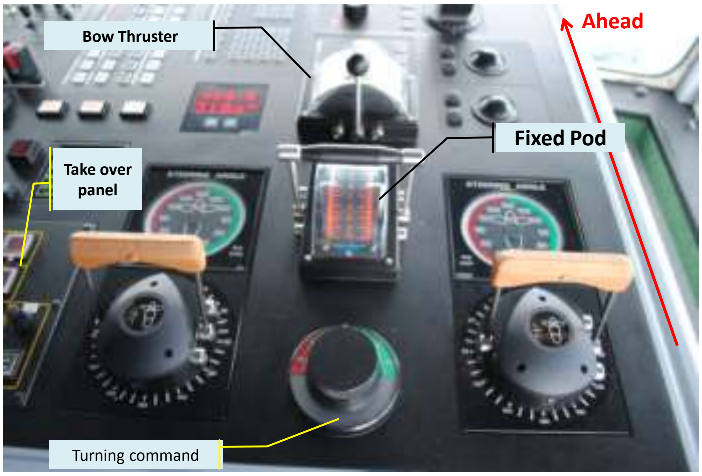
This ACD handler will reduce the sense to establish the actual setting by their size and design. (ball shape of the body) Primary ACD information is presented in a small led display instead of a fixed rose. The "in command" can easily be pushed by accident.

Handling the thrust magnitude by the lever is clearly sensible and observable, but to set the direction the hand is moved to the steering pin. However the steeing pin should be disregarded with the ACD HD in azimuth angles aft of abeam.

The design of an ACD HD as shown here seems to be better fit for a full sense handling approach. Changing the thrust power while the hands are on the body to control the azimuth can be done without leaving the ACD HD. This design is also specific developed for an ACD system without a reverse rpm option.

A lay out where the bow thruster control is between and in line with the stern ACD thrusters (and with the same lay out) as shown here may create confusions for the ship handler in particular if the ACD HD are used by feeling and not by observing.

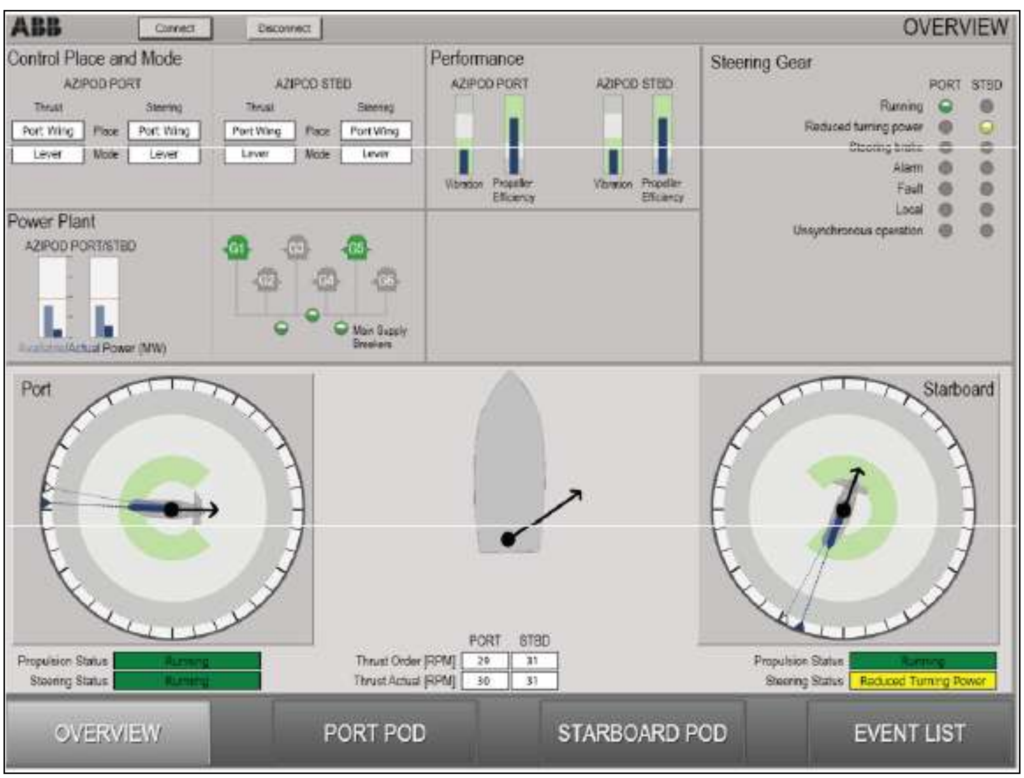
The lay out of these ACD controls are clearly placed in the console together with the primary ACD status information. The centre fixed pod control is designed as a conventional telegraph which will not confuse the ship handler during the handlings of the ACD HD's. The bow thruster is placed in front of the fixed pod. The ship handler will handle the thruster without the need of seeking the equipment by eye contact. The position of the turning control is also in a "handy " position for the navigator.



For this particular ACD console the primary ACD status is nearby the ACD HD, the secundary ACD status information is presented on a monitor perpendicular to the ACD handlers. The ship handler standing behand the ACD HD will move his head 90° to observe this information, but is not disturbed by this information when observing the primary information.

However, a lot of information and command buttons are placed in this console. Ther may be a confusion to the ship handler working in stress conditions.

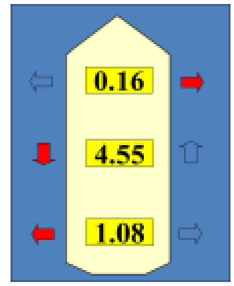
12.2 ACD status display

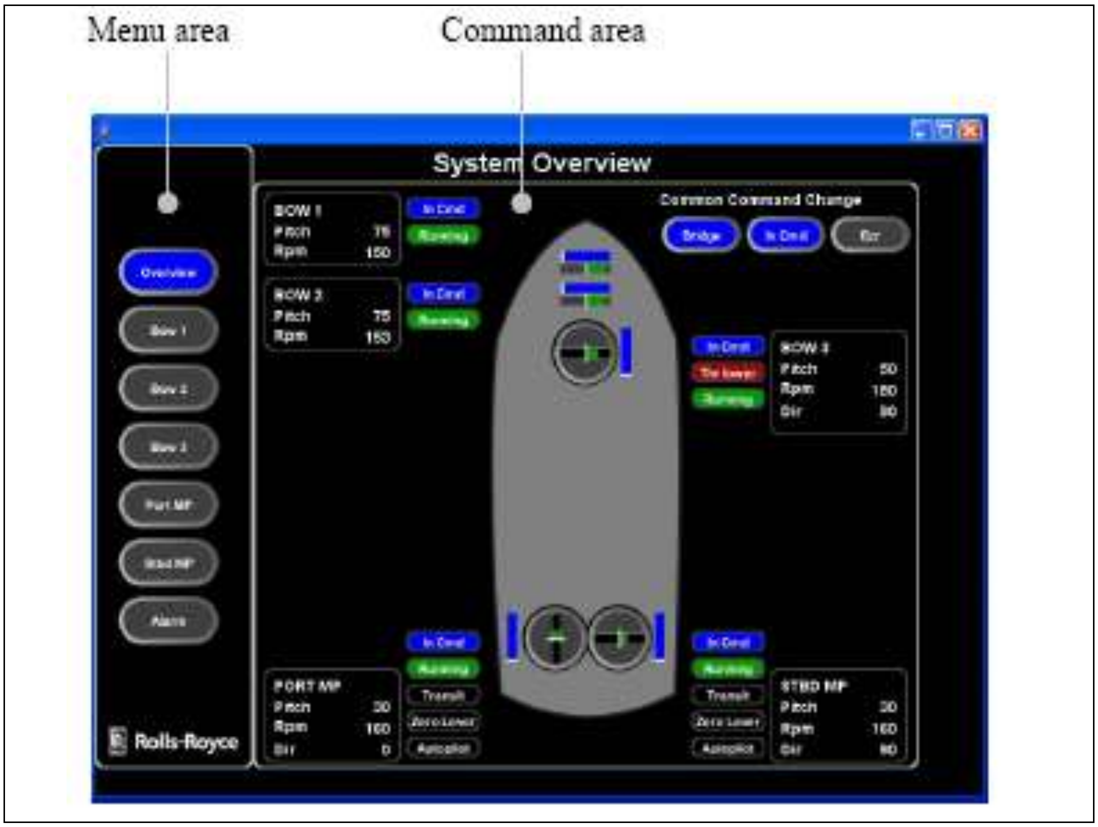


The display of the actual ACD performance as a primary source of information as indicated above is well separated from the secondary information. The direction of the ACD thrust is clearly displayed by a force vector. The length of the vector represents the magnitude of the thrust. The actual power relative to the maximum capacity should be observed in the bar graphs in the “Performance” menu.
Also a resulting thrust force is shown in the display. However, it is not clear whether this force is also shown on its working line to indicate the moment relative to the centre of gravity of the ship or ½ ships length.
The green arc indicates the allowable direction of the ACD but related to the direction of the water wash and not to the thrust. This is not clear to the observer without background knowledge.
Unless operation manuals have been studies a text like “steering status “ will not be clear to each observer, for instance the pilot.
A more significant choice of distinguishable colours would improve the time needed to retrieve information from this monitor as required during more intense ship handling situations.

This display uses a more significant colour setting.
The thrust by the ACD pod’s and bow thrusters are presented as longitudinal and lateral force vectors in the ship contour on the right side. The ship handler is able to ascertain the speed in longitudinal and lateral direction and can estimate the turning effect. In this particular case the ship will have some speed ahead, a movement to starboard and a turn to port.
The magnitude of the thrust force vector is easily observable relative to the maximum value.

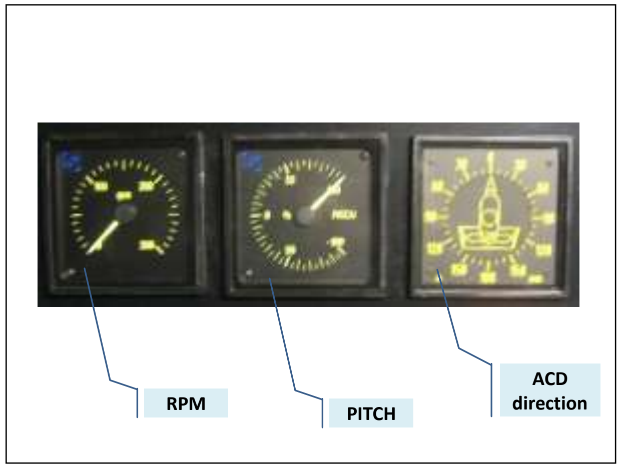
There seems to be a mixtures of primary and secondary information in this display. The generator frequency stands near the ship speed and rudder limit information. A ship contour picture with longitudinal and lateral speed windows would be more quickly and easily observable by the ship handler.



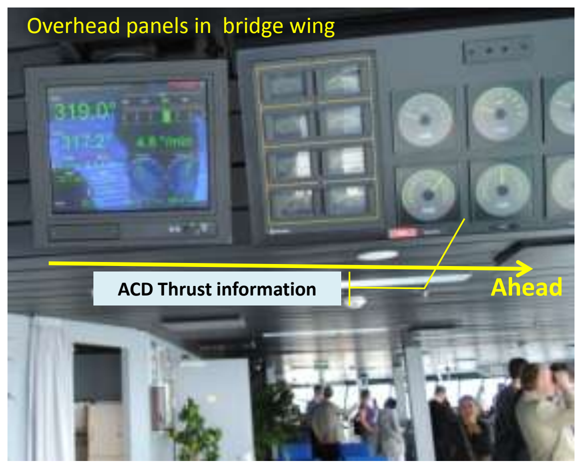


Also in this display the primary and secondary information is not fully separated from each other.
The actual ACD pod setting presentation is simple but not specific indicated whether the green bar indicated the thrust or the water wash.
Primary ACD information like the ACD pod settings The size of these figures are rather small, which implicates more time for the ship handler to retrieve information by observation.
From this display it is more difficult for the ship handler to ascertain the ship movement by observing these green graph bars .

An ACD thruster display like this one does not give us any information in which direction the thrust is as long as the observer is unaware of dealing with an azipull or azipush system

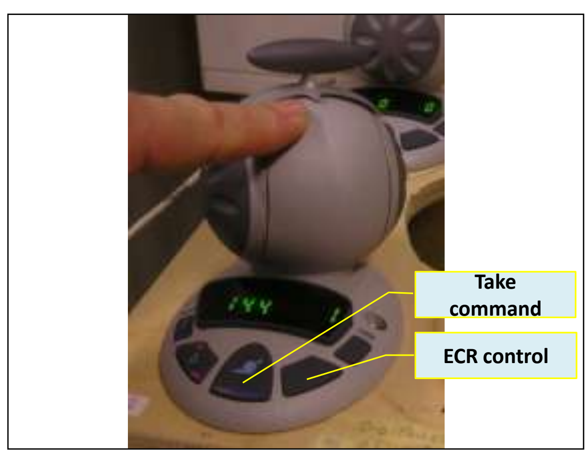


A simple but very clear indicator is shown here. Only a split second observation of the ship handler is enough to clarify the actual ACD status. However the actual thrust magnitude is not shown in this indicator and should be observed by indicators in an overhead panel aside of the ACD control console.



12.3 In Command / Take Over controls

As indicated before the "take over" command may, if misused, create critical ship handling situations. These commands should well distinguished from handling the ACD HD. From that point of view the shown layout with the "in command " buttons as a part of the ACD handlers is not optimal .



The take over controls in this lay out are aside of the ACD HD but close enough to use the commands from the ACD handler position but far enough to avoid accidental pushing the buttons. As an extra security the push buttons are covered by a Plexiglas protection.

In general it can be stated that the existing products differ in great extend from each other and are rather representing the individual view of the manufacturer than based on a general philosophy regarding implementation of relevant ergonomic rules.
Each observed system has in one way or another a less optimal element in the design or layout of the ACD CD components.
In other words, for the future more work has to be done to get more harmonized and optimal designed ACD control systems fully fit for the use by the ship handler in various manoeuvring circumstances.

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AZIPILOT WP 3.3 - **Review of the human physical and behavioural components**