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Revolutionary RAmora Brings Tele-operated Capability to Ship-handling Tugs

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SYNOPSIS

Drone technologies are set to open up a new realm of possibilities for tug operations. The uncrewed RAmora 2400 is the flagship within Robert Allan Ltd's new TOWBoT (Tele-Operated Workboat or Tug) series. Equipped with an advanced control system derived from ROV/AUV technologies, this highly manoeuvrable vessel is designed to work in tandem with a conventional tug during ship-handling, while being operated remotely by an experienced tug master. Also bringing capability for close proximity fire-fighting, spill response, and toxic environment operation, TOWBoT vessels such as RAmora have the potential to become powerful new players in the modern tug fleet.

INTRODUCTION

Ship-handling tugs are being increasingly challenged in a number of ways. Ships are getting bigger, especially container ships,[1] requiring more power from the tugs handling them and higher forces during indirect modes of operation. Likewise, as ships' minimum manoeuvring speeds creep higher, so do the speeds required of tugs when connecting lines. In addition, new oil and liquefied natural gas (LNG) terminals are coming on line in exposed coastal areas, requiring more ship-handling tugs to be operated in rough water conditions.

By thus increasing the demands on ship-handling tugs, are we correspondingly escalating the risks to their crews? Indeed, ship-handling already has inherent risks that need addressing; for example, incidents with tugs operating near a ship's bow with the ship underway suggest that this type of operation is particularly risky and deserves special attention[2].

Faced with such mounting demands on tugs and potential dangers to crew as ship-handling continues to push the bounds, the tug industry is now at a significant crossroads. The time has come to think seriously about what uncrewed vessel technologies can offer, and where they have a role to play in the future.

While the technical challenges should not be understated, we have the opportunity to adapt and integrate drone control and sensor technologies already developed and proven in other applications. In fact, the bigger hurdles may be in developing an appropriate regulatory framework and achieving acceptance within what is traditionally a conservative industry. However, with drones becoming ubiquitous and autonomous ships being discussed, there is little question they will be part of our industry soon.

This is in fact good news, as these technologies present the marine sector with an array of possibilities. Recognising this, Robert Allan Ltd seized the opportunity to innovate and in particular to address the challenges and risks discussed above.

Drawing on its decades of experience designing tugs, Robert Allan Ltd set about conceiving an uncrewed ship-handling tug called RAmora, a tug it believes will provide tug operators with a new option for ship-handling tasks that involve higher risks to crews, such as bow tug operations.

By embracing now the possibilities that uncrewed operations can bring, the remotely operated tug can be a springboard to a whole new class of uncrewed workboats intended for tasks that are not only too dangerous, too dirty – or even too dull – for crewed vessels, but also may be done with an even higher level of autonomy.

Figure 1: Ship handling entering harbour with bow and stern tugs. *Photo: sab89*

TECHNOLOGIES AND CURRENT TRENDS

Today we routinely rely on computer-based automatic controls to help fly our planes and drive our cars more safely, and even to intervene when human error may lead to an accident. Examples of this include digital fly-by-wire (FBW) systems, which began replacing the conventional manual flight controls of an aircraft with an electronic interface in the 1980s. Then pioneered by Airbus, they are now the industry standard due to the key benefits they afford. For instance, in addition to keeping an airliner safely within its flight envelope at all times, Airbus lists among FBW's benefits the commonality of controls across its product range, improved flight safety, a reduction of mechanical parts, and real-time monitoring of systems. It also touts FBW as the company's principal competitive advantage.

A more recent example is drive-by-wire (DBW) technology, which can keep a car in its lane or apply the brakes before a driver can react if there is risk of collision with other traffic *(Figure 2)*.

Figure 2: Fly-by-wire Airbus A380 and drive-by wire Tesla Model S

These electronic, computer-controlled architectures underpin systems with even higher levels of autonomy that are completely unmanned, including drones. Rapid advances in mobile and compact motions sensing and navigational systems, driven in no small part by the mobile device revolution, have now made it possible to pack immense processing power, highly precise sensors and high bandwidth communications into the type of small drones that have become commonplace, even for the average consumer.

Figure 3: Mine trucks like this are going driverless
Photo: Flickr arbyreed

The application of these technologies to military use is well established, particularly with uncrewed aerial vehicles. However, autonomous technologies have also been quickly adopted by the commercial industry, such as on mobile work platforms in many areas for remote operation, and especially in situations involving risky and/or repetitive work where labour costs are high. In Australia for example, Rio Tinto operates 69 driverless trucks shifting ore at three mine sites 24 hours a day, 365 days a year[3]; other mining companies will soon follow *(Figure 3)*.

Even the marine sector has begun to take notice. Over the past few years, several projects have been laying the groundwork for a whole new class of future autonomous surface vessels (ASVs) for trans-ocean cargo shipping. These developments include:

- China's Uncrewed Multifunctional Maritime Ships Research and Development Project, which was set up in 2012 by the Maritime Safety Administration (MSA) with Wuhan University of Technology and completed in July of 2015[4], and which involves all-day networked sea supervision, intelligent cruise and rescue and motorised multipoint coverage by shore-vessel based detection.
- The European Union's Maritime Uncrewed Navigation through Intelligence Networks (MUNIN) project, which similarly was started in 2012 and also largely completed in July 2015, and which involves research studies on the costs and benefits of uncrewed ships, as well as simulated sea trials with a prototype ship[5].
- The Rolls-Royce led Advanced Autonomous Waterborne Applications (AAWA) initiative, announced in July 2015 is a two-year project funded by Tekes (Finnish Funding Agency for Innovation) that includes industry, academic and classification society partners looking at design, technological, regulatory and other factors in using uncrewed ships.

Still, the industry has its concerns. Today, much like the air industry at the introduction of FBW, the topic of whether we need or even want autonomous ships has been one of intense discussion, particularly in view of the many operational, safety and regulatory aspects to grapple with before they can become a reality. Even so, the level of interest remains high.

That is not to say that remote operation of uncrewed or autonomous surface vessels is something new, but only that until now, few have been designed for non-military work boat tasks that actually influence their environment. Rather, USVs in the military or security sector are designed for patrol and interdiction, and based on Rigid Hull Inflatable Boat (RHIB) platforms or derivatives thereof that are intended for high speed *(Figure 4)*. ASVs outside that sector are mostly developed as small (often less than about 4m) vessels that are typically equipped for surface or subsea data collection or remote surveillance.

Figure 4: Survey and Navy autonomous surface vessels

For workboat tasks, however, these types of ASVs are not generally suitable for several reasons. For one, compared to a small scientific ASV, a workboat platform has to be big enough to accommodate both its equipment and the power and/or energy storage needed on board to power it. Also, the 'command and control' links need to be fast and reliable enough for a remote operator to control work tasks safely with the help of a high level of on-board smarts and, depending on the application, certain autonomous capability.

Hence, we at Robert Allan Ltd propose that workboat tasks require an entirely new type of uncrewed vessel, being a Tele-Operated Workboat or Tug (TOWBoT), such as the RAmora already mentioned. These TOWBoTs are designed and equipped to accomplish work tasks in a dynamic surface environment, whether under direct human supervision in real-time or autonomously where such applications are appropriate.

In many respects this TOWBoT can be thought of as a surface-based equivalent of the commonly-used underwater remotely operated vehicle (ROV). Like an ROV, the TOWBoT is equipped with many automatic piloting functions and telepresence features to assist the remote operator. Yet, while ROVs are used for 'subsea intervention' tasks, TOWBoTs are designed for 'surface intervention' tasks, and particularly those that are dangerous, undesirable or sometimes even impossible for conventional crewed workboats.

THE DANGERS OF SHIP-HANDLING

To be sure, the riskier aspects of ship handling need to recognised and managed carefully. As noted at the outset, modern operations are placing more demands on ship handling tugs than ever before. These demands may be causing certain ship-handling tasks to become incrementally more dangerous, as signalled by a number of incidents over the last decades, particularly concerning ship handling at speed off the bow[2].

Perhaps more so in Europe than in North America, it is common practice to have a tug put a line up to the ship's bow (connect) while underway to assist with steering while coming into port. Working in this 'centre lead forward' position, the tug shifts from one side of the ship to the other to provide steering assistance, and must do so in a way that manages the towline safely during the transitions to prevent towline snagging, snatch loading or tow tripping *(Figure 5)*.

Figure 5: **Smit Barbados** *handling* **Atlantic Conveyor** *in the Mersey* *Photo: Darren Hillman*

Putting a line up to a ship's bow at speed requires intense concentration and skill on the part of the operator[6]. The speeds during these connections can be fairly high. While up to six knots is typical, larger seagoing ships and particularly newer container 'megaships' often find it challenging to keep below six knots. Still higher connection speeds may be necessary in certain wind and current conditions to maintain ship manoeuvrability. These speeds bring greater risks to working under the bow, such as the following:

- Higher propensity for the tug to be drawn into the bow or side of the ship, particularly at the shoulder, due to the hydrodynamic interactions when the tug gets close to the ship[7], particularly with ASD tugs, which can be difficult if not impossible to steer away from the side of the ship if the drive end gets too close or makes contact;
- Less reserve power on the tug to manoeuvre out of harm's way should something go wrong, since more power needs to be devoted to maintaining speed;
- Greater risk of tow tripping (girting) by reason of the higher towline forces in relation to tug stability;
- Less margin for reaction time on the part of the tug master, because everything happens more quickly;
- Increased likelihood of damage from contact, since both the hydrodynamic forces and kinetic energies of tug and ship square with speed.

Figure 6: Tanker **Adygeya** *with tug* **Shalder** *on bow, Shetland Island* *Photo: John Bateson*

Clearly, working under the bow at speed, particularly when putting a line up, is an unforgiving situation *(Figure 6)*, and more so should there be some human error or an equipment problem. Becoming pinned to the ship's side or ending up crosswise in front of bow or over the bulb can lead to capsize, as illustrated tragically in the case of ***Fairplay 22*** at Hook of Holland in 2010[8]. We learn from these incidents of course, working to make ship-handling as safe as possible in the circumstances with improvements in training, safety management systems, safer tug design and better deck equipment.

However, such incidents also highlight the truth in the saying: "Experience isn't the only teacher, it's just the most expensive one." As we see connection speeds increasing and a future where new megaships will require even higher towline forces from indirect mode operations while working under the bow, should we not ask ourselves if tug crews need to be out of these situations? Is it time look at a new way of doing things?

TOWBoT – TAKING ON THE DANGERS

Beginning in 2014, Robert Allan Ltd undertook the design of an all-new concept to take on ship-handling tasks and specifically those involving risky situations – a remotely-operated tug. The flagship vessel in its TOWBoT series, the RAmora has been conceived to address aspects of ship-handling that pose the highest risks to crews, like those of working under the bow discussed above *(Figure 7)*.

Figure 7: RAmora remotely-operated tug

To be clear, RAmora is designed to be ideally suited to riskier workboat tasks or hazardous environments; it is not intended to replace a crewed tugboat for the vast majority of ship-handling operations. A modern crewed ship-handling tug is proven highly effective and safe when dealing with different ships, changing winds and currents, busy port traffic and communications with pilots. By and large, a human tug captain can be relied upon to make good on-the-spot operational decisions based on quickly and continually changing conditions. This adaptability to changing situations and experience on the part of the tug captain makes crewed tugs indispensable for the foreseeable future.

Figure 8: RAmora working in tandem with conventional tug centre lead forward position

Even where remotely operated tugs such as RAmora take on those ship-handling operations that would otherwise put crew at risk, we feel that experienced captains must also be in command. That is why our vision of RAmora is a work platform under the direct control of an experienced tug captain at all times, working from a console that provides enough telepresence 'feel' to be fully effective from a remote vantage point. To illustrate, captains who have experienced a modern full bridge simulator for training understand how a virtual environment can be created with 360-degree imagery, sounds and other feedback to make a virtual bridge very real indeed.

What's more, even as remote operation would not forego the advantages of conventional tug operation, it would bring opportunities to simplify the tug controls for the operator, to build in safety features to prevent human error and to manage faults automatically where practical – where it helps, rather than hinders.

RAmora REVEALED

RAmora is in fact a synthesis of three technologies *(see Figure 9, overleaf)*:

- A propulsion arrangement drawn from Robert Allan Ltd's RAVE concept, featuring two VSP units located co-axially along the centreline of a tug hull;
- Drone controls, derived from well-established ROV and AUV control systems;
- A line transfer arrangement, using a crane system to pass and retrieve line.

Figure 9: Three key RAmora technologies: RAVE tug, line transfer crane, AUV/ROV controls

Combining these known ingredients assures us of reliable results. For instance, in arranging RAmora's propulsion using VSPs set up as in our RAVE tug concept[9], it is possible to instantaneously shift thrust vector. This is an especially ideal configuration for a remotely operated tug from a controllability point of view *(Figure 10)*, because having VSPs installed in-line fore and aft enables it to yaw quickly to whatever orientation is best for the ship handling operation and makes side stepping easier.

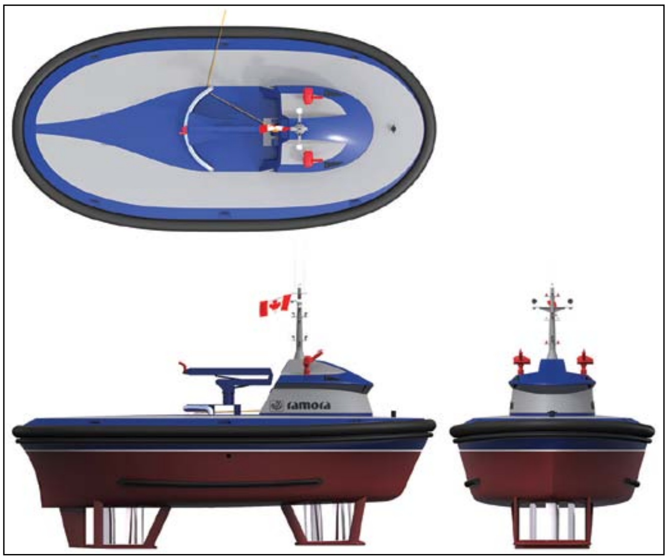

Figure 10: RAmora arrangement with fore and aft VSP propulsion

Additionally, by creating RAmora as a remotely operated and uncrewed vessel, we have been able to produce a highly streamlined, purpose-built and safe design, as illustrated in two areas.

First, with no deckhouse and wheelhouse in the way, the deck equipment can be ideally installed: the staple near midships, the winch out of the way toward the one end and the deck clear enough for a towline to swing through a much wider angle than on a typical tug – almost 360 degrees. What's more, the smoothly polished and curved staple has a wide slot close to the deck, so that the towline can to slide to port or starboard when pulling from the side. This keeps the tow point outboard and low, thereby making capsize from tow tripping virtually impossible, because the upward pull of the towline from the outboard end of the staple's slot limits the heel angle possible, and the tug is simply pulled sideways through the water until the tow tripping situation is corrected.

Second, the winch is housed within an open-ended house toward RAmora's 'bow' end. The navigation mast is integrated with the top of the house, and fire monitors are fitted port and starboard. Inside, a watertight access leads to the below deck machinery spaces as well as ventilation-related equipment and some of the control electronics. The shape of the house is designed to clear green water effectively when towing in seas.

With respect to RAmora's line transfer arrangement, the system used to pass the towline without deckhands on board has its origins in a line handling crane installed on a Robert Allan Ltd 'Z-Peller' tug in the 1970s, which was used to lift heavy hawser to the ship's crew. To deliver the towline from RAmora to the ship, a crane boom with a flexible delivery arm at the end is used to position a messenger line to where ship's crew can reach it and pull in the towline. Once the towline is secured, the crane boom is retracted into its stowed position with the towline free to slide through the ring. Towline recovery at the conclusion of a ship-handing operation is the reverse. A stopper at the towline eye splice prevents the towline eye from passing through the ring, thereby preventing the towline eye from being winched in past the staple. To help keep RAmora – and hence the end of the boom in seas – steady during this process, its Voith Roll Stabilization system is available, which makes use of both VSPs of the propulsion arrangement referred to above.

As noted above, RAmora is designed for use in fire-fighting situations. Specifically, it is equipped with off-ship fire-fighting (fi-fi) capability to FiFi1 standard. Two 1,200m^3/hr fire monitors are supplied by electrically-driven fire-fighting pumps. In addition, the line-handling crane boom is fitted with a smaller 600m^3/hr fire monitor and camera.

A hybrid power generation system supplies the power for propulsion, towing equipment, fire-fighting, and other systems, comprised of two lithium ion polymer battery banks and two diesel generator sets on a DC bus. RAmora's VSP units are electrically driven by means of compact permanent magnet (PM) electric motors. The battery banks are sized to allow for extended battery-only operation. Alternatively, diesel generators start automatically as required once the state of battery charge drops below pre-set levels. The batteries can also be charged from shore power.

RAmora is designed for periodic maintenance ashore between working cycles. A watertight door in the winch house leads to the machinery spaces below deck. A large flush hatch in the main deck allows removal of larger equipment. The vessel can rest safely on its VSP guards, so does not require a cradle or blocking when docked or for transport by ship or barge. This makes RAmora operable and maintainable with minimal shore side support facilities all over the world.

Vessel particulars (RAmora 2400 model):

Length overall, moulded	25.8m
Rule length	23.5m
Breadth, moulded	12.0m
Depth, moulded	4.0m
Navigational draft	5.5m
Gross tonnage	320
Speed	approx 12 knots
Propulsion power	2 x 2,000kW
Bollard pull	55 tonnes
Total complement	0 persons

THE CONTROL SYSTEM

We believe adapting a control system already proven in a similar application, rather than developing one from scratch, will significantly reduce technical risk. The control system needs to manage control of onboard devices and equipment, perform guidance functions, manage faults, maintain safe clearances to obstacles in the workspace, interface with the operator and manage the stream of data back and forth from the operator station. Hardware and software need to be reliable enough for safe ship handling and robust enough to perform flawlessly in day to day use in a harsh marine environment with almost no maintenance.

These basic attributes are found in control systems evolved through application in ROVs, AUVs and automated surface vessels. RAmora's control system is based on software and hardware developed by International Submarine Engineering (ISE) in Port Coquitlam, British Columbia called ACE (autonomous control engine). ACE is based on a series of proven modules, well tested through application in virtually all ISE's vehicle systems since 2000, including ROVs, AUVs and specialised systems such as the US Navy's pressurised rescue module (PRM) system used within the submarine rescue diving and recompression system (SRDRS) *(Figure 11)*. Through continuous development over many different vessel system applications there is an extensive library of interfaces to third-party devices and equipment related to sensors, navigation and communication.

With ACE as the basis, the work becomes mainly one of configuration for the RAmora application which, though not trivial, is straightforward. The basic system architecture *(Figure 12)* is based on having the core of the control system on RAmora and a separate console on the 'command tug' or shore-based location. The controller on board RAmora is called the vehicle command computer (VCC), and the operator station is called the operator command console (OCC). The two are connected continuously through a command and control (C&C) link. As with an ROV, the operator of RAmora will have a high level of direct control, but is aided by auto functions and safety interlock features that intervene to prevent unsafe situations.

Figure 11: RAmora control software is a derivative of that used on US Navy pressurised rescue module (PRM), **Falcon** *Photo: US Pacific Fleet*

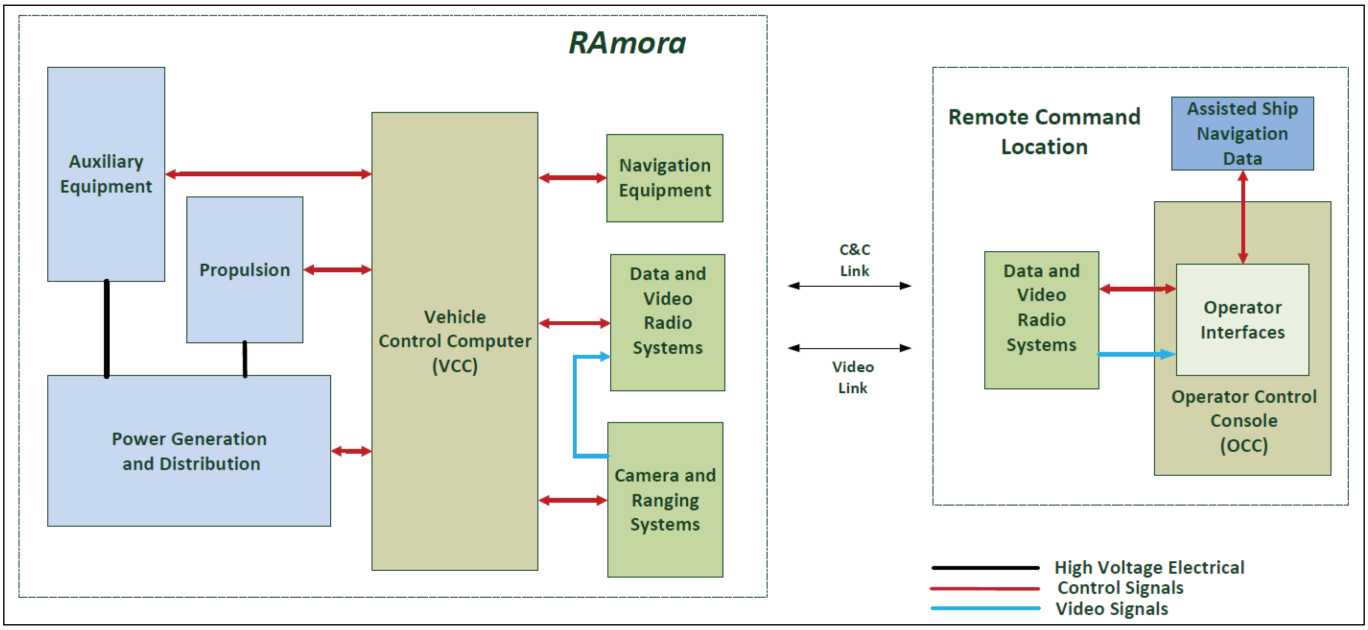

Figure 12: Block diagram of control system

All systems, sensors and devices on-board RAmora that need to be controlled or monitored are interfaced to the VCC. All essential closed-loop real time control is done by the VCC so that critical processes will not be affected by interruptions in the wireless command and control link (except where a safe stop is pre-programmed as an automated response to detection of such an interruption). The VCC and associated power management units are housed in a weatherproof housing on-board and powered by the essential services bus.

OPERATING RAmora

While we can imagine the possibility of RAmora ship handling rather like a Google driverless car operates on the road – perhaps scanning and analysing the workspace with 3D scanning technology such as LIDAR and itself deciding how to handle a ship – we feel neither the technology nor the industry are quite ready for it (yet). Instead, RAmora will still depend on the situational awareness and skills of an experienced (and specially trained) tug captain in working communication with other tugs, pilots and harbour controller.

RAmora operates in a highly dynamic environment involving moving ships, other tugs, ever changing surroundings and environmental conditions and a towline to contend with. It is the transitions that a typical ship-handling tug goes through during a ship handling sequence that are the most challenging for a tug captain. The captain needs high fidelity real time information on the ‘workspace’ at all times. Therefore, the OCC is designed to give the operator fully immersive telepresence.

Arranged somewhat like in a modern tug simulator, 360-degree live video is one of the main sources of information for the captain. Ergonomically, the goal is to take the best from the bridges of modern tugs, and make enhancements to compensate for some loss of feel aspects that arise from not actually being on board, such as no seat-of-the-pants’ feel of motions and limited depth perception from 2D imagery. In addition to displaying other data from RAmora, the console graphical user interface (GUI) includes continuous real-time measurement of range to the ship, along with an electronic chart view of the ship and other traffic nearby based on AIS and other on-board sensors.

To give the captain a good real-time feel of the situation, low latency and high definition video is essential. Subject to regional regulations in the country RAmora operates in, the video link will use the unlicensed industrial, scientific and medical (ISM) radio band. The separate C&C link will generally be over a licenced marine band. Both the video and C&C links are fully redundant and encrypted for reliability.

Although many operations will be line-of-sight between the OCC location and RAmora, the wireless systems must be capable of non-line-line-of-sight (NLOS) operation as well. This covers situations where RAmora is on the opposite side of the ship from the command tug or out of sight from the shore station. Repeaters can be used to get around obstacles to line-of-sight. Depending on the situation, repeater systems can be based on shore, placed on the ship (perhaps by the pilot upon boarding), or even installed on a tethered aerial drone launched from the tug.

In most situations, the captain will operate RAmora by joystick, much like an ROV. Joystick inputs are translated by the controller into the required thruster commands to manoeuvre, maintain position or change heading. These ‘fly-by-wire’ auto functions make the tug simple and safe to pilot, thereby leaving the operator less loaded and more able to focus on the ship-handling operation itself. At the same time, safety interlock features can be active and ready to intervene in potentially unsafe situations that develop from human error.

Winch controls are close at hand along with a graphical display of line tension and payout. Critical alarms are both visual and audible. Emergency stops can be initiated at any time. The ‘safe mode’ responses to an emergency stop, for instance what happens with the thrusters and winch, are managed by the fault and safety management system.

SHIP-HANDLING SCENARIO WITH RAmora

All of these benefits are likely best demonstrated by seeing RAmora in action. Accordingly, a typical scenario is outlined below - in this case where tugs are sent out to meet a ship approaching a harbour that requires assistance to manoeuvre and dock. This scenario features a conventional ASD ‘command tug’ under the control of ‘Capt T(ug)’, and RAmora operated remotely by a second captain, ‘Capt R(Amora)’, from a console on board the command tug. (In principal, RAmora could also be operated from shore, the ship itself or other vessel of opportunity.)

- Captain T on the command tug is tasked to meet the ship. The duo leaves the pier.
- They transit toward the ship meeting point, with Capt T driving the command tug and Capt R supervising RAmora, which is set to follow the command tug automatically at a close distance, essentially travelling as one unit through the harbour *(Figure 13)*.

Figure 13: Duo in transit to the meeting point

- The pair arrives at the meeting point outside the harbour, and takes position along the shipping channel to prepare to pass lines up to the inbound ship's bow and stern while underway. As the ship approaches, Capt T contacts the pilot on the ship and they agree on a maximum speed of 6 knots for the line connection.
- As the ship arrives, the duo falls in with the ship, with the command tug at the stern and RAmora near the bow.
- First, the command tug positions itself to receive a heaving line from the ship for a stern line at 6 knots. Once the tug is in place, it catches the heaving line and the tow line is passed up by messenger line and connected to the ship's stern fitting in the usual way.
- When that is completed, the command tug falls aft and positions itself to be ready to apply braking and steering if needed during the bow connection process. The ship continues at approximately 6 knots as it approaches the harbour.
- With the command tug thus positioned, Capt R works from on board the command tug to position RAmora to pass up the bow line. At this point, RAmora is running ahead of the ship, just aft of its bow to starboard, matching its speed. Capt R sets the controller to automatically maintain this position while transferring the towline.
- When RAmora is stabilised, Capt R focuses attention on passing the messenger line up by means of the uncrewed tug's line transfer crane, which is extended aft toward the bow of the ship where the messenger can be hooked by the ship's crew *(Figure 14)*. Once the messenger is in hand, it is run through the bow chock by the ship's own bow line messenger or some other means. Then the towline is pulled aboard as it is paid out from RAmora's winch and made fast to the ship's bow towing fitting.

Figure 14: Towline connection with line transfer crane

- Once the bow line is made fast and the line transfer crane retracted, Capt R drives RAmora away from the hull of the ship. The tow line is automatically payed out as required.
- When the tow line is appropriately slack, RAmora is positioned ahead of the ship and placed in a 'ship follow' mode to match its position. Now when the ship turns, speeds up or slows down, RAmora maintains its relative position at a safe distance regardless of visibility *(Figure 15)*.

Figure 15: Moving with the ship with RAmora in centre lead position, slack line

- With the tug duo so positioned, both the command tug at the ship's stern and RAmora at its bow are ready to assist the ship as it enters a narrow channel leading to the harbour.
- As a tight starboard bend in the channel approaches, the ship's pilot asks Capt R for RAmora to pull starboard *(Figure 16)*. Capt R uses joystick control to move RAmora to starboard to assist with the course change.

Figure 16: Pulling starboard

- Once the turn is made, Capt R returns RAmora to its slack line 'ship follow' position ahead of the ship, still moving at 6 knots.
- In due course, the ship is stopped just off of the berth in preparation for the final berthing sequence.
- At this point, the ship's pilot works with both RAmora and the command tug to bring the ship alongside the berth at the tow lines at bow and stern. As the ship makes contact, both tugs move around to the outside to push while the ships mooring lines are made fast *(Figure 17, overleaf)*.
- With the ship safely moored, its crew release the tow lines. RAmora extends its crane while the line is recovered to keep the tow line and messenger line clear of the water to prevent fouling of propellers.

Figure 17: Final berthing and mooring lines made fast

- Finally, with towlines stowed, the two tugs begin heading back to the tug pier; Capt R again places RAmora into 'tug follow' mode to match the command tug, and the pair travel as one through the harbour, ready for the next ship-handling assignment.

OTHER OPERATIONS

The above demonstrates RAmora's usefulness in a classic ship-handling scenario that is susceptible to risks. Yet there are also other operations that pose challenges to crewed tugs, and the RAmora concept is equally well-suited to those tasks. We will review four of these here: confined canals and channels, hazardous environments, pull-back operations and fire-fighting.

Confined canals and channels

Challenges commonly arise when working in canal systems, especially those with locks, where tugs are typically depended on to assist with manoeuvring ships. This is an issue, because in such canals *(Figure 18)* or other confined channels the space on either side of a ship is often limited, whether by distances to the sides or opposing traffic or both. This requires tugs to work as 'close in' to the ship as possible, and to be as small as possible.

Figure 18: Handling ships in the Panama Canal
Photo: Ted McGrath

It is working within those bounds where RAmora's fore/aft VSP configuration proves particularly helpful, because the tug can be easily oriented to keep its side to the ship (with a line up) and be quickly shifted from one side to the other while occupying a minimal amount of 'swing room' either ahead of or behind the ship. Side-stepping is also possible, which is used in cases where the lock length is limited. In addition, being an uncrewed vessel operated remotely, the prospect of being in a lock with the ship is much less concerning, and the captain who directs RAmora can therefore give full attention to the task at hand without the added anxiety (or its cumulative effects). Even should minor contact with the sides of the lock occur, RAmora is designed to tolerate such events by being fitted with cylindrical fendering all around.

In principle, such purpose-built design elements would enable RAmora to be used at either end of a ship, while it is controlled remotely either from on board the ship or from the shore side of the lock itself. This enables the tug to be kept inside the lock with the ship with towlines up and connected at all times, moving ships in and out of locks, and transiting adjoining canals promptly and safely *(Figure 19)*.

Figure 19: No crews at risk with RAmora working in a lock

Hazardous environments

In addition to the above challenges, tugs face a further issue as noted in the introduction. The number of LNG terminals is growing worldwide, and more tugs than ever before are operating in terminal environments where a spill or gas leak can make it dangerous for a conventional crewed tug to operate *(Figure 20, overleaf)*. For example, those tugs can be fitted with systems to detect gas and to seal and/or pressurise interior spaces for short periods, but if there is a leak, they would typically still need to move out of a hazardous area as soon as possible. Obviously, even in such cases it would be very difficult to make the decision to break off operations in the midst of a critical ship handling operation, especially if doing so might put the ship or terminal facility at risk.

In contrast, RAmora's design prepares it to cope with even these situations. The wet type exhaust systems on the tug prevent them from being sources of ignition, and additional precautions can be taken by fitting other intrinsically safe or explosion-proof equipment. Perhaps most crucially, the diesel electric/battery hybrid powering system enables it to operate on batteries alone for enough time to follow through with a critical

Figure 20: Tugs handling LNG tanker in Rotterdam *Photo: Franz Berkelaar*

ship handling operation in an emergency. Doing this remotely with the uncrewed vessel would avoid leaving crew exposed in the heart of peril.

Pull-back operations

Uncrewed vehicles are also finding their niche in high endurance, repetitive operations, as the earlier example with mine trucks showed. An example of such tasks in the marine sector can be seen in the offshore industry. There, single point mooring (SPM) systems are used for the mooring and transfer of liquid cargo to tankers where a dedicated shore-based facility is not available. One of the main advantages to these systems is that they can service ships of any size, right up to very large crude carriers (VLCCs). Although the idea is that the tanker is free to weathervane in the prevailing wind and current, tugs are needed in some situations for ‘pull-back’, ie to keep the tanker in the desired orientation or prevent it from overrunning the mooring in certain wind and tide conditions *(Figure 21)*. These pull-back operations can require many hours of sustained operation in rough and uncomfortable sea conditions.

Figure 21: Tanker on single point mooring with pull-back tug *Photo: Christy & Griffin*

While not necessarily dangerous, pull-back operations with conventional tugs can certainly be wearing for a skilled tug crew, as well as tedious and dull. With RAmora on the other hand, these operations can be sustained automatically and indefinitely, whether day or night and regardless of sea conditions, without exposing crews to fatigue or discomfort. Once connected, supervisory control of the vessel can be provided from a command tug, from the tanker itself, or from a shore-based command location.

Fire-fighting

Finally, TOWBoT vessels like RAmora could prove invaluable in fire-fighting situations. Many modern tugs and offshore vessels are often equipped with off-ship fire-fighting capability to protect human life and prevent loss of infrastructure. However, fires in ports and on ships come with risks beyond the fire itself. Explosions and the fumes from the release of toxic airborne substances from burning chemicals, petroleum products, creosote-soaked pilings and the like can be deadly.

Conversely, because RAmora has no crew it can be sent into a toxic or explosive situation as early as possible, before it is deemed safe for a crewed fire-fighting vessel. This could result in knocking down a fire much more quickly, and thereby reducing the potential damage and devastation. Moreover, RAmora can work more closely to a fire than a crewed vessel is able to, directing water and foam more effectively on the source and for extended periods *(Figure 22)*. In this situation also, the twin VSP thrusters provide excellent positioning.

Figure 22: RAmora fire-fighting

SAFETY, CERTIFICATION AND REGULATION

In order to achieve the benefits and opportunities of TOWBoT vessels like RAmora, such vessels need to be properly addressed under an appropriate regulatory and legislative framework. Here, there is clearly work to be done. For instance, rules on remotely operated or autonomous vehicles have not yet been established under IMO or any Flag state. Classification societies on the other hand have, or are developing, rules around automation, but there are gaps which need to be filled to reach a point where such vessels are covered. In addition, regulatory issues present particular challenges with regard to autonomous vessels on international voyages (such as cargo ships), as addressed in the MUNIN and AAWA projects.

In addition, classification society rules tend to be geared towards ensuring a vessel design is safe, particularly for its crew. However, in the case of an uncrewed TOWBoT like RAmora, the focus is appropriately placed more on safety of the vessel when navigating amid other nearby vessels or structures, safety of the ship being handled, and safety to the environment.

Accordingly, without a complete framework of prescriptive or goal-based class rules, it becomes crucial to work closely with a major classification society to take a risk-based approach to these vessels, as Robert Allan Ltd is planning with RAmora. The goal of this approach is to reduce overall risk to a level that is lower than that of a conventional tug operating in the same role.

There are, however, certain existing class rules that cover the construction, propulsion, powering and equipment aspects of RAmora reasonably well as those features are for the most part conventional, and in many cases this includes type approvals for equipment and outfitting items. Also, stability criteria applicable with a fore/aft VSP thruster configuration and midships tow point have already been established with the RAVE tugs, and an argument can be made that the stability criteria could be relaxed to some extent without crew aboard. To simplify matters further, rules related to crew lifesaving or domestic systems can be dispensed with. The remaining regulatory gaps concern the control system (including human-machine interface aspects).

In terms of legislation, aside from classification of the uncrewed vessel itself, the legal situation for operating an uncrewed vessel is presently far from clear. This is due partly to many of the laws now in effect having a long history anchored in tradition and premised on a ship that has a crew. As a result, the following are among the many questions being wrestled with by maritime law experts[10]:

- Is an uncrewed ship a 'ship' as defined within maritime law, especially given the variations of what a ship is under various marine laws?
- What are the legal obligations and liabilities of the remote operator? Is the operator considered a 'master' or 'commander' of this ship in the current state of maritime law?
- Will the master of a seagoing ship being handled by RAmora continue to be in command of the tow?
- What is the legal situation with respect to salvage rights, both by an uncrewed ship and of an uncrewed ship?

The complete gamut of such issues extends well beyond the scope of this paper.

When it comes to operating in a local setting, however, the situation for uncrewed ships happily may be less complicated than it is for those engaged in international voyages. Specifically, regulations applied to RAmora may be subject to discretionary power extended to local regulators for vessels operating in port or harbour in regulations to establish 'special rules'. For instance, IMO's International Regulations for Preventing Collisions at Sea (COLREGS) states in Rule 1 concerning application[11] (italics added for emphasis):

> Rule 1(b) Nothing in these Rules shall interfere in the operation of *special rules* made by an appropriate authority for roadsteads, harbors, rivers, lakes or inland waterways connected with the high seas and navigable by seagoing vessels. Such special rules shall conform as closely as possible to these Rules.

COLREGS also allows exceptions for vessels of special construction:

> Rule 1(e) Whenever the Government concerned shall have determined that *a vessel of special construction* or purpose cannot comply fully with the provisions of any of these Rules with respect to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound-signalling appliances, such vessel shall comply with such other provisions in regard to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound signalling appliances, as her Government shall have determined to be the closest possible compliance with these Rules in respect of that vessel.

Also, in accordance with SOLAS, RAmora will be equipped by virtue of its telepresence sensing to uphold the classic legal obligations to maintain a proper lookout and to proceed at a safe speed while operated (remotely), and will carry all required lights and signals.

Ultimately then, while moving ahead with RAmora now is clearly advantageous, current circumstances dictate a fact-specific approach. Where possible, this would involve applying or being guided by existing regulations. Yet even where IMO regulations and flag state rules for uncrewed vessels remain absent, or gaps in applicable regulations or law need addressing, the best strategy will consist of all interested parties co-operating on a case-by-case basis, so that the designer, operator, class, port authority and flag state regulatory bodies work together to determine the needed regulations and establish a legal framework specific to the vessel, its jurisdiction, and its planned operations. An example of this would be considering RAmora as a special case under SOLAS and other applicable rules.

The challenge here is to strike the right balance between safety and unnecessarily restrictive regulations, and aim to achieve interim, locally-applicable rules that are at least clear enough about obligations and liabilities of the various parties for operations to take place. In any case, the onus is on all developers and early adopters of TOWBoT vessels to keep safety paramount. If we did not, one or two negative incidents could see industry acceptance of remote operated vessels set back by years.

Finally, in spite of any present uncertainties, we at Robert Allan Ltd are confident that a 'can do' and collaborative attitude between all parties will result in a practical way forward being found, at least until the regulations and law have evolved and matured through experience.

LOOKING AHEAD

Once the typical development hurdles with any new technology are overcome, TOWBoTs such as RAmora will quickly prove their worth in taking on tasks that are too dangerous or undesirable for crewed tugs. Then when these vessels have a track record established, wider industry acceptance will follow and regulatory and legal questions in time will be sorted out, not only for RAmora, but for the many other uncrewed vessels such as cargo ships that are on the horizon.

This may bring in a new era where cross-pollination from remotely operated systems and drones in other industries and applications becomes possible and rapid advances can be made as new opportunities are recognised. Similarly, incremental advances in workspace sensors, obstacle avoidance algorithms, wireless technologies, and artificial intelligence can open up new possibilities for RAmora and its derivatives for autonomous or semi-autonomous operations well beyond ship handling.

Indeed, within reach are even more potential applications beyond those addressed above, such as long-distance line towing, rescue and salvage and oil-spill response, either working in a co-ordinated fashion with other vessels on-site or over the horizon, and anywhere else where the work is unsafe or unpleasant for crews. We may soon see the day when TOWBoTs are first on the scene to rescue a disabled containership drifting towards a lee shore in a storm, or are dispatched from a standby pen to monitor and manage an oil spill in a remote location under the co-ordination of an emergency response centre hundreds of miles away, even if only to deal with the situation while other help is on the way. With RAmora and TOWBoTs to come, the boundaries are shifting; new possibilities are opening to achieve unprecedented levels of ship-handling capability and improve overall safety at the same time.

Figure 23: RAmora underway

REFERENCES

[1] International Transport Forum, *The Impact of Mega-Ships*, OECD, 2015; http://www.internationaltransportforum.org/pub/pdf/15CSPA_Mega-Ships.pdf

[2] Hensen H, *Safe tug operations: Who takes the lead?*, *International Tug & OSV*, July/August 2012

[3] Dias K, *Driverless trucks move all iron ore at Rio Tinto's Pilbara mines, in world first*, ABC News, 18 October 2015

http://www.abc.net.au/news/2015-10-18/rio-tinto-opens-worlds-first-automated-mine/6863814

[4] Press Release: *Uncrewed Multifunctional Maritime Ships Research and Development Project Passed the Acceptance, Maritime Safety Administration of the People's Republic of China*; http://en.msa.gov.cn/index.php?m=content&c=index&a=show&catid=336&id=165

[5] *MUNIN Maritime Uncrewed Navigation Through Intelligence in Networks*; http://www.uncrewed-ship.org/munin/news-information/downloads-information-material/munin-deliverables/

[6] Slesinger J, *Shiphandling With Tugs*, Second Edition, pp161-169, Cornell Maritime Press, 2008

[7] Geerts S, *Hydrodynamic Forces in Ship-Tug Interaction*, Ghent University, *Tugnology '11*, Antwerp.

[8] The Dutch Safety Board, *Collision and capsizing of tug Fairplay 22 on the Niewe Waterweg near Hook of Holland 11 November 2010* (project number M2010ZSV1111-01), March 2012

[9] Lisagor O, Jürgens D, Palm D, *RAVE Tug – Application, Hydrodynamic Characteristics and Manoeuvrability* , *Tugnology '11*, Antwerp

[10] Van Hooydonk D, The law of uncrewed merchant shipping – an exploration, *The Law of Uncrewed Merchant Shipping*, (2014) 20 JIML; http://www.ericvanhooydonk.be/media/54f3185ce9304.pdf

[11] *The International Regulations for Preventing Collisions at Sea* (COLREGS), International Maritime Organization.[XX]; Slesinger J, *Shiphandling with Tugs*, Second Edition, pp161-169, Cornell Maritime Press 2008