Stern Boat Deployment Systems and Operability

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ABSTRACT

Ship-deployed boats are essential to the success of many of the U.S. Coast Guard's seagoing missions. In recent years, boat deployment systems have evolved beyond the traditional side-davit system with dual falls, and now include systems that deploy Rigid Hull Inflatable Boats (RHIB) via stern ramps that are integrally designed into the transom of the mother ship. A worldwide assessment of vessels with stern-launch capability undertaken by the Coast Guard confirmed that no established analytical approach was used in the design stage, nor was a standard or criteria set available to the designers of these systems. Consequently, a dedicated effort was undertaken to review existing system evaluation *approaches, develop boat deployment criteria and analysis methodologies, conduct stern boat deployment operational tests, and perform percent time operability (PTO) analyses in order to develop a workable design and evaluation methodology for stern-ramp cutters. This paper documents the findings of the worldwide survey and the current state of the art for boat deployment assessment. Specifically, criteria for stern-ramp motions, a ramp availability criterion and stern-ramp deployed boat criteria are covered, along with an example case using these criteria to establish the PTO of stern ramp operations for typical ocean environments.*

INTRODUCTION

Ship-based boats are essential to the successful prosecution of many of the U.S. Coast Guard's seagoing missions. The ability to launch and recover boats in a broad range of environmental conditions is necessary to complete these missions. In recent years, boat deployment systems have evolved beyond the traditional side-davit system with dual falls, and now include systems like Rigid Hull Inflatable Boats (RHIB) deployed via stern ramps integrally designed into the transom of the mother ship.

As part of the Coast Guard's need to conduct technical assessments of existing cutters and proposed ship designs to establish the effectiveness of the various boat deployment systems, engineering criteria and methodology must be available. Within the Coast Guard in the mid-1990s, there was a developing interest in stern deployed boats from oceangoing cutters, and the Deepwater Project was considering design ideas for replacement cutters including a new class of Medium Endurance Cutters and a National Security Cutter class. The Naval Architecture Branch of the U.S. Coast Guard Engineering Logistics Center undertook the initiative to develop criteria for design and evaluation of stern launch and recovery systems for small boats from ships up to 400 feet. To this end, a systematic approach was taken to conduct a worldwide assessment of vessels with stern-launch capability, develop boat deployment criteria and analysis methodologies, conduct stern boat deployment operational tests, and perform percent time operability (PTO) analyses.

The purpose of the worldwide search of candidate vessels operating with stern deployment systems was to determine their design criteria and to determine their operating characteristics. The ships identified ranged in length from the U.S. Coast Guard's own 87-ft WPB (Marine Species Class) to the 300-ft Japan Coast Guard Cutter *Erimo* (ex-*Ojika*). The investigation involved meeting with owners, operators and designers to determine the characteristics of their stern deployment systems, the process and the research done by which they selected the stern launch and recovery system and how they optimized it. The survey specifically included questions regarding standards and criteria used in the design of these vessels. The result of this investigation confirmed that no established analytical approach was used in the design stage, nor was a standard or criteria set available to the designers of these vessels.

Consequently, a dedicated effort was undertaken to review existing system evaluation approaches, conduct ship motions studies and generally draw together diverse viewpoints of other investigators into a workable design and evaluation methodology for stern-ramp cutters. The developed approach would have to be applicable to stern deployment of RHIBs and Fast Response Craft (FRC) from various sizes of cutters, would allow comparison to side-boat deployment systems, and would have to be relatively easy to employ given the analysis tools in existence today.

This paper documents the findings of the worldwide survey and the current state of the art for stern boat deployment assessment. Criteria sets for side-davit motion criteria are reviewed, and the recently developed stern-ramp motion criteria, ramp availability criterion and stern-ramp deployed boat criteria are covered. Finally, an example case using these criteria to establish the PTO of boat recovery via a stern ramp for a typical North Atlantic Ocean environment is provided.

NOMENCLATURE

a = Threshold water depth at the ramp sill.
B_{WL} = Breadth on waterline.
Δ = Displacement.
GM_T = Transverse metacentric height.
H_s = Significant wave height.
L_{pp} = Length between perpendiculars.
m_0 = Zeroth moment of the relative motion spectrum.
m_2 = Second moment of the relative motion spectrum.
$\Phi(.)$ = Probability integral.
r_{44} = Roll inertia radius.
σ = Standard deviation of the relative motion process; relative vertical displacement rms.
σ_v = Standard deviation of the first derivative of the relative motion process; relative vertical velocity rms.
T_M = Draft at midship.
T_{RA} = Minimum average ramp availability time interval for the retrieval operation; criterion limit.
T_Z = Mean zero-crossing period.

τ_+ = Time duration that the relative motion exceeds the threshold, "a".

$\tau\_$ = Ramp availability duration; time duration that the relative motion is less than the threshold, "a"; i.e., ramp sill (or other required depth) underwater w.r.t. local wave elevation.

$\langle \tau\_ \rangle$ = Mean ramp availability duration.

Y(t) = Ramp sill vertical relative motion process; defined to be positive when the selected point on the ship rises above the local water level.

Head Seas are 000^o relative wave heading and seas on starboard beam are from 090^o.

WORLDWIDE STERN LAUNCH AND RECOVERY CAPABILITY

The process of developing the assessment methodology started with a worldwide search to identify candidate vessels and their designers that presently operate stern deployment systems.

In preparation for the survey, a standard list of questions was developed that would provide uniform responses that could be compared across all the vessels. The questions focused on the operation of the systems as well as any changes that would be desirable. A similar set of questions was developed for the system designers to assess the design criteria used and to determine what, if any, changes would be made for the next generation of stern boat deployment systems.

The following ships were visited during the course of our research:

a. Japan Coast Guard patrol vessel *Erimo* in Tokyo, Japan
b. Mexican Navy ship *Justo Sierra* in Acapulco, Mexico
c. U.S. Navy Patrol Craft *Tornado* in Little Creek, Virginia
d. Canadian Coast Guard Ship *Gordon Reid* in Victoria, British Columbia, Canada
e. Netherlands Antilles and Aruba Coast Guard Cutter *Jaguar* in Curaçao, Netherlands Antilles
f. Finnish Frontier Guard Offshore Patrol Vessel *Telkkä* in Turku, Finland
g. USCG Coastal Patrol Boat *Hammerhead* in Baltimore, Maryland
h. German Sea Rescue Service vessel *Vormann Steffens* in Bremerhaven, Germany
i. Swedish Coast Guard High Endurance Class *KBV 201* in Karlskrona, Sweden

The survey provided valuable information on the design parameters and operation of stern boat launch and recovery systems. In addition to investigating the launching systems, the types of FRCs that were used were also investigated to determine if any special modifications were needed for their use with the stern ramps. It should be noted that all the vessels surveyed for stern deployment capability also had an alternative, traditional boat launch system available.

Other vessels identified, but not visited, with stern boat deployment capability include the Philippines Coast Guard vessels *BRP San Juan* and *BRP Edsa II* and the United Kingdom Customs and Excise ships *HMCC Seeker* and *HMCC Searcher.*

Types of Recovery Systems

The stern launch systems investigated are categorized into four distinct systems with variations on arrangement details. The systems are categorized as follows:

1. Well Dock (as exhibited on the Japanese Coast Guard patrol vessel *Erimo*, Figure 1)
2. Fixed Ramp (as exhibited on the USCG Coastal Patrol Boat *Hammerhead*, Figure 2)
3. Hinged Ramp (as exhibited on the Canadian Coast Guard Ship *Gordon Reid*, Figure 3)
4. Extended Ramp (as exhibited on the Swedish Coast Guard vessel *KBV 201*, Figure 4)

The results of the survey revealed that there were two basic configurations of sloping stern ramps. They are

a. A shaped ramp designed to fit the hull form of the FRC, and
b. A flat ramp with longitudinal tubular rails (or bunks) that provide support and help center the small boat during retrieval.

Well Dock

The stern well dock system is employed on the Japan Coast Guard patrol vessel *Erimo*. This was the largest ship, at 91.4 m (300 ft), identified with a stern launch capability. In the well dock system, the small boat is carried inside the ship in a dry compartment that must be flooded before the boat can be launched.

The *Erimo* is unique in that the 5.5-m FRC is backed out of a stern well under its own power (not launched down a ramp). The arrangement is shown in Figure 1. The boat is kept in a normally dry compartment behind a watertight stern gate. There is a wave-dampening flap installed near the entrance to the stern well that dampens the water motions in the well to maintain the required water depth for the FRC. The wave-damping flap has a roller installed on its upper edge to permit the FRC to pass over it without causing any damage to the hull. The well is lined with fendering material to protect the FRC.

The FRC is a decked-over boat with an operator's cockpit. A foam-filled fender surrounds the boat at the deck level for protection. The fenders prevent damage to the small boat during launch and retrieval. A diesel-driven water jet provides propulsion.

To launch the small boat, the well is flooded, the stern gate opened, the wave-dampening flap is pulled down, and the small boat exits under its own power. The control of the small boat while backing is limited. To

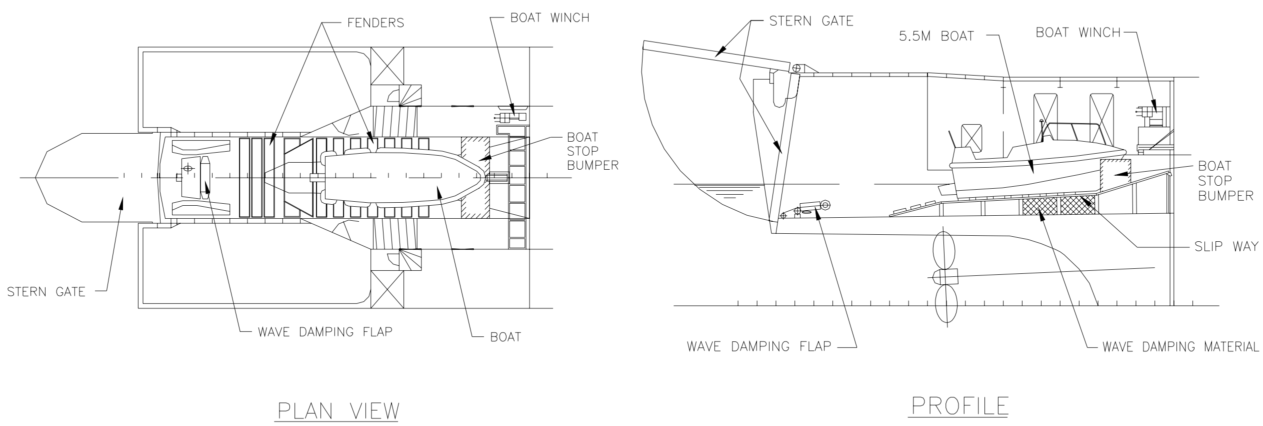

Figure 1. Stern launch well dock arrangement of Japan Coast Guard patrol vessel *Erimo*.

recover the FRC, the boat powers its way into the well dock and is secured. The stern gate is closed and the well is pumped dry.

In addition to the stern well, the ship was equipped with Miranda davits for side launching the rescue craft. The Miranda davits give the ship the ability to launch the small boats up to Sea State 4. The crew prefers to use the side-launched boats because the level of expertise needed is less for the side-launch system. The other ships in the Japan Coast Guard use Miranda davits. The *Erimo* is the only ship that uses a stern well to launch a small boat. Training can take as long as a year before crewmembers become proficient at launch and retrieval operations from the stern well.

Sloped Stern Ramp

Sloped stern ramps can be categorized into two different arrangements; the shaped ramp where the ramp surface is built to suit the shape of the FRC and lined with friction reducing material, and a ramp with a flat surface with tubular rails to guide and support the FRC.

A typical example of a shaped ramp lined with friction reducing material is that of the *Hammerhead* shown in Figure 2. The arrangement of *Jaguar* is very similar.

Shown in Figure 3 is the arrangement of the stern launching ramp on the *CCGS Gordon Reid*. This is an example of a ship with a flat ramp surface with tubular rails. The figure also shows the hinged ramp feature. The arrangement of the *Tornado* is similar without the hinging capability and the stern doors open externally.

The arrangement of the *KBV 201*, shown in Figure 4, provides an example of a downward hinging stern gate. The *Vormann Steffens* uses a similar arrangement of the hinging stern gate.

Summarized in Table 1 are the general characteristics for the ships with stern ramps. The vessels ranged in size from 26.5 m (87 ft) for the U.S. Coast Guard's Coastal Patrol Boat *Hammerhead* to 74.4 m (244 ft) for the Mexican Navy ship *Justo Sierra*. The length of the ship

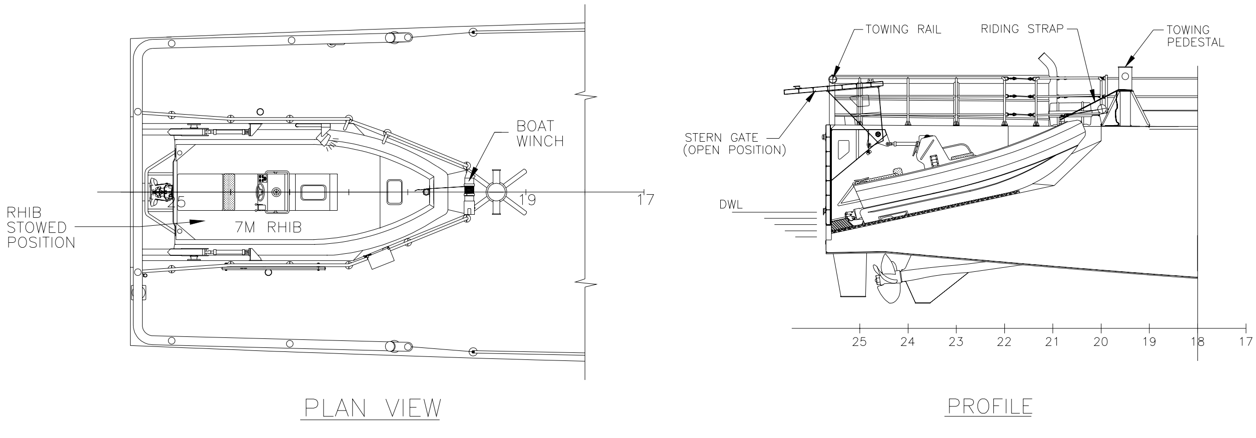

Figure 2. Typical sloped ramp built to the shape of the FRC (*USCGC Hammerhead*).

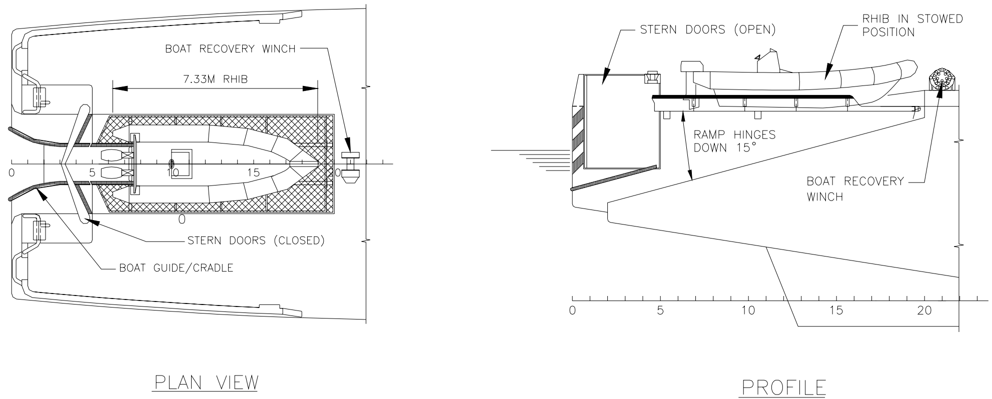

Figure 3. Hinged ramp with tubular rails used on the *CCGS Gordon Reid*.

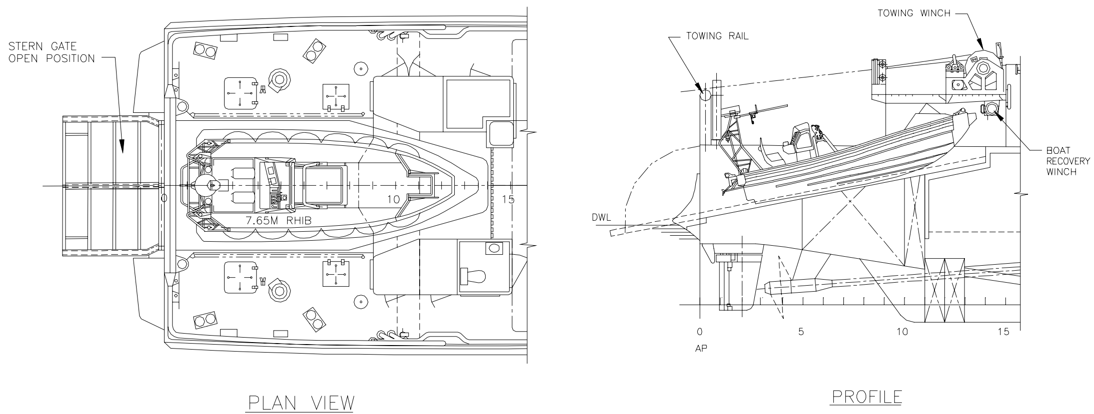

Figure 4. Example of a downward hinging stern gate (*KBV 201*).

Table 1. Ship and Ramp Characteristics

Ship	Year Built	Length of Ship	Type of Stern Ramp	Slope of Ramp	Sill Depth	Operating Sea State
Justo Sierra	1999	244’-0”	Shaped Ramp	8¼°	0”	3
Tornado	2000	179’-0”	Flat Ramp w/Rails	16°-18°	15”	3
Gordon Reid	1990	163’-10”	Hinged Ramp w/Rails	15°	34”	6
Jaguar	1998	140’-5”	Shaped Ramp	14°	12”	4
Telkkä	1999	161’-5”	Ramp w/Cradle	7°	-12”*	2
Hammerhead	1998	87’-0”	Shaped Ramp	12°	14”	4
Vormann Steffens	1989	90’-3”	Ramp w/Self-capture	14°	24”	1
KBV 201	2001	170’-7”	Ramp w/Rollers	12°	12”	4

*Sill on the *Telkkä* is 12 in. above the waterline for ice operations.

affects the motions and accelerations at the stern. These motion responses to operation in a seaway will vary with the ship length, geometry, wave characteristics, ship heading and speed.

Major Elements of Stern Deployment System

The main parameters of the stern deployment system that could significantly influence the ability to recover the boat safely are as follows:

- Ramp sill depth
- Shape of ramp opening
- Ramp slope
- Ramp surface
- Ramp side and clearance
- Overhead clearance
- Stern door or gate configuration
- Water management system
- Capture mechanism
- Stern flaps/wedge

Ramp Sill Depth

One of the most important factors in stern ramp operability is sill depth. This is the submerged depth at the aft end of the ramp. It governs the time available for recovery of the small boat. There is an optimum sill depth for each stern deployment system design and this depends upon the ship and the seas in which the boat must be recovered. In general, greater sill depth translates into a greater ability to operate in higher sea states. Greater sill depth usually ensures more water inside the ramp, thereby providing a longer time of ramp submersion. However, other operational criteria may influence the determination of maximum sill immersion.

Our investigation shows that sill immersion is very important to the ramp design and must be greater than a certain level (0.5 to 0.75 m (1.5 to 2.5 ft) depending on the particular arrangements of the designed system) in order to be effective. Less than this amount of depth and the stern ramp deployment operability and effectiveness could be drastically reduced due to a very short ramp availability time and the high probability of extreme impact accelerations induced during “dry landing”.

The vessels investigated had sill depths that varied from 12 inches above to 34 inches below the design waterline. Generally, ships that are operated in colder climates, where ice is a consideration, had ramps with the sill at or above the waterline. This was done to reduce the possibility of ice entering the ramp area. In order to increase the effective sill depth for recovery of the small boat, these ships employed either a stern gate that hinged down forming a ramp extension or a cradle that was extended beyond the stern. Such is the case for the Swedish Coast Guard vessel *KBV 201*, the German Sea Rescue Service vessels and *Telkkä*, a Finish Frontier Guard vessel.

Shape of Ramp Opening

Several of the ships visited had boat well openings that were either well rounded or had stern doors that opened to form a “funnel” to aid in the recovery of the small boat. In every recovery system investigated, where the ramp terminated at the transom, the small boats were observed to bounce off the corner of the ramp entrance. Most of the small boats were RHIBs with inflatable or foam-filled collars. The collars were either covered with specially reinforced materials or fitted with rub strips to protect the collar from damage during recovery. The well-rounded entrance corners permitted the coxswain to fend off the corners, without damage, as the RHIB was powered into the ramp area. The use of square or sharp corners at the intersection of the transom and boat well will increase the wear to the collar of a RHIB.

Ramp Slope

Ramp slope or angle was observed to be more important to launching than to recovery. Ramp slopes varied between 7 degrees on the Finnish Frontier Guard *Telkkä* up to 18 degrees on the *USS Tornado*. All vessels with ramp slopes of 12 degrees or higher are capable of launching their small boat without assistance. In the case of the *Justo Sierra*, the presence of the overhead flight deck restricted the ramp angle. The 8¼-degree slope of the *Justo Sierra’s* ramp is too low to permit the FRC to overcome its own static friction and self-launch. Capstans located on each side of the ramp are used to pull *Justo Sierra’s* boat down the ramp.

Ramp Surface

In order to facilitate launch and retrieval, most ramp surfaces are lined with high molecular weight plastics, such as Ultra Poly, to reduce friction on the sliding surface. This was true for all ramps except for the ramps on the *Telkkä*, *Vormann Steffens*, and *KBV 201*. These mother ships use a wheeled cradle, rollers, and wheels, respectively, to permit movement of the boat in the ramp. The wheeled cradle of the *Telkkä* permits launching the FRC with a low, 7-degree ramp slope.

The ramp surfaces of the other mother ships were found to be either flat (i.e., no deadrise) with friction reducing tubular bunks or shaped with friction reducing material attached directly to the ramp surface. The friction reducing pads are of composite construction with a cushioning layer, to absorb impacts, below the Ultra Poly surface.

Ramp Side and Clearance

Ramp side clearance was observed on the ships to vary widely from as small as four inches to as much as 18 inches. The clearance must be sufficient to give the coxswain confidence when entering the ramp, but not so much that the FRC will come to rest out of position. Too great a clearance also gives the coxswain increased confidence that translates directly into faster recovery speeds. The faster recovery speeds in turn lead to greater deceleration forces when contacting either the ramp walls or the ramp surface.

One vessel, the *USS Tornado*, was designed to carry two different size RHIBs. To accomplish this, the ship has an adjustable side fendering system and movable longitudinal bunks in order to custom fit each RHIB.

Overhead Clearance

On the mother ships with gates that hinge to the overhead, the clearance between the small boat and the open gate can be of great concern to small boat crews. Of all the vessels visited only thee expressed concern with their overhead clearance during recovery. These were the *Jaguar*, *Hammerhead*, and *KBV 201*. Of the other vessels visited, the *Gordon Reid, Telkkä* and *Tornado* had outward hinging doors with no overhead restriction. The *Justo Sierra* and *Vormann Steffens* would not perform launch operations seas above Sea State 2 thus avoiding high vertical motions. On *Hammerhead* and *Jaguar*, the open gate that is stowed over the ramp area imposes an overhead restriction. On the *KBV 201* there was a tow rail present over the ramp at the transom. With the overhead restrictions, the boat crews had the perception that the overhead obstacle was closer than it actually was and it created apprehension when entering the ramp area.

Stern ramp configurations with overhead constraints, such as hinged stern gates, transom bulwark, overhead deck, etc., could significantly reduce operational effectiveness of the stern ramp system. Therefore, in a stern ramp design, the overhead clearance should be considered as one of the system design and operational constraints, and it should be evaluated with respect to the limiting sea condition.

Stern Door or Gate Configuration

The ramp transom openings are closed either by doors that hinge outward or by gates that hinge up or down. All the stern doors and gates observed were hydraulically powered. The outward hinging doors used on the *USS Tornado* open to 105 degrees to form a funnel shaped entrance to the ramp area. The coxswain would try to get the RHIB into the center of the ramp, but can use this funnel shape to help guide the RHIB if needed. Upward hinging gates must be designed so that there is sufficient overhead clearance for personnel and equipment during launch and recovery. To achieve this clearance the hinge points are placed high on the ramp walls, which also keeps the gate operating equipment out of the way of the small boat during recovery operations.

Two vessels, *Vormann Steffans* and *KBV 201*, use a downward hinging stern gate. The ramps for these vessels end at the waterline at the stern. The surfaces of the gates are covered with wheels and rollers to form a ramp extension when deployed. They provide a sill depth of between 12 and 24 inches at the end of the fully deployed stern gate.

Water Management System

A water management system provides a stern ramp system with the ability to reduce the speed of water washed out of the ramp such that a small boat is not flushed out of the ramp area with the receding water. At the same time, such systems may modify the phase angle of the water motion inside of the ramp delivering more water to the ramp entrance when the mother ship is heaving and pitching up. An effective water management system can contribute to higher operability for stern ramp boat deployment.

The importance of water management was evident on two vessels, the *Gordon Reid* and the *Tornado*. Both of these vessels use tubular rails or bunks to guide and support the RHIB during recovery. With the rails, the RHIBs were supported above the ramp surface that allowed the water to flow out under the small boat's hull.

The ramp surface of the *Gordon Reid* is made of expanded metal that aids in dampening the waves faster and allows the water to dissipate quickly beneath the RHIB. The use of a water management system is especially important when operating in higher sea states where there is considerable wave action in the ramp.

Capture Mechanism

Capture of most small boats during recovery is accomplished by having a deck hand (winch operator) pass the winch line to the bowman in the small boat, who would attach it to the boat. For safety reasons it is not desirable for a crewmember to enter the ramp area and attach the winch line to boat. Use of an automated capture mechanism reduces the number of crew needed to perform the recovery evolution. Three vessels have different methods of capturing the small boat so that the winch line could be attached without the aid of a bowman in the boat.

On the *Telkä*, launch and recovery operations are accomplished with the aid of a longitudinally moving cradle with an integral, hydraulically operated arm that would reach over the RHIB bow and hold the boat in the cradle. With the boat captured in the cradle both the boat and cradle are winched up the ramp as one unit.

The *Vormann Steffens* employs an automatic capture mechanism that would engage the bow of the FRC as it enters the ramp. As the boat crosses the ramp threshold, special pins mounted on the bow of the FRC would be caught by the mechanism and pull the boat up the ramp. At the head of the ramp the boat is put on a riding hook and the mechanism disconnected. The pin feature on the FRC bow and the capture mechanism were specialized designed to mate together. Proper alignment between the bow pins and the capture mechanism is necessary for the system to work, hence the use of the system is limited to lower sea states.

On *KBV 201*, the winch operator attaches the winch line to the small boat with the aid of a long pole. The winch hook is attached to one end of the pole. During recovery, the winch operator uses the pole to reach over to the boat's bow eye and connects the winch line to the boat. After attachment, the pole is pulled free of the winch line and the boat winched up the ramp.

Two sources of power are used on the winches for recovery, electric and hydraulic. One vessel, *Jaguar*, uses an electric capstan for recovery. Recovery winches and capstans have line speeds that range from 100 to 200 feet per minute. This is necessary to pull the FRC quickly up to the stowed position so that the stern doors or gates could be closed.

Stern Flaps/Wedge

One ship visited, *Tornado*, has a stern flap installed to increase the ship's performance. A secondary benefit that the stern flap provides is to effectively increase the sill depth by extending the ramp surface further below the waterline. However, to be effective in increasing the sill depth, the stern flap must have its upper surface at or near the angle of the ramp and should incorporate some method for guiding the small boat into the ramp.

Stern wedges have also been used to increase ship's performance. The use of a stern wedge increases the submergence of the transom, and so, as with a stern flap, it is possible to design a stern wedge that enhances the performance of the stern ramp. In this case, the aft end of the ramp could be lowered into the wedge area increasing the sill depth. Increasing sill depth generally increases the range of sea conditions the boats can safely be recovered in.

LAUNCH AND RECOVERY OPERATIONS

During the survey of vessels with stern deployment capability, it was observed that manning requirements to support boat deployment varied from ship to ship. The Swedish Coast Guard *KBV 201* needed only two people to launch and recover the small boat, one on deck and one in the FRC. The coxswain would pull the remote disconnect from his control station to launch and the winch operator would connect the winch line, via a long pole, to the FRC for recovery. The majority of launches and recoveries could be performed with two personnel in the FRC and one winch operator. A few vessels needed more. These included the *Tornado* and the *Justo Sierra*.

All the ships' operators interviewed responded that they could launch the small boat in any sea condition that the small boat could safely handle, but recovery was limited by the sea state. When the sea state exceeded the maximum for safe recovery, the ship would escort the small boat to calmer water where it could be recovered.

The majority of the ship operators preferred launching with the ship's course set directly into the waves (000°). As an alternative, they would fall off the wave by up to 30 degrees to reduce their pitching motion. Operators on the Finnish vessel *Telkkä* and the Swedish Coast Guard ship *KBV 201* preferred to run with the waves at the same speed as the waves. This gave the *Telkkä* the optimum condition for deploying their cradle and RHIB.

On the *CCGS Gordon Reid*, it was preferred to run in parallel to the crest of the waves (heading of 090° relative to the waves) when they performed boat operations in high sea states. It should be noted that this cutter has dramatically different hull geometry from all the other ships surveyed, and was designed for launch and recovery of the small boat as a primary mission of the ship while operating in a specific area of the world. The necessary space was reserved to install such a system around this mission. Almost all other designs considered stern boat deployment as secondary mission. Additionally, the Canadian Coast Guard employs permanent crew and has an excellent training procedure implemented aboard the ship.

Launch and Recovery Procedure

The procedures for launching and recovery for all the FRCs are very similar. In general, to launch a FRC, the bowman trips the quick release hook and the FRC slides down the ramp and out the transom. On a ramp with a low slope angle, the FRC must be backed out with a winch. The FRC's engines are started when the propellers are in the water.

There are a few exceptions to the launch procedure. Some FRCs are designed to run with the engines dry for a short period of time and do not need to be lowered into the water before starting. In these cases, the engines are started before the quick release line is pulled. Another exception is in the control of the launch. Normally the coxswain is in control of the launch, however, on some ships, it is a deck hand who is responsible for determining when to launch the small boat.

Most of the recovery procedures were nearly identical. The coxswain must time the boat's entrance into the ramp to coincide with the sill's greatest submergence. When the coxswain sees an opportunity, he accelerates the FRC into the transom opening and up the ramp. The winch line is passed to the bowman who attaches it to the FRC, and the FRC is then winched up the ramp to the stowed position.

There are a few differences between the various ships' recovery procedures; most notable would be the method for capturing the RHIB during recovery. On the *Telkkä*, a mechanical arm captures and holds the RHIB in the cradle and then the cradle is winched into the ship.

Table 2. Launch and Recovery Characteristics

Ship	Launch Heading	Ship Speed	Launch Time	Recovery Heading	Ship Speed	Recovery Time
Justo Sierra	0°	1-3 kts	20 sec	0°	0 kts	15-20 sec
Tornado	0°	5 kts	18 sec	0°	5 kts	12-20 sec
Gordon Reid	90°	5-6 kts	10 sec	90°	5-6 kts	8-18 sec
Jaguar	0°	5-8 kts	8 sec	0°	6-10 kts	10-14 sec
Telkkä	180°	6 kts	35 sec	180°	6 kts	12-15 sec
Hammerhead	20°	3-5 kts	7 sec	20°	3-5 kts	9-12 sec
Vormann Steffens	0°	5-6 kts	6 sec	0°	5-6 kts	10-15 sec
KBV 201	180°	5-8 kts	10 sec	180°	5-8 kts	10-12 sec

On the *Hammerhead*, the RHIB is driven all the way up the ramp, captured by a "lasso", and held in place until the winch line is connected to pull the boat to the stowed position. A detailed discussion of launch and recovery procedures is provided by Sheinberg et al. (2001).

Characteristics for Launch and Recovery

Summarized in Table 2 are the launch and recovery characteristics of the ships investigated. The ship speed for most launchings is between 3 and 6 knots. This gives the mother ship enough forward motion to maintain her course but still slow enough for the RHIB to escape the effects of stern wake turbulence immediately after launch.

Launching times vary directly with the launching procedure. The launching time is defined as the time from when the command to launch is given until the boat is clear of the transom. The quickest launches (7 seconds) are experienced on those ships where the small boat's diesel engine can be run dry. On these vessels, after the stern gate was opened all that was involved to launch was to pull the quick release mechanism. Adding a winch to lower the boat into the water before starting the engines increases the launch time to about 10 to 15 seconds. When the cradle or assistance is needed to launch the boat, as was the case for the *Telkkä* or the *Justo Sierra*, the time approaches a maximum of 35 seconds.

During recovery, the majority of the ship operators prefer the same course as they do for launch, head seas to 30° off the waves. The exceptions are the *Gordon Reid*, *Telkkä*, and *KBV 201*. The reasons they prefer their recovery directions are the same as for launch. The mother ship speed for recovery is nearly the same for recovery as for launch. However, *Jaguar's* recovery speed is doubled to nearly 10 knots or twice that of other ships. At the higher recovery speed, the water jet driven RHIB must travel at a higher speed where it has better directional stability, necessary during the recovery operations.

The recovery times are typically quicker than launch times. The recovery time is defined as the time it takes from when the coxswain decides to enter the ramp until the RHIB grounds on the ramp. At that point, the RHIB is attached to the winch and hauled up to the storage position.

Type and Size of Small Boat

The FRCs or small boats observed on the vessels investigated fell into two categories, RHIBs and others. The characteristics of the FRCs are summarized in Table 3.

The majority of the FRCs are RHIBs between 7 m and 7½ m long with one 11-m RHIB. Three ships, the *Erimo*, *Justo Sierra* and *Vormann Steffens*, used small

Table 3. Ship and Boat Characteristics

Ship	Small Boat	Boat Type	Propulsion
Erimo	5.5 m	Fiberglass FRC	Water Jet
Justo Sierra	11 m	Aluminum FRC	Water Jet
Tornado	7 m 11 m	RHIB RHIB	I/O Water Jet
Gordon Reid	7.33 m	RHIB	Outboard
Jaguar	7 m	RHIB	Water Jet
Telkkä	7.4 m	RHIB	Water Jet
Hammerhead	7 m	RHIB	Water Jet
Vormann Steffens	7.5 m	Self-righting FRC	Inboard w/skeg
KBV 201	7.65 m	RHIB	Water Jet

boats other than the RHIB. The *Erimo's* FRC is a fiberglass boat with an operator's cockpit located amidships. The *Justo Sierra's* FRC is an aluminum hulled Interceptor with an operator's cabin and seats aft for a boarding party of four. The *Vormann Steffens'* FRC is a self-contained and self-righting rescue boat.

Power is provided by diesel engines in all but one of the FRCs, the *Gordon Reid's*, which uses gasoline-powered outboards. The outboards provide the RHIB with several advantages. The engines are lighter with a higher power-to-weight ratio and are more directionally stable. They are also very responsive to throttle, very maneuverable, and can be changed out quickly. Their disadvantages include the lower units hanging below the ramp, requiring a cutout or raising before winching up the ramp, a generally shorter life expectancy, and they use the more hazardous gasoline.

Most of the diesel-powered small boats use water jet propulsion with the exception of the U.S. Navy's 7-m RHIB, that uses an I/O drive, and the *Vormann Steffens*, that uses a single propeller protected by a skeg. The larger 11-m boats use twin water jets. Water-jet drives have the advantages of no projection below the hull to interfere with launch and recovery, the diesels can be designed to be run dry before launching to give quicker launch times, and the jet drive has the edge on maneuverability but has a lack of directional stability when operating in the ship's wake. In order to compensate for this they must travel faster in the wake and approach the stern ramp at a higher speed.

Small Boat Design Considerations

When the small boats enter a stern ramp, the impacts due to grounding on the ramp and fending off the ramp corners and walls require special reinforcements on the FRC. The collars on RHIBs must also be reinforced to be more abrasion resistant to the scuffs and scrapes that accompany recovery. The stem and bottom of the FRC must be reinforced to withstand the impacts with the ramp deck caused by recovery and wave motions.

Two RHIBs, those used on the *Gordon Reid* and *Jaguar* use a collar section that wraps completely around the stern. The collar provides additional flotation to prevent the stern from submerging during launch and recovery.

Crew comfort and safety is another concern. As boats travel faster over heavy seas, the more discomfort it transmits to the crew. Long hours of high-speed operation in rough seas can be injurious to the crew. The impacts can cause back, knee, neck, joint, and muscle injury. As a minimum, it will cause fatigue, discomfort and pain. The introduction of ergonomic shock absorbing seats has helped reduce the injury rate, has increased operating times for the boat crews, and should be considered when outfitting the boats.

New steering control stations have been recently introduced to the RHIB industry. As an alternative to the steering wheel and separate engine throttle controls, a handlebar style steering station has been introduced. Along with steering control, the handlebars incorporate controls for speed and water-jet bucket position. This allows the coxswain to control the boat's speed and direction without removing his hands from the handlebars.

HYDRODYNAMIC CONSIDERATIONS ON OPERABILITY AND DESIGN

Stern Wake and Propeller Wash Influence on Recovery

The combined effects of wake of the mother ship, propeller wash and waves on the maneuvering ability of a small boat approaching a stern ramp present a hydrodynamic problem that has not been numerically analyzed due to the complexity of its nature. The factors that influence the wake are the ship's hull form and the propeller wash. They combine to form turbulent eddies that make slow speed transit of the wake difficult. The effects of the wake and propeller wash on a small boat's maneuvering ability when approaching a stern ramp are presently best understood through empirical observations. All the ships, except the *Tornado*, had two propellers. During launch and recovery operations, it was observed that the wake would form a depression between the two propeller washes. This trough would occasionally aid in centering the RHIB during recovery operations. On the *Tornado*, which has four propellers, recovery operations are performed with the two inboard shafts declutched to help reduce the propeller wash on centerline.

Every FRC exhibited difficulty navigating the wake and maintaining a straight-in approach. The stern wake made it difficult to maintain directional control of the small boat. As the sea states increased, the wake effects worsened. The natural tendency of the coxswains was to oversteer when making the approach to the ramp. In all sea states, except flat water, a last minute correction was observed as the RHIB traversed the stern wake and entered the ramp.

The slow speed directional control of the RHIB, when equipped with water jets, is minimal thereby making transit of the wake difficult. The approach speed of the RHIB needs to be approximately twice the speed of the mother ship to maintain good directional stability. On the *Jaguar*, to maintain better directional control on the RHIB, the mother ship recovery speed is increased to between 6 and 10 knots. This permits RHIB recovery speeds of between 12 and 20 knots, providing better directional control during recovery.

On the *Gordon Reid*, the RHIB is equipped with outboard propulsion that exhibited better directional control at the recovery speeds than did the water jet propelled boats.

All stern deployment systems observed are located on the ship's centerline. The recovery course of the RHIB is centered between the more turbulent parts of the wake produced by the propellers. Better maneuverability and directional control of the RHIB can be maintained, increasing the likelihood of a successful recovery.

Hydrodynamic Phenomena at the Stern and Potential Analytical Tools

From the hydrodynamic point of view, the problem of deploying a small boat from the stern of a larger vessel can be divided into three general regimes; wave induced motion of the mother ship and small boat, characteristics of the stern wake and propeller wash, and local effects inside of the stern ramp. The larger hydrodynamic regime concerns the motions induced upon the mother ship and small boat due to the incident ocean waves and the resulting effects of wave sheltering and radiated wave patterns. The local hydrodynamic regime involves those effects generated by the mother ship upon the ocean as the ship is propelled through the sea. This regime includes the stern wake of the mother ship and the propeller wash. Investigations of the third regime, local effects inside the stern ramp, will help with both the ramp design and the operability of using the ramp for launch and recovery.

The first regime is generally solved through seakeeping analysis, while the others require computational fluid dynamics (CFD) analysis for a solution. Unfortunately, stern-ramp deployment operations at sea from a moving ship involve all regimes. If the operation were not near the ship's wake and propeller wash, then seakeeping methods provide the solution. On the other hand, if there were no waves, then a CFD approach to the problem could be employed.

Table 4. Stern Boat Deployment System Hydrodynamic Phenomena and Assumptions

Problem	Description	Assumption
Motion in a seaway	Whole-ship seakeeping motions	Easily solved to a fair degree of accuracy with readily available strip-theory seakeeping programs.
Wave sheltering and reflection	A smaller vessel operating in the lee of a larger vessel will be sheltered to some extent from the incident ocean waves.	Several panel-method seakeeping programs can tackle this problem. The solution, however, concerns the zero-speed case only. For stern ramps, this effect is especially important for the head and following sea directions. Wave sheltering is a relatively small effect at the stern of a frigate as compared to the greater lee provided by the full length of the mother ship for side-davit recovery.
Two-body motions	Radiated waves from a vessel operating in close proximity to another vessel will tend to affect the motions of the other vessel.	Seakeeping programs are beginning to handle this problem. Modeling is tedious and complicated to implement and the solutions may not be accurate. The effect of radiated waves from a larger vessel affecting the motions of the boat is greater for side-deployment systems. This effect is neglected at the stern as wake and propeller wash predominate.
Maneuvering in stern wake	A smaller vessel operating near the stern of a larger vessel will have to pass though the local wave pattern of the larger ship's wake.	This is an extremely difficult and computationally intensive problem to solve. It is known that RHIBs with good acceleration and directional stability can successfully navigate through the wake and onto a stern ramp. Water-jet propelled RHIBs have been observed to be directionally unstable when operating in the wake of a ship, however, utilizing a more experienced coxswain has minimized this problem. Operationally, the ship's speed during launch and recovery should be kept below the level where stern wake becomes a problem.
Maneuvering in propeller wash	A smaller vessel operating near the stern of a larger vessel will have to pass through the currents and eddies generated by the larger ship's propellers.	This is an extremely difficult and computationally intensive problem to solve. It is known that RHIBs with good acceleration and directional stability can successfully navigate through the propeller wash and onto a stern ramp. Water-jet propelled RHIBs have been observed to be directionally unstable when operating in the propeller wash of a ship, however utilizing a more experienced coxswain has minimized this problem.
Interior hydrodynamic effects	This includes a multitude of local hydrodynamic effects impinging on and interior to the stern ramp including beach effects, sloshing, run up, and water drainage, as well as modifications to the undisturbed wave elevation due to the ship's forward motion and attitude.	For the most part, the hydrodynamic effects interior to the stern ramp have not been solved numerically except insofar as they have been inherently captured in the results of stern-ramp model tests. The ramp availability approach assumes an instantaneous wave surface elevation that is undisturbed within the ramp (or at least at the location of the sill). This may be calibrated to a specific ship's ramp configuration and speed based on model test results.

A number of hydrodynamic issues associated with the design of the stern ramp system are described in Table 4 including a listing of the significant hydrodynamic effects and the assumptions taken for each. The first item in the table, relative motions in the seaway and operability assessment of the stern ramp in a seaway, has been predicted using the U.S. Navy's Ship Motion Program (SMP) and Seakeeping Evaluation Program (SEP) suite, and Marintek's Vessel Response (VERES) Program. Each of these programs is based on strip theory and has been well verified. These programs give similar results, and both were used to aid in the investigation of the operability of the stern ramp on various sized cutters in typical ocean environments of the North Pacific and North Atlantic Oceans. However, because each of these programs use strip theory to solve the equations of motion, they are limited to that area and cannot be used to investigate the effects due to other hydromechanics issues such as wave sheltering, two-body motions, stern wake, propeller wash and interior effects to the stern ramp. Not only does stern ramp configuration play a significant role in the severity of impact loads between the mother ship and returning RHIB, but configuration aspects affecting water mitigation within the stern ramp along with the turbulence astern influence the degree of success and safety of the stern ramp system.

To address these other areas of concern, several analytical tools were investigated to determine which would be the best to aid in solving these problems. They were grouped into two main areas; impact loads of small boat on the stern ramp and maneuvering of the small boat across the stern wake and propeller wash near the entrance to the stern ramp. The list of tools that were reviewed was by no means exhaustive, but composed of those readily available to the Coast Guard and Navy.

Four numerical tools investigated to determine if any could aid in determining the impact loads of the small boat on the stern ramp of the mother ship. The first method was based on a time-domain model of an icebreaker impacting an ice sheet (after Popov, 1967). This model would calculate the loads on the small boat and stern ramp of the mother ship. In adapting this model, the mother ship takes the place of the ice sheet and would be assumed to be rigid and stationary with the vertical, transverse and longitudinal motions superimposed on the small boat. A parametric series of approaches would be conducted to determine the impact loads for the different approach velocities and impact locations on the boat. These impact loads, or forces, would then be translated into accelerations acting upon the occupants of the small boat to be compared against established criteria. This approach is simple and would provide a first-cut approximation of the loads and accelerations on the small boat. The mother ship geometry could also be modified to account for different stern ramp designs. However, it is not the most realistic approach because the mother ship would normally be moving with some forward speed, and the mother ship would have wave-induced motions in a seaway.

The second approach investigated to solve the two-body impact loads was to use a program named WAMIT (Wave Analysis MIT) developed by WAMIT Inc. WAMIT is a linear, zero-speed, frequency-domain program that can calculate the motions of two bodies in close proximity to each other. Wave-induced ship motions are calculated independently for each vessel. Although some of WAMIT's shortcomings, lack of determination of impact loads between the vessels and the fact that all calculated results are in the frequency domain, can be overcome through correcting them in a post processor, the fundamental underlying zero-speed assumption of WAMIT makes the complete solution unattainable. Basically, there is no way to solve the two-body hydrodynamic problem of small boats approaching the mother ship with significantly higher speeds. This results in the program failing to account for the influence of the speed difference between the ships on the impact.

The third analytical tool investigated to solve this problem was the Stern Ramp Model (SRM), which uses the Large Amplitude Motion Program (LAMP) developed by Science Applications International Corporation to calculate the ship motions. LAMP is a time-domain ship motion tool that uses non-linear hydrostatics and Froude-Krylov wave forces and linear hydrodynamics. The SRM has a method for tracking the contact between the ship and the boat and determining the reaction forces and kinematics. However, the current configuration of the SRM cannot calculate the hydrodynamic interaction between either the mother ship and the boat, or the planing forces on the small boat.

Because of this limitation, it is difficult to use this model as a stern-ramp design tool. The hydrodynamic interaction between the mother ship with stern ramp and the boat is important in order to determine the veracity of SRM output of the reaction forces on the boat during contact with the mother ship. Additionally, discerning the impact of changes to the ramp design would involve calculating the hydrodynamic interaction between the two vessels.

The last analytical tool reviewed for solving the problem of determining impact loads of one body to another is SWAN 2 developed by Professor Sclavounos at the Massachusetts Institute of Technology (Kim and Sclavounos, 1998). This linear, time-domain code computes calm water sinkage and trim, six-degrees-of-freedom wave-induced motions, and local and global structural loads. Currently there is no provision within the code for calculating two-body motions and impact loads.

Two analytical tools were investigated to solve the second problem of predicting the stern wake and propeller wash in the vicinity of the stern ramp within an ambient seaway. Both involve cutting edge computational fluid dynamics computation methods. The first method is the Reynolds Averaged Navier Stokes code. This code would provide an overall picture of the flow field in the vicinity of the ship. It also can provide propulsor inflow characteristics and the effect of the propulsor in calm water. This method is most commonly used for analyzing different integrated propulsor and hull configurations. Although this methodology can give a good description of the flow field near the ship, the technology has not matured enough to incorporate the ambient wave field into the flow field.

The second method (Lin, 2002) calculates the non-linear interaction of the ambient wave field and the ship-generated wake, as it is moving through calm water. This calculation can be used for all parts of the ship. Although this model shows promise, it is still in the early stage of development. It has been implemented with only double-ended hulls such as the Series 60 hull form and the Wigley Hull. The model still has to be extended to ships with a transom stern. In addition, no ship motions have been calculated for these ships in waves. The program's limitations of not considering the propeller wash aspects in the stern wake, the wave-induced motions of the ship, and the wake behind a transom stern make it very limited in its use currently. However, this approach shows promise because its calculation of the non-linear interaction between the ship generated and ambient waves may be able to provide a more exact definition of the stern wake, which can help in predicting the small boat maneuvering problems behind the ship on its approach to the stern ramp.

Based on the above review, it was concluded that none of the readily available computer programs at present have the capability to calculate all the phenomena considered crucial for simulation of the stern ramp recovery operation and thereby influence the stern ramp design. The parameters considered most critical to influencing stern ramp design are the prediction of water motion inside the ramp, the prognosis of impact acceleration induced on the small boat as it hits the stern ramp, and modeling of the small boat maneuvering in the wake and propeller wash behind the mother ship in the vicinity of the stern ramp. Although some of the available programs may aid in performing calculations of some particular phenomena, none are able to simulate these three effects that might significantly influence the selection of the optimal stern ramp design. Additionally, there was no verified analytical method identified that simulated the motion of water inside the stern ramp.

Model Testing

The review of the available analytical approaches presented earlier indicates that none of the available computer programs can solve the complex hydrodynamic phenomena that occur around the ship stern and inside of the ramp arrangement during an entry of the small boat. At the present time, model tests, especially with large-scale models, are considered the most effective tool for optimizing stern ramp design. Model tests afford the opportunity to model both the complex hydromechanics in and around the stern ramp during the FRC deployment and retrieval and the induced loads on the mother ship and FRC. A series of the model tests with systematic variation of the stern ramp parameters can therefore be the simplest way of selecting the optimal configuration of the stern ramp. Other parameters that can be evaluated during model tests are the limiting sea state, size of the FRC and main particulars of the mother ship. Furthermore, any additional system attached to the stern ramp such as a water-motion control system, boat capture mechanisms, etc., and its effect on the operability of the stern ramp could easily be verified by the model test.

When preparing for a model test, both the model size and wave conditions must be calculated. Each these factors depends on the particulars of available model test facilities and the sea conditions that will be investigated. Generally, it is recommended to use as large a model as possible, preferably with a scale ratio between 1:10 to 1:12.5. There are many benefits of using larger models for testing stern ramp operability. With the large-scale models more measurement equipment will be able to be installed in the small boat. With the extra equipment, it would then be possible to measure not only the boat accelerations but also the boat position in relation to the mother ship, the baseline loads on the boat, and the ability to video the boat's approach to the stern ramp etc. Using large-scale models also reduces the scale effect especially when modeling the time of recovery operation. Additionally, in order to observe and quantify changes in the stern ramp deployment operability as a result of application of different capture mechanisms or any additional design features of the ramp (such as drainage system, damping system, fenders etc.) the relatively large models of such arrangements are necessary.

Most of the recent model tests looking at stern ramp operability and design have been performed at indoor facilities. If larger scale models are required for testing launching or retrieving mechanisms, then outdoor facilities might also be considered as an alternative solution. Such facilities are however not recommended for performing sensitivity or optimization studies on stern ramp parameters. These types of tests require controlled environment and waves of specified heights and periods. Such conditions are difficult to achieve on an open lake or marine bay.

As a part of the USCG's investigations into the availability of using a stern ramp for the launch and recovery of a boat from a frigate or cutter type vessel in higher sea states, a series of model tests were conducted. These tests were performed for a systematic series of stern ramp recoveries under specified wave conditions for a variety of different headings.

The overall objective of these tests was to determine the capability of the stern ramp for small boat deployment and recovery in a variety of different wave conditions. Other beneficial information obtained from the model tests included identification of the key ship responses crucial in the evaluation, comparison of the different boat launch systems, and calibration of the ship motion program used for prediction of the long-term operability.

The model tests were conducted in the deep-water ocean basin at Marintek using frigate- and cutter-type modes as the mother ship and a water-jet driven and radio-controlled planing model as the fast small boat (Werenskiold, April 2001 and March 2003). Two models of the mother ship, one in scale 1:22.88 (the frigate) and the second in the scale 1:12.5 (the cutter) were used in these tests. The full-scale length (L_{pp}) of both mother ships was approximately 119 m (390 ft) and the length of small boat was about 11 m (36 ft). The test matrix for the frigate model (the model of 5.3 m (17.4 ft) in length) was set to measure the mothership and small boat responses at two speeds (5 and 10 knots), five wave headings (0, 45, 90, 135, and 180 degrees off bow), and for three sea states (Sea State 5, Sea State 6 and Sea State 7, respectively). The operability of the stern ramp recovery on the frigate mother ship was also tested for three sill depths. These tested alternative sill depths (0.305 m (1 ft), 0.610 m (2 ft) and 0.914 m (3 ft)) were obtained by trimming the ship model by the stern. Model tests with the frigate-sized cutter mother ship (the larger model of 9.5 m (31.2 ft) length) were aimed at assessing the relative effectiveness of alternative stern ramp widths and different water managements systems. These tests were carried out in one selected sea (Sea State 6) and one wave heading (30 degrees off bow).

During each of the tests, the mother ship model was suspended in a soft spring system that allowed the model to freely heave, roll and pitch. The spring system was designed to provide representative surge, sway and yaw characteristics for a low speed operation in rough water. The mother ship model was self-propelled and was fitted with a propeller whose pitch and speed were representative of full-scale operation. In addition, since the model scale of ship wake and propeller wash affecting the operation of the FRC close to the stern were physically represented, the modeled results closely resembled the full-scale operation. A coxswain sitting on the carriage in a position just astern of the mother ship operated the radio controlled small boat.

The test program included a series of runs with the mother ship alone and the mother ship with the small boat. The tests conducted with the mother ship alone were recorded the water motion inside of the ramp and the relative motion at the ramp entrance. The tests with the mother ship and small boat entering the ramp were performed with different environmental conditions to determine the operability of ramp. The following data were collected during the model tests for both the mother ship and small boat:

- Mother ship motions at six degrees of freedom at the ship center of gravity
- Acceleration in three axes at three locations: ship center of gravity, bridge and stern (operator position).
- Vertical and transverse acceleration at two locations: midship on the main deck and on the leeward side (side-launch operator position).
- Relative vertical wave motions at seven positions: bow, midship on both sides, stern on both sides, and at two locations inside of the ramp.
- Ship speed and propeller revolutions.
- Propeller wake and ship wash at three positions aft of the stern in the FRC approach area.
- Small boat accelerations in three axes close to boat center of gravity.

Results obtained from the model tests with a large model, representing a frigate-sized cutter, have proved that such a procedure can effectively be applied to optimize the stern ramp design. The test results clearly demonstrated that for some stern ramp configurations the number of successful entries were significantly larger than for other types. This was primarily due to the effect of improved water management inside of the ramp and the lower number of collisions with the stern for the fairly formed ramp entrance. Three different ramp configurations were considered within this test series. Ramp no. 1 was a narrow ramp without the water management system. The ramp entrance to the sea was straight and not rounded. Ramp no. 2 had the same ramp entrance form and width as Ramp no. 1, but a water drainage system was added.

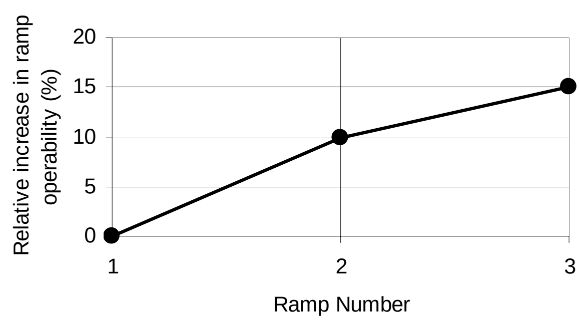

Figure 5. Effect of ramp arrangement on stern ramp operability (from model test results).

Comparing the two configurations (see Figure 5) demonstrated a relative increase in successful recoveries of 10 percent by the addition of an effective water management system. Ramp no. 3 had a wider interior width, its entrance to the sea was additionally widened (with the entrance angle of 30 degrees), and the ramp edges at the transom were rounded. It had the same water drainage system as for Ramp no. 2. In this case, the relative increase in successful recoveries was 15 percent compared to Ramp no. 1.

The model test results were used to verify and calibrate the predicted mother ship response computed from the VERES ship motion program. This program was also used to compute the long-term prognosis of operability of the stern ramp boat deployment. An example of such prognosis is given in the following section.

The second objective achieved by these model tests was the development of the mother ship motion criteria for stern ramp operability. Based on the test results, two mother ship responses have been identified as key parameters for assessing stern ramp system operability. These crucial responses are the relative vertical motion and sway motion at the ramp entrance on the mother ship. Two operability criteria related to these selected mother ship responses have been proposed and the limiting amplitudes of these critical responses have been defined (Kauczynski and Werenskiold, November 2001).

DESIGN CRITERIA FOR STERN-RAMP BOAT DEPLOYMENT

Since 1995, the U.S. Coast Guard has been developing and refining boat-deployment seakeeping criteria. This effort has included compiling analysis techniques, collecting data for analysis through at-sea dedicated trials and model tests, and conducting seakeeping motion, comparison studies. Much of this effort has been directed towards side-davit systems, but recently it was recognized that the Coast Guard would need to develop a consistent set of criteria for stern deployment of small boats to assess stern-boat deployment systems.

For the purposes of performance evaluation of boat deployment from cutters, three criteria sets are considered. The first group is the mother ship motion criteria, which are the same for side-davit and stern-ramp boat deployment. The second criteria set considered takes into account the relative motion of the stern ramp sill in and out of the water, and is embodied in a ramp availability criterion. Combined, these two criteria sets can be used to compare different launch systems on the same cutter or between difference cutter platforms. They can be readily applied using existing strip-theory, frequency-domain seakeeping evaluation programs. The third set of criteria is based on the deployed boat and its capability to affect a successful recovery onto a stern ramp. It imposes a standard for stern-ramp deployed boats to meet so that they can match the level of system performance provided by the mother ship. The deployed boat criteria can be evaluated through model tests or full-scale testing with instrumentation on the small boat, or through the application of impact loads time-domain models. Through a dedicated model test program with a frigate-sized mother ship and FRC, the deployed boat criteria have been related to the motions at the stern of the mother ship. In this way, they too can be evaluated from the point of view of the mother ship motions in a seaway using standard seakeeping analysis approaches.

Mother Ship Motion Criteria

The basic motion-limiting criteria for side-davit boat deployment (both launching and recovery) (Minnick et al., 1999) are given by

Criterion	Limit
Roll	< 8.0º SSA
Pitch	< 2.5º SSA
Vertical Acceleration	< 0.2 g SSA at Boat Station
Lateral Acceleration	< 0.2 g SSA at Boat Station

These criteria are also applied to mother ship motions for stern-ramp, self-propelled boat deployment (recovery as the limiting operation) of a high-performance RHIB or FRC (U.S. Coast Guard, Apr. 2001).

The criteria set was developed as a result of dedicated full-scale trials in the Bering Sea in 1995. A joint Alaskan Patrol (ALPAT) using the *USCGC Boutwell* (WHEC 719) and *USCGC Harriet Lane* (WMEC 903) was conducted for the purpose of quantitatively and qualitatively comparing the operational capabilities of the Coast Guard’s 378-ft and 270-ft Class cutters in identical Alaskan sea conditions during a typical ALPAT. During these trials both cutters most often utilized their RHIBs, launched and recovered from single-point davits, for boarding fishing vessels. The single-point davit on the *Boutwell* was fitted with a constant-tension winch. The technical details of this Joint ALPAT are reported in U.S. Coast Guard (February 1996) and by Minnick et al. (June 1999).

The approach used to determine criteria for side-boat deployment was to identify all boat launch or recovery events, correlate the events with the capability assessments (“go” and “no-go” assessment) and the recorded motions data. The data were then rank ordered by degree of difficulty to determine the limiting motions and motion magnitude. The ship motion measurements pertaining to side-boat deployment were pitch, roll, lateral and vertical accelerations at the pilothouse, and the lateral and vertical accelerations at the boat location.

The resulting data set indicated that transverse acceleration was not directly associated with the “no-go” situations. The limiting parameters were found to be pitch, roll and vertical acceleration at the pilothouse or at the boat deployment site. It was assumed that once the decision was made from the pilothouse to launch or retrieve a small boat, actual timing and on-site decision-making transferred to the bosun in charge at the boat station. By comparison of the significant single amplitude (SSA) motions and the minimum "no-go" ship motion measurements it was concluded that a vertical acceleration limit of 0.2 g SSA was the natural break point between the "go" and "no-go" situations and was applicable to both the pilothouse and boat station.

While not a direct validation of this result, an earlier study on the deployment of a towed array from a transom compartment of a naval vessel underway was conducted by Thomas et al. (1992). Array deployment and recovery operations are conducted in head seas or bow seas in order to keep the array cable taut. Other headings can result in surging that cause complications with the winch system and risk fouling the propellers. Array deployment and recovery operations can be hindered in heavy seas due to excessive ship motions at the stern, which interfere with the ability of personnel checking and straightening out the cable as it comes off the winch drum. Using measured motions data along with noted assessments of when a crewmember could successfully deploy the array or not, a similar methodology was used to determine the limiting motion and that motion's magnitude. In this case, the limiting motion for severe degradation of crew performance was also determined to be vertical acceleration with a magnitude of 0.15 g SSA. Both boat deployment and towed array deployment require similar human interactions (reaching, lifting, connecting hooks, etc.) to accomplish the task, so it is reasonable to expect that the magnitude of the vertical acceleration that limits the safety of these tasks would be roughly the same.

Lateral accelerations on the mother ship can also be limiting if the crew on the mother ship cannot perform their duties. This can be referred to as a separate limiting criterion of lateral acceleration. It has been found that if the lateral acceleration on the mother ship exceeds the value of 0.2 g SSA, the crew's performance degrades significantly.

For side-boat deployment using Miranda-type davits, additional constraints, such as a vertical displacement limit, may be justified.

Ramp Availability Criterion

Within the Coast Guard, the problem of evaluating the feasibility and operational effectiveness of recovering a boat via a stern ramp was encountered when developing a series of feasibility studies, using state-of-the-art design synthesis programs, to produce a number of conceptual designs for the National Security Cutter. The completed designs were compared for seakeeping performance using a PTO analysis. This not only identified the need to establish appropriate criteria to evaluate stern-launch systems, but also established that ramp sill emergence in a seaway could easily complicate stern-launched boat recovery from relatively longer cutters, such as a National Security Cutter, in higher sea conditions.

In conjunction with the survey of ships with stern deployment systems, efforts were underway to develop a coherent stern-ramp evaluation methodology. Consequently, a number of parametric studies were conducted that took into account the responses from the operators of stern-ramp vessels, measurements of deployment operations on these vessels, theoretical hypothesis and comparison with dedicated model tests. The seakeeping analytical studies compared side-davit and stern-ramp performance for three sizes of notional cutters: National Security Cutter, Medium Endurance Cutter and Patrol Craft. Limiting responses on all heading and reasonable speeds over a range of sea conditions were investigated and overall PTO evaluations conducted.

This lead to the inclusion of a ramp availability criterion with the mother ship motion criteria into a motion-limiting criteria set for stern-ramp, self-propelled boat deployment (recovery as the limiting operation) of a high-performance RHIB or FRC (U.S. Coast Guard, April 2001). The ramp availability criterion is given by

Criterion		Limit
Mean Ramp Availability	>	Minimum Ramp Availability Duration
$\langle \tau_{-} \rangle$	>	T_{RA}

The ramp availability criterion is based on a frequency domain representation of the undisturbed water depth at the entrance to the stern ramp where the threshold distance "a" is set as follows:

a = sill water depth at the ramp sill for RHIBs
a = sill water depth at the ramp sill minus forward draft for displacement boats

Ramp sill depth refers to the vertical distance from the mother ship's still waterline to the lowest point in stern ramp or stern well at the transom. For vessels with a stern flap, the flap's upper surface may allow it to be effective for boat recovery operations. In this case, the effective ramp sill depth may be considered the vertical distance from the still waterline to the lowest point on the upper surface of the stern flap that effectively supports boat recovery. The flap upper surface should have about the same slope as the stern ramp and provide some means of transverse constraint to keep the boat from sliding to one side.

Ramp availability is the period of time during the relative motion process at the ramp sill when the water depth over the sill is deep enough to avoid bottom contact on a boat being recovered. The ramp availability criterion provides a linkage between sill depth, sill emergence frequency, vertical relative displacement on the mother ship and the small boat acceleration performance.

Predicted sill emergence frequency, the relative vertical displacement and ramp availability are readily related in frequency-domain calculations similar to those employed for deck wetness or bow slamming predictions. Different formulations of these interrelated responses may be more readily adaptable to seakeeping response analysis and a PTO evaluation approach over others. A detailed derivation and theoretical discussion of the limits of applicability for this ramp availability formulation are given by Dalzell (2003). A summary of the derivation for the expected average duration for ramp availability and approach implications is presented here.

In the self-propelled retrieval operation onto a stern ramp, the boat approaches and lines up on the ramp and, according to the judgment of the coxswain, accelerates and drives as far up the ramp as possible. At this time, the boat is secured by some mechanism and winched the rest of the way up the ramp. Certainly, it would be unwise for the boat to hit the ramp just as the sill emerges; in fact, there may be a required minimum depth of water over the sill for a reliable landing. It can reasonably be assumed that under severe conditions the coxswain will watch the ship motion relative to the local water surface and start the drive to the ramp when it appears that the ramp is on the downward part of its cycle when the water depth over the sill will be greatest. The coxswain needs time to decide to go, to accelerate the boat, and to move the boat onto the ramp. At the moment of threshold crossing, the water depth over the ramp sill needs to be deep enough to avoid bottom contact on the boat, at least until the bow has "grounded" on the ramp and has been hooked on. Thus, it possible to employ a criterion that involves the statistics of the duration that the depth of water over the ramp sill is greater than some specified depth. Such statistics would define a "ramp availability" time. The associated criterion would be the minimum time required for the retrieval operation.

The overall evaluation and comparison approach involves the conventional linear-random model of the sea and the ship motions. Following the approach by Dalzell (2003), the motion processes are assumed to be Gaussian and zero mean, and these assumptions allow the application of some existing results from threshold crossing theory. First, the relative vertical motion at the location of the ramp sill, Y(t), is assumed to be a random Gaussian zero-mean process. Relative vertical motion is defined as the difference between the absolute ship motion at some point on the static waterline and the local water elevation. (It should be noted that some special ship motion computations beyond the usual strip-theory methods may be required to refine the estimates of the local water elevation just aft of the ship or over the ramp sill.) Relative motion is zero when there are no waves to excite the ship, and under these circumstances, the depth of water over the sill is the nominal still water value.

A fragment of the relative motion process, Y(t), is sketched in Figure 6 along with some definitions that relate the problem to the mathematical threshold crossing problem. The relative motion process is defined to be positive when the selected point on the ship rises above the local water level. Thus, if the relative motion is positive and equal to "a", the water depth over the sill is the original depth less "a". The value "a" is a constant "threshold" that depends upon the geometry of the problem. If "a" is set equal to the depth of water over the sill for no-wave conditions, then during times the relative motion when Y(t) exceeds "a", the sill will be emerged. Alternately, if "a" is set equal to the nominal depth of water over the sill less an allowance for the draft of the boat to be recovered, then during times the relative motion when Y(t) exceeds "a", the water over the sill will be less than the draft of the boat.

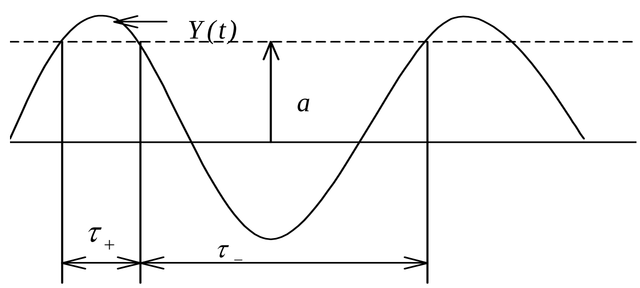

Figure 6. Definition sketch for transom sill relative vertical motion.

As shown in Figure 6, the time duration that the relative motion exceeds the threshold, a, may be denoted τ_+. Similarly, the time duration that the relative motion is less than the threshold may be denoted τ_-. Thus the threshold problem involves the statistics of τ_- for a specified threshold, a, and random process, Y(t).

The average length of the time intervals during which Y(t) is less than "a" is denoted by $\langle\tau_-\rangle$. The theory yields a solid estimator for this quantity as:

$$\langle\tau_-\rangle = \textbf{Error!}\ \exp[(a/\sigma)^2/2]\ \Phi(a/\sigma)$$

$$\langle\tau_-\rangle = T_Z \exp[(a/\sigma)^2/2]\ \Phi(a/\sigma) \qquad (1)$$

where σ is the standard deviation of the relative motion process, Y(t), σ_v is the standard deviation of the first derivative of the relative motion process, and $\Phi(.)$ is the standardized Normal probability integral. Normally, the standard deviations would be computed as the square roots of the zeroth and second moments of the relative motion spectrum, (m_0 and m_2). From a frequency-domain prediction of the motion, they can be obtained as the relative vertical displacement rms and the relative vertical velocity rms.

It should be noted in the equation that functions of (a/σ) modify the mean zero-crossing period, $T_Z = 2\pi\sigma/\sigma_v$, to result in the average time interval. The quantity $T_Z \exp[(a/\sigma)^2/2]$ is an estimate for the mean time between threshold up- or threshold down-crossings. What the probability integral does is to determine the part of the average up-crossing period where the process is expected to be below the threshold. When the threshold is zero, $\Phi(a/\sigma)^2 = 0.5$ and the average time interval during which $Y(t) < 0$ is half the zero crossing period. When the threshold is very large $\Phi(a/\sigma)$ approaches unity and the average time interval during which $Y(t) < a$ approaches the mean time between threshold up-crossings.

The reciprocal of the estimate for the mean time between threshold up- or down-crossings ($T_Z \exp[(a/\sigma)^2/2]$) is the expected number of threshold crossings per unit time, a computation that has been done in support of deck wetness criteria for many years. The only moderately new thing computationally in Eq. 1 is the probability integral, $\Phi(.)$.

The frequency-domain criterion is that ramp operations be considered unsuccessful or more than usually dangerous for a given sea and operational condition if

$$\langle \tau\_ \rangle < T_{RA} \qquad (2)$$

where T_{RA} is a minimum average ramp-availability time interval during the retrieval portion of a boat recovery operation.

The survey of ramp-equipped ships reported earlier did ascertain a first-level estimate of appropriate minimum average recovery duration by comparing the measured values of the averages with the stated sea state capability. These are given in Table 2. From this it was determined that a realistic average recovery time for a high-powered RHIB or FRC can be reasonably expected to be near 12 seconds with a minimum physically possible recovery time of 5 seconds.

It should be borne in mind that a recovery time (physical minimum or average) and an average ramp-availability interval are two different measures. The time to complete the boat recovery operation is longer and distinctly different from the actual retrieval interval during recovery (which is related to ramp availability time). Different criterion levels for the minimum average ramp-availability time interval, T_{RA}, have been explored. For high-powered FRCs considered for open-ocean deployment, a minimum average ramp-availability time of about 5 seconds corresponds favorability to the time required for these boats to complete the final segment of their approach and entrance onto a stern ramp.

Finally, it is important to note that ramp-availability time interval does not take into consideration any sway/yaw motion of the mother ship or FRC, impact loads between the FRC onto the ramp, and the propeller wash and other wave/wave turbulences that can occur in the stern wake. Each of these items must be considered in conjunction with the time interval for ramp availability. Additionally, the experience of the coxswain and crew can greatly affect the minimum average time interval for recovery.

Stern-Ramp Deployed Boat Criteria

One of the factors limiting the operability of stern ramp deployment systems is the small boat response in the last phase of the retrieval operation. During an entry into the stern ramp the small boat operability is limited by the boat's structural capability to withstand the impact loads generated on contact with the stern ramp and the surrounding ship structure. Simultaneously, the induced impact accelerations must be kept on a level acceptable for the boat's occupants to assure a safe recovery operation.

Based on data collected from the public transport studies (Hoberock, July 1976) and the operational limits adopted by the IMO Code of Safety for High-Speed Craft, Werenskiold (April 2001) has proposed the following three safety levels related to the acceptable exposure of persons on board a small boat:

- *Safety Level 1*, which represents minor risk of injury to standing people when holding.
- *Safety Level 2*, which represents minor risk of injury to sitting people.
- *Safety Level 3*, which represents minor risk of serious injury to sitting people.

The safety levels are defined in terms of the vertical and horizontal accelerations. The limiting maximum accelerations are based on the safety of personnel on board and include a suitable margin of safety for damage of the small boat (see Table 5). These proposed limits should be regarded as providing a significant safety margin for seated persons in the FRC who are well prepared for possible impacts when the boat enters the stern ramp. Therefore, Safety Level 3 should be applied for operating crew assumed to be sitting with lap belts,

Table 5. Limiting Values of the Maximum Accelerations Induced on the Small Boat

Safety level	Criteria: Maximum acceleration not to be exceeded		
	Vertical	Transverse	Longitudinal
1 (Minor risk standing persons)	0.60 g	0.25 g	0.25 g
2 (Minor risk sitting persons)	0.80 g	0.35 g	0.35 g
3 (Risk of injury sitting persons)	1.00 g	0.50 g	0.50 g

while the more constraining Safety Level 2 is for seated persons on board who are not members of the operating crew. The limiting values correspond to the maximum accelerations and it is expected that such maximum will be induced in a moment when a boat first hits the ramp structure by its bottom or side. Maximum vertical load of 1.0 g at the center of gravity of the FRC is also generally applied as the structural design load for such a high-speed craft.

For practical applications, such as the comparison of the mother ship hull designs, selection of the optimal ramp particulars, evaluation of arrangements of different ramp configurations, or development of an operator guidance system, it is useful to express all the operational criteria of the stern ramp deployment in terms of the mother ship responses.

In order to find a relationship between the mother ship responses and the FRC impact accelerations during FRC entries of the stern ramp, a parametric study was performed with data provided from the model tests. Analysis of the model test results was performed by assessing the number of unsuccessful FRC recovery operations along with consideration of the following factors:

- Vertical impacts between FRC bottom and ship or ramp structure.
- Transverse impacts between FRC sides and ship or dock structure.
- Longitudinal impacts during entry and docking or securing.
- FRC maneuverability and seakeeping performance in open sea or approach area.
- FRC controllability and forward acceleration capability during entry.

An "unsuccessful recovery" has been defined as a case when the boat's vertical or horizontal accelerations exceeded the defined levels. Criteria for assessment of impact loads were related to the accelerations experienced by personnel on board the FRC (as listed in Table 5).

Results of the model tests clearly show that the operability and limitations of stern-ramp recovery systems are dependent on a combination of technical (or physical) factors and human factors. Based on results of this analysis, it was found that the mother ship relative vertical motion at stern is the main factor that contributes to the FRC vertical impact acceleration. The reduction of operability due to FRC longitudinal impact accelerations are mainly caused by the craft hitting a higher part of the ramp structure. This includes the longitudinal component of imposed transverse FRC accelerations, as this is dependent on FRC speed of entry as the mother ship moves to one side. Consequently, transverse stern displacement by the mother ship has been identified to be the fundamental technical factor that causes large FRC longitudinal impact accelerations. Finally, the reduction of operability due to the FRC transverse impact accelerations appears to be mostly dependent on coxswain skill and therefore dependent upon human factors.

Thus, the mother ship's vertical relative motion and sway at the stern are key parameters that influence the magnitude of the impact accelerations on the FRC during ramp entry. Because of this, they have been used as the limiting parameters in two proposed operability criteria for the safe stern ramp operation. The first criterion sets the maximum acceptable amplitude of the relative vertical motion at the stern. The second criterion, the "small boat maneuvering criterion", sets the limit on sway motion at the stern of the mother ship.

Both these criteria can be used to assess risk of the boat recovery operation. They were deduced from dedicated model tests on a frigate-sized mother ship. Different criterion levels may be more appropriate for different sized mother ships, for different entrance shapes or boat-to-ramp well side clearances. These matters are still under investigation.

Stern Vertical Relative Motion Criterion

The limiting magnitude of the relative vertical motion at the stern of mother ship, shown in Table 6, was obtained through analyzing the results of the model tests with a mother ship of frigate size and hullform. The safety levels shown in the table classify the risk of the recovery operation and are related to exposure of persons on board the small boat as shown in Table 5. The percent time the stern ramp is operable (PTO) was defined by the number of successful recovery operations recorded in the model tests. These were computed from the model test results by taken into account number of recoveries with the impact acceleration below the accepted level.

Table 6. Limiting Magnitudes of the Relative Vertical Motion at the Ramp Entrance (rms)

	Ship speed	100% of successful recovery	90% of successful recovery	80% of successful recovery	70% of successful recovery
Safety level 1	5 knots	0.65 m	0.78 m	0.90 m	1.05 m
	10 knots	0.45 m	0.55 m	0.65 m	0.75 m
Safety level 2	5 knots	0.70 m	1.20 m	1.70 m	2.20 m
	10 knots	0.45 m	0.75 m	1.00 m	1.28 m
Safety level 3	5 knots	0.85 m	1.65 m	2.45 m	3.25 m
	10 knots	0.55 m	1.00 m	1.45 m	1.90 m

Referring to Table 6, the amplitudes of vertical relative motion are the lowest for safety level 1, slight risk of injury to personnel standing in the FRC, as this is the most restricted case. Because definitions of safety levels 2 and 3 are more relaxed, the resulting limiting impact load values, and corresponding limiting relative vertical motion values, are higher.

In the model tests, recoveries of the small boat were initiated at arbitrary time points. Such results must therefore be considered as conservative. By assuming that a coxswain with medium experience will steer the small boat during recovery maneuvers, a part of the most "impropriate" recoveries performed in the model tests could be rejected. Therefore, in practical application, it is proposed to use in the limiting ship response corresponding to 90 percent of the successful recoveries.

Small Boat Maneuvering Ability Criterion

During the beam and oblique seas part of the model test matrix, the number of unsuccessful operations was considerable despite the relatively low amplitudes of the vertical motion at the vessel stern. The main reason that so many of the recovery operations were classified as "unsuccessful" was that the magnitudes of the longitudinal impact accelerations measured on the small boat exceeded the established criteria listed in Table 5. Based on model test results, the magnitude of sway at the stern has been selected as a critical ship response, which is directly related to maneuvering problems during stern ramp FRC recovery operations. In beam and oblique seas, the small boat usually maintains more power to keep its position on the centerline behind the ship's stern. On these headings, the mother ship's hull does not shelter the boat maneuvering during approach to the stern ramp, and more power is required to balance the wave and wind effect and to keep the course. This effect will cause higher longitudinal acceleration when boat hits the ramp or ship structure. An analysis of the model test results provides a basis for the settings of the limiting sway amplitudes for a mother ship of frigate size and hullform (see Table 7).

Table 7. Limiting Sway Responses (rms) at the Stern Applied in the Maneuvering Ability Criterion

	Ship speed	100% of successful recovery	90% of successful recovery	80% of successful recovery	70% of successful recovery
Safety level 1	5-10 knots	0.50 m	0.55 m	0.60 m	0.70 m
Safety level 2	5-10 knots	0.50 m	0.75 m	1.50 m	2.25 m
Safety level 3	5-10 knots	0.50 m	2.10 m	4.20 m	6.30 m

Human Factors and Experience of the Coxswain

Another parameter that causes "unsuccessful" recovery operations of the FRC into the stern ramp relates to human factors. In these cases, the transverse accelerations exceeded the limiting values due to the small boat striking the side of the stern ramp at the moment of its entry onto the ramp. The coxswain's ability to keep the FRC in position behind the ship stern and to select the time to start entry are considered to be the main actions that determine the impacts of the FRC on the ramp sides during entry into the stern ramp.

According to model test results, the significance of human factors increases when the higher safety levels are considered. Human factors are strongly dependent on the coxswain skill and experience. For practical application, it is proposed to consider results obtained from the model tests as representative for the level of skill of a coxswain with medium experience. These are presented in Table 8.

Table 8. Loss of operability (in percent) Due To Human Factor (for a medium experienced /skilled coxswain)

	Ship speed	Wave heading off bow				
		0˚	45˚	90˚	135˚	180˚
Safety level 1	5 knots	5	5	5	5	5
	10 knots	5	10	10	5	5
Safety level 2	5 knot	10	15	15	10	15
	10 knots	15	10	5	15	5
Safety level 3	5 knots	10	15	20	20	20
	10 knots	15	10	20	20	20

The loss of operability due to human factor should be deducted directly from the PTO computed by applying the "technical factors". For a more experienced coxswain, the deduction listed in the table could be decreased by one-third. This effect cannot be completely dismissed since it is based on the induced lateral impact accelerations that can exceed the limit even with a very experienced coxswain.

STERN-RAMP BOAT DEPLOYMENT APPLICATION EXAMPLE

A range of the reduced operability of the stern-ramp deployment caused by the mother ship and boat responses is demonstrated by an example computed for a frigate-type hull. The selected hull has the following particulars:

Length between perpendiculars, L_{pp}	122 m (400 ft)
Breadth on waterline, B_{WL}	16.3 m (53.5 ft)
Draft at midship, T_M	5.0 m (16.4 ft)
Displacement, Δ	5050 tonnes
Transverse metacentric height, GM_T	1.85 m (6.10 ft)

Roll inertia radius, r_{44} 0.346 B_{WL}

It was assumed that the ship has a single stern ramp placed along the ship's centerline. The ship is equipped with bilge keels (of width 1 m (3.3 ft) and a length of 25 percent of L_{pp}) and two rudders. Three alternative sill depths (0.305 m (1 ft), 0.610 m (2 ft) and 0.914 m (3 ft)) have been considered in the computations. The ship speed for the recovery operation was selected to be 5 knots.

The PTO for stern ramp launch and recovery are calculated by comparing motion-limiting criteria with the mother ship motion predictions in representative sea states in one specific geographic region. For these computations the grid point no. 263 in the North Atlantic Ocean, located south of the Gulf of Maine was selected. The joint probability of significant wave height and modal period combination on an annual basis for this grid point are taken from the wave atlas (Naval Oceanography Command Detachment, 1983 and 1985). At this ocean area the statistical data show that the peak of the wave modal period is 9.7 seconds and a probability of occurrence of the wave height greater than 0.305 m (10 ft) is about 28 percent.

The applied set of the operational criteria for stern ramp deployment consists of the seven following criteria that have been discussed with the adopted limiting values as listed:

Roll motion,	8.0 deg SSA
Pitch motion,	2.5 deg SSA
Vertical acceleration at boat station,	0.2 g
Lateral accel. at the boat station,	0.2 g
Ramp availability time,	T_{RA} = 5 sec

Relative vertical motion at the ramp entrance,
1.20 m (3.94 ft) rms for Safety Level 2
and 90% successful recoveries

Sway at the ramp entrance,
0.75 m (2.46 ft) rms for Safety Level 2
and 90% successful recoveries

Computations of the mother ship responses were performed by running the VERES ship motion program. This linear-strip theory program calculates 6-degree-of-freedom response amplitude operators. Since amplitudes of the relative vertical motion derived by the program do not include an effect of the altered wave amplitudes in vicinity of the hull as well as disturbances of the water level behind the stern due to the propeller wash and stern wake, the program has been modified by adoption of a set of semi-empirical factors. These factors have been derived by comparison of the ship relative vertical motion at the stern measured during the model tests with the considered vessel and computed by the VERES program. The irregular sea conditions have been modeled by using the Pierson-Moskowitz wave spectrum with the wave spreading factor assumed to be $\cos^2$. All wave directions were considered in the analysis.

Results of the PTO analysis are shown in Figures 7 through 11. The total operability obtained by applying all the listed operational criteria is given first in Figure 7. Each particular criterion is considered separately in the following figures except for vertical and lateral accelerations at the stern and relative vertical motion at the stern, which were not limiting.

In addition, the effect of a range of sill depth on the stern ramp deployment operability computed with the ramp availability criterion is presented in Figure 12. All these results have been computed without including the operability loss caused by possible human factors that for the considered range of the wave height and headings would not be larger than 10 percent.

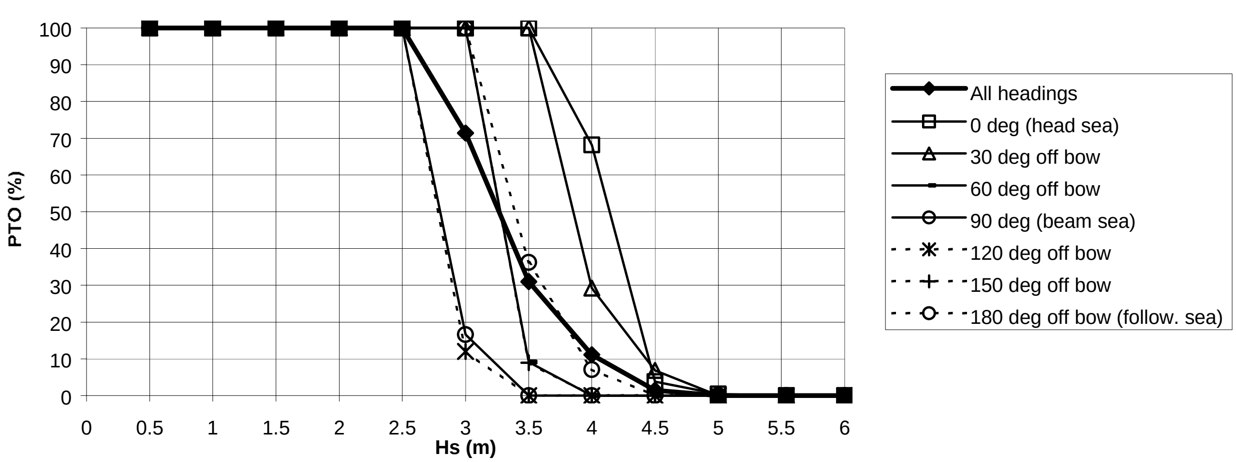

Figure 7. Stern ramp operability from example frigate at 5 kts - All Operability Criteria.

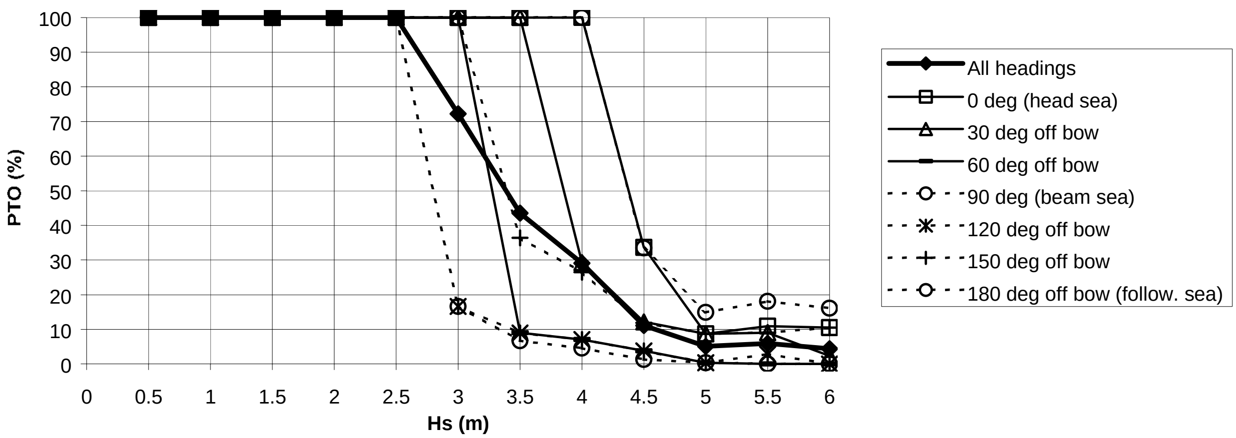

Figure 8. Stern ramp operability from example frigate at 5 kts - Roll Motion Criterion.

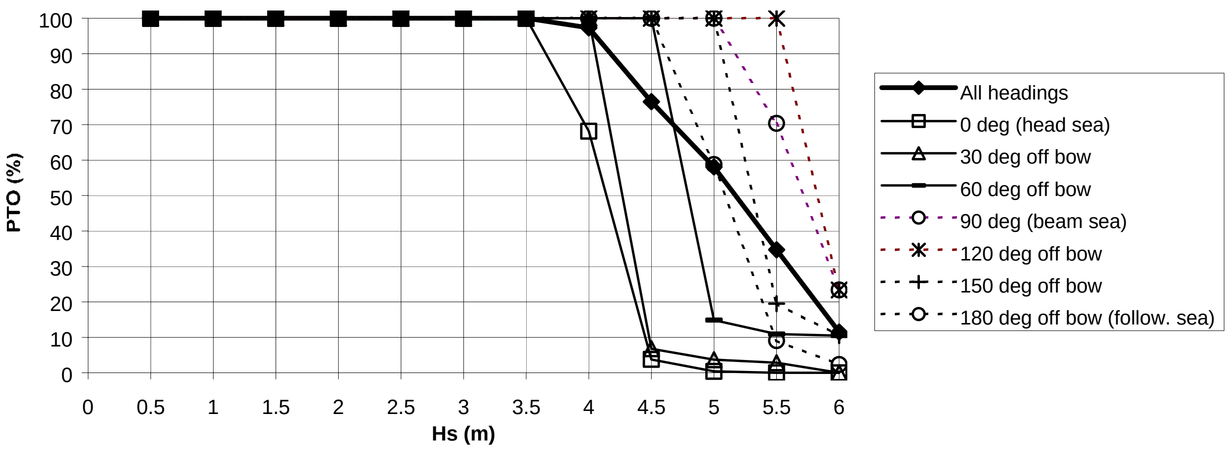

Figure 9. Stern ramp operability from example frigate at 5 kts - Pitch Motion Criterion.

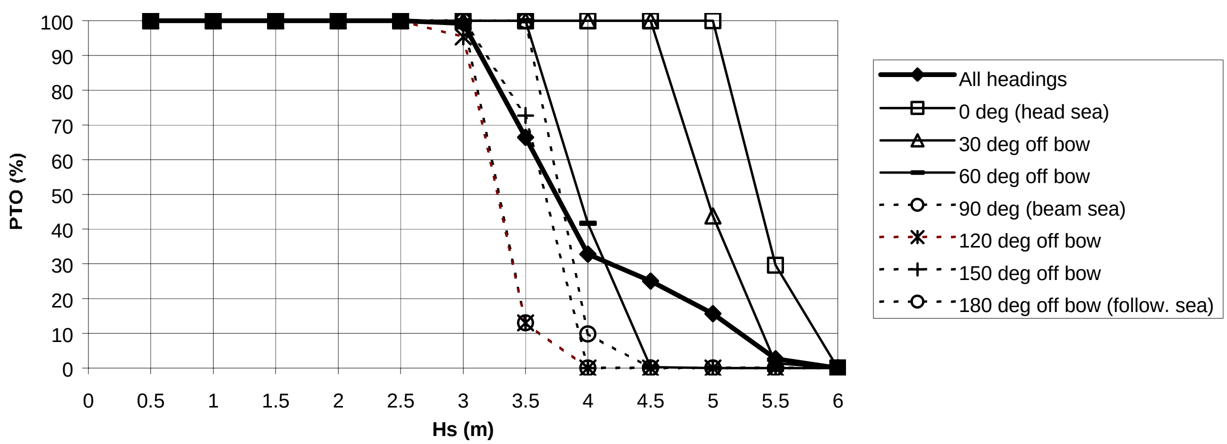

Figure 10. Stern ramp operability from example frigate at 5 kts - Sway Motion at Stern Criterion.

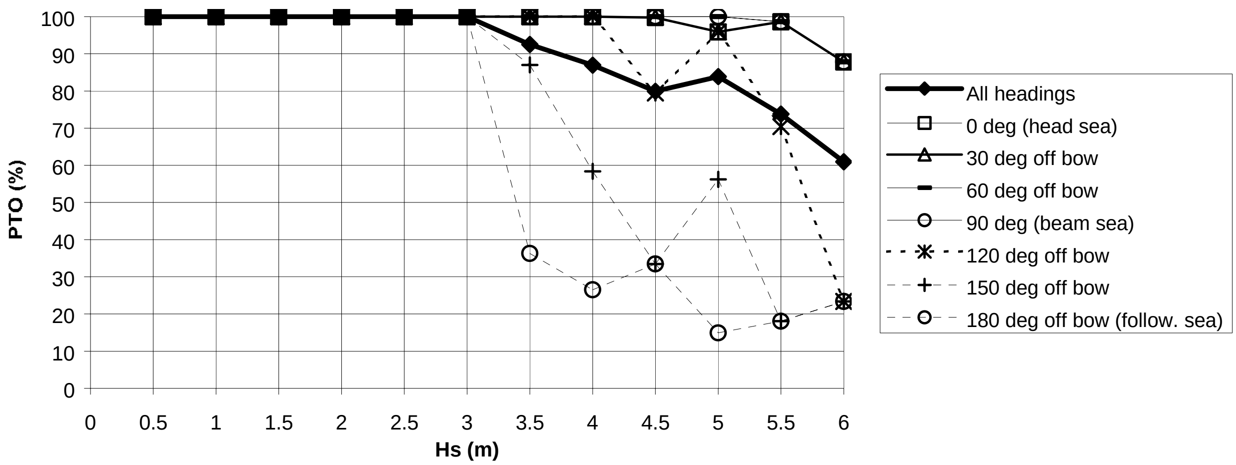

Figure 11. Stern ramp operability from example frigate at 5 kts - Ramp Availability Criterion and 1-ft Sill Depth.

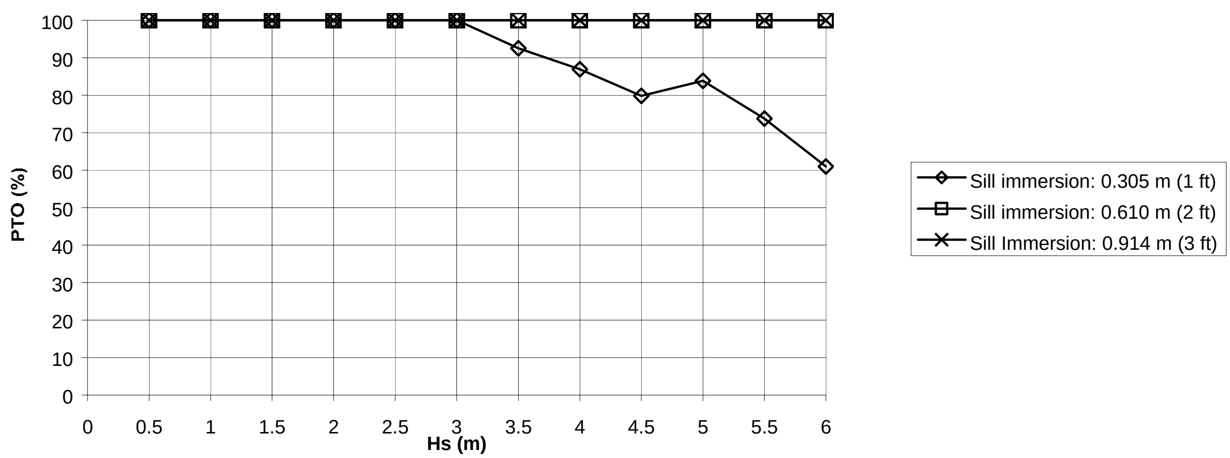

Figure 12. Stern ramp operability from example frigate at 5 kts - Ramp Availability Criterion and Variable Sill Depth.

To investigate an effect of ship size on the operability of stern ramp deployment, similar computations were performed for four additional vessels having an overall length between 26.5 m (87 ft) and 98.5 m (323 ft). The sill depth was set at 0.305 m (1 ft) for all vessels. Comparisons of the PTO for stern ramp deployment for all these ships (including the frigate) are shown in Figures 13 and 14 for the head and beam seas, respectively.

The main conclusions that are important for the stern ramp design and optimization based on results of these computations are as follows:

1. At the considered ocean region, the long-term operability will be 100 percent for seas condition up to a significant wave height up to 2.5 m (8.2 ft) for the frigate-sized vessel.

2. The highest operability will be achieved in head and bow seas (100 percent operability in waves with a significant wave height up to 3.5 m (11.5 ft), or just beyond mid-SS5), and the lowest is in beam seas.

3. The operational criteria that have the largest impact on the limited stern ramp deployment operability for this example are the criteria related to the roll and sway motions. This indicates why the beam direction is not preferable for such an operation.

4. For the frigate-sized ship considered, and when the sill immersion is equal to 0.61 m (2 ft) or more, the ramp availability criterion is not limiting even in seaways with a significant wave height up to 6 m (19.7 ft).

5. Results of computation clearly show a relation between the ship size and a level of the stern ramp operability.

6. Selection of the optimal wave heading for the stern ramp deployment is more important for longer ships. For small ships, the operability of the stern ramp deployment does not differ significantly between the head sea and beam sea directions.

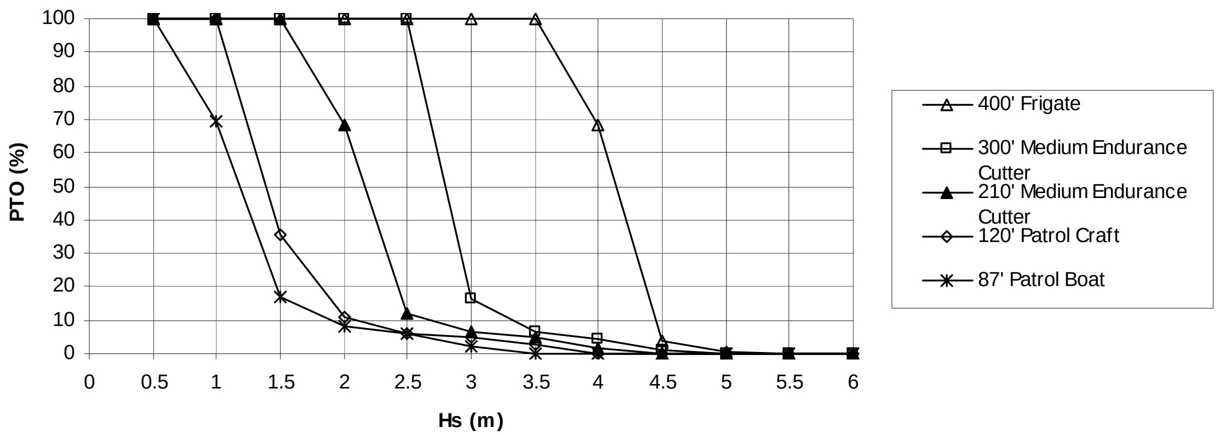

Figure 13. Stern ramp operability for five ships of different length at 5 kts in head seas - All Operability Criteria.

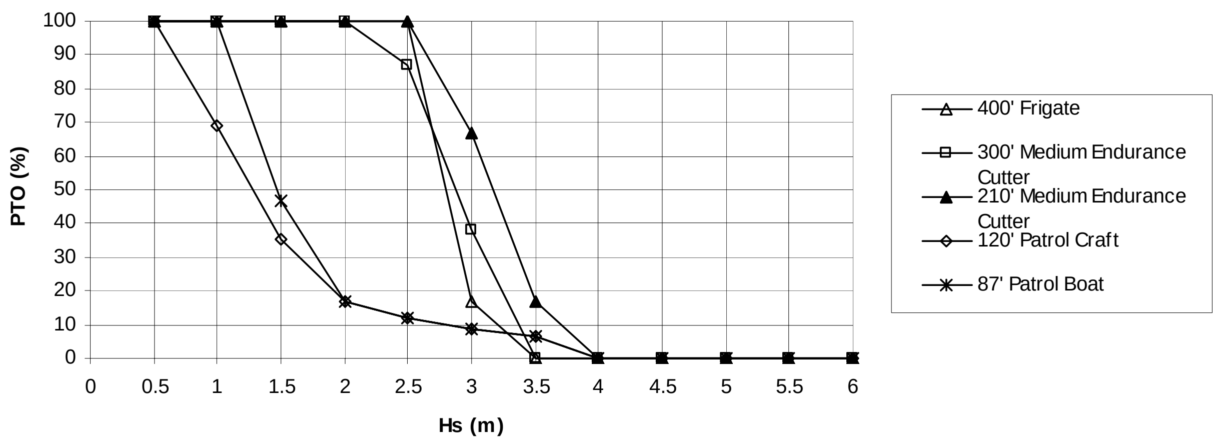

Figure 14. Stern ramp operability for five ships of different length at 5 kts in beam seas - All Operability Criteria.

CONCLUSION

The effort undertaken by the U.S. Coast Guard led to the development of three sets of design criteria for the evaluation of stern-ramp boat deployment. The first addresses mother ship motions for stern-ramp operations and was adapted from similar side-davit motion criteria. The second is a ramp availability criterion that quantifies the effectiveness of sill depth at the stern ramp. Finally, a collection of stern-ramp deployed boat criteria is proposed. The latter have been translated into motion responses at the stern ramp of the mother ship in order to facilitate evaluation and comparison of different mother ship hull designs.

Vertical acceleration at the stern ramp as a mother ship motion criterion was revisited. Here is a situation where the ship's vertical acceleration has a direct bearing on the ability of a crewmember on the ship to perform a task, and requires dexterity, agility and timeliness to secure the returning boat. As long as the securing operation requires a crewmember's ability to toss a line to a boat bowman, lasso a bitt or kingpost, or engage a self-locking device, then the vertical acceleration criterion is needed for crew safety.

For stern-ramp vessels, a ramp availability criterion was defined in terms of fundamental whole ship motions that could be extracted from time-domain seakeeping analysis.

Deployed boat criteria have been introduced that requires the induced impact accelerations on the small boat to be kept on a level acceptable for the boat's occupants to assure a safe recovery operation. Results from the model tests of a frigate-type mother ship show that the operability and limitations of a stern ramp recovery system are dependent upon a combination of technical (or physical) factors and human factors. The technical factors include mother ship vertical relative motion at the stern as contributing to the FRC vertical impact acceleration and transverse stern displacement by the mother ship causing a large longitudinal component of impact acceleration from transverse FRC impacts. Finally, the reduction of operability due to the FRC transverse impact accelerations is assumed to be mostly dependent on coxswain skill and therefore dependent upon human factors.

All in all, the ramp availability criterion and the deployed boat criteria provide the system connection between the mother ship's ability to provide a safe haven and the returning boat's ability to achieve it.

Parametric studies indicate that roll, pitch, and vertical and lateral acceleration at the stern could easily be the limiting factors over the ramp availability criterion for some ships with stern ramps and adequate sill depth. Hence, the criteria set for mother ship motion has been kept with the addition of ramp availability and deployed boat criteria to form coherent criteria for stern-ramp boat deployment.

The stern boat launch and recovery criteria related to the motions of the mother ship were deduced from dedicated model tests on a frigate-sized mother ship and the impact accelerations experienced by a FRC entering the stern ramp. Different criterion levels may be more appropriate for different sized mother ships, for different entrance shapes or boat-to-ramp well side clearances. At present, the model testing approach provides a more direct means to ascertain the acceptability of a particular mother ship and ramp design over present-day analytical means.

With the exception of the ramp sill immersion, the various criteria are not related to other physical ramp particulars such as the ramp breadth, ramp slope angle or entrance form, or the effectiveness of a water management within the ramp. The proposed criteria are at present well suited for feasibility and PTO analyses, but do not provide the means for design and optimization of the stern ramp particulars or configuration. Model testing with large-scale models (mother ship and FRC) have been demonstrated to provide an effective means to optimize the configuration of stern ramp details.

Finally, boat coxswain proficiency with FRC docking into a stern-ramp equipped vessel operating in a seaway depends greatly upon experience. Recent model tests with radio-controlled small boats returning to the stern ramp of a frigate-sized ship have indicated that the effective operability of a coxswain with roughly medium-level experience is about 20 percent less as compared to an experienced coxswain. Simulation-based training or hands-on training in a model basin may provide an effective means to develop coxswain skill prior to facing the challenge in the real ocean environment.

The investigations undertaken have shown that the main particulars and form of a stern ramp can be optimized in order to achieve a higher operability level for a given sea condition. Parameters of the stern ramp designed for operation in a Sea State 5 or higher must be carefully selected and depend upon magnitude of the wave induced motion characteristics of the mother ship and deployed boat. Similarly, the optimal operational conditions, such as wave heading and applied forward speed, might be different for different classes of ships. Since rules of designing an optimal stern ramp have not been established and because a systematic, all-encompassing series of model tests with stern ramp configurations have not yet been performed, selection of the optimal stern ramp may be a process involving some iteration. In this situation, the proposed sets of operational criteria for the stern launch and recovery system should be seen as the first step in the direction of providing guidelines for stern ramp design. More model tests, full-scale measurements and theoretical studies are still required to complete the process of stern ramp design and for evaluation of its operational performance in a seaway. The authors are in the process on developing a detailed design procedure for boat stern launch and recovery system construction.

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Discussion

Robert G. Allan, Fellow

The authors are to be congratulated for tackling a very complex subject, and attempting to formulate appropriate design criteria for current and future applications of stern-launch systems for rescue craft. The systematic approach proposed provides useful guidance for all involved in the design process of such systems, from the most practical designer to the sophisticated analyst.

As a practical small craft designer, I have had the privilege of being involved in the design and testing of a number of projects involving stern-launched rescue craft, including the Canadian Coast Guard Type 500 SAR Cutter *Gordon Reid*, one of the vessels evaluated in the authors' study. Therefore I am very pleased to be asked to comment on the work the authors have done in attempting to bring order both to the design process, and more critically to the evaluation of the merits of alternative systems proposed.

There are very few issues raised in this paper with which I would disagree, however there are some aspects of the design of boat recovery systems upon which I would like to elaborate.

Implicit in the design of an effective boat recovery system is the necessity to make the fastest possible transit of what I would call the "transition zone", where the RHIB moves from waterborne support in free water to a fully mechanically supported mode on the ramp or whatever other device is used to stow it on the Mother Ship. The rest of the process is relatively easy, however it is in the transition zone where the greatest risks of personnel injury and boat damage exist. This process involves:

- a well-timed entry into the ramp (almost totally operator dependent).
- safe and accurate landing on and connection to the "shore", (design dependent), and
- removal from, or implementing barriers to the wave-affected zone (design dependent).

The authors have addressed all these features, and have stressed the critical importance in the entire operation of the operator's skill. The importance of this factor cannot be over-stressed, and thus success rates of almost any system could be improved by a proper training regime. It also perhaps begs the question why well-trained personnel are not maintained and suitably rewarded for their skill in this difficult and often dangerous role.

The author's identify some features that are fairly critical to the proper design of a stern ramp launch/recovery system. Many of these seem to fall under the realm of simple common sense, but it is worthy that they are identified, at the risk of stating the obvious. These features include;

- the use of a "funnel" shape to centre the boat in the ramp,
- the use of well-rounded transom corners,
- a method of reducing the accelerations due to landing on the ramp structure, and
- avoiding the use of overhead structures.

In the case of the latter, I would say that the authors have been too gentle in their critique of those designs which incorporated this feature. In the interests of maximizing the safety and speed of the launch and recovery operations, I would not hesitate to state that such a feature should in no case be considered unless the clearance above the maximum height of the RHIB in the worst conceivable operating condition was at least 2 metres. Even at that, the operator of the RHIB is bound to have the perception of having to thread a needle.

Contrary to what is stated in the paper, the landing device in the CCG Type 500 Class cutters comprised a set of simple large diameter PVC pipes, (not UHMW), bolted to an adjustable framework to support the RHIB, much as would the "bunks" on a simple boat trailer. PVC was chosen after a series of tests to find a material which not only had a suitably low coefficient of friction to enable self-launching, but more critically which would deflect appreciably under impact to minimize the accelerations on landing. This material is very inexpensive, and the design permitted easy replacement of the pipes should they wear out or be damaged. Incorporating a simple shock absorber system in the support of these slides could further reduce the impact on the RHIB on landing.

One of the features of the recovery system on the *Gordon Reid* that did not receive much attention in the paper, but which I think is worthy of further comment is the use of the hinged platform within the stern ramp. This ramp comprised a simple lightweight aluminum frame, supporting a deck of non-corrodible, lightweight, reinforced GRP grating (not expanded metal as described in the paper). Above this base were the PVC "runners" discussed above. This hinged platform served two purposes: (1) as described in the paper it had the immediate effect of some wave mitigation from the boat hull interface, and (2), more critically, it enabled the boat to be rapidly removed a large distance from the wave interface, bringing the boat crew and any rescuees onto a horizontal working deck from which they could be far more easily and safely be removed from the RHIB.

I would like to reinforce the author's conclusion that at least for the foreseeable future large scale model testing is the most reliable means of evaluating the suitability of a stern launch/recovery system. In the design of the Type 500 cutters, working in association with Offshore Research Ltd. of Vancouver we conducted an extensive series of large scale (1:10) manned model tests in the open ocean. These tests were conducted to evaluate the same set of data as the authors measured in a laboratory setting, with similar conclusions. I would argue however the authors claim that the use of outside testing is of limited value. By use of a wave buoy in the vicinity to collect sea state data, and bearing in mind the associated influence of wind and irregular waves, it is arguable that outside testing provides a far more realistic test of a system's operability. Indeed it is less friendly in terms of post-testing analysis, but the results are certainly far more realistic. I am also somewhat surprised by the author's observations and conclusions re best relative heading of the Mother ship and rescue boat in recovery operations. All the model (and subsequent full-scale) testing performed for the *Gordon Reid* class proved very conclusively that the best relative attitude was in beam seas. The relative motions between the two vessels were much less in roll than in pitch and yaw, and even though the smaller craft is more exposed to wind and wave influences in this attitude, the reduction in relative pitch appreciably increased the ramp availability, and reduced the accelerations of landing in the ramp. In this context therefore I would ask the authors, had the operators who preferred a more fore and aft recovery attitude ever even tried a beam-on recovery, and if so, what were the results?

Another observation/comment of the authors, which I would challenge, is that concerning the poor slow-speed manoeuvrability of a RHIB with water-jet propulsion. In the hands of a well- trained operator, a water-jet driven boat is actually far more manoeuvrable than an outboard or stern-drive propelled boat. However this capability relies solely upon the operator maintaining high engine rpm and controlling the thrust vector with the jet buckets. This is somewhat counter-intuitive for most small boat operators who are used to outboards or stern-drives, where in close quarters the natural thing to do is reduce engine rpm. In a jet boat the thrust is totally rpm dependent, and hence the operator must enter a confined space with his engines close to full rpm for maximum control. Again, this observation of the authors reinforces the need for well-trained personnel in the specific boats used.

In conclusion, I would like to thank all the authors for this excellent paper, which should prove a very valuable first step to the advancement of ever better and safer rescue boat launch and recovery systems. Clearly there is still much more work to be done in the ability to simulate the relative behaviour of two diverse vessel types in close proximity, with so many external influences, however it is obvious that the authors have charted the first stages of that difficult course very well.

Per Werenskiold, Visitor

Congratulations to the authors on a very complete presentation of an ambitious worldwide assessment of vessels with stern-launch capability, and the effort to develop boat deployment criteria and design analysis methodologies.

The authors provide the most comprehensive state of the art survey and discussion of issues as:

- vessels with stern ramp capability, vital ship, stern ramp design and small boat (RHIB) parameters,
- operational experiences, launch and recovery procedures,
- main hydrodynamic effects influencing the operability of stern ramp deployment and alternative numerical modeling methods,
- design process integrating criteria for ship design, design of ramp system, RHIB performance and human performance, and finally
- use of model tests, especially with large-scale models, as the most effective tool for optimising stern ramp design.

Having being involved in the establishment of stern ramp operability criteria and project leader for five comprehensive stern ramp model test and detailed design programs, two issues comes in mind on reading the paper:

1. What types of phenomena shall be considered to optimise the stern ramp system operability?
2. How can assessment criteria precisely reflect these effects to enable a consistent design optimisation?

All aspects for answering these questions are considered in the present paper. However, I would like to elaborate this further by adjusting Table 4 in the paper. In particular the problem areas are given a proposed priority according the importance to achieve a successful recovery operation. (See Table 9)

Thus I assume that the most sensitive (limiting) phase of the stern ramp recovery operation is the boat's entrance into the ramp that has to coincide with "sufficient" water level in the sill. In addition, the boat has to be protected inside the ramp until captured and secured.

The authors states that problem areas 1 to 3 above are extremely difficult and computational intensive problems to solve, - if at all possible to be solved numerically by state of the art programs. In addition any design method need to apply relevant criteria to enable comparison and optimisation of designs. The question should be asked if numerical tools can be applied for other purposes than comparison of ship designs based on criteria related to ship stern relative wave motions, no stern ramp effects considered.

The priority areas to be considered should be defined by performance requirements, assessed by quantitative measurements and performance should be classified according to well-defined criteria. An example is provided in Table 10.

Table 9. Proposed Priority of Problem Areas for Optimisation of Stern Ramp Recovery

Priority / Problem Areas	Phase of Recovery Operation	Type of Aspect	Available Tools
1) Interior ramp hydrodynamic effects	Entry of ramp and boat securing.	Ramp design / arrangements	Model Tests
		RHIB speed / accel. capability.	Ship / RHIB Trials
2) RHIB manoeuvring in propeller wash	Final approach and decision to start entry	RHIB navigating performance	Ship / RHIB Trials
		Coxswain qualities	NONE
3) RHIB manoeuvring in stern wake	Approach at safe distance from ship	RHIB navigating performance	RHIB Trials
		Coxswain qualities.	NONE
3) Ship motion in seaway	Influences final approach and entry	Ship stern relative wave motions	Strip-theory ship seakeeping
4) Wave sheltering and reflection	Small effect head sea approach and entry	Ship design	Panel-method 0 kn.
		Masters ship operation	NONE

The recent stern ramp model test programs has all included detailed studies of main parameters that could influence the relative wave motions inside the ramp, in the sill and in the entrance area, i.e.: water management / damping systems, ramp sill depth and stern design. For each of the actual projects major contributions to higher operability for the stern ramp boat deployment are achieved. In addition parameters that will permit the coxswain to power the RHIB into the ramp without major impacts towards hard structures of ramp entrance and sides are studied in detail.

All the above-mentioned problem areas and main parameters influencing the stern ramp operability are thoroughly discussed by the authors, however no assessment of the relative importance is indicated. Comments to the above "priority list" and coherence of quantification methods will be great interest.

Table 10. Performance Requirements for Problem Areas

Problem Areas	Performance Requirement	Quantification	Type of Criteria
1) Interior ramp hydrodynamic effects	The relative wave amplitudes in the ramp entrance (sill) should be as small as possible, and mean value as large as possible.	Model tests: Measurement of relative wave in sill	Technical / Consistent
	RHIB should be able to maintain directional control in the stern/ramp wake.	Experiences / Trials	Technical / Qualitative
	RHIB should be able to accelerate onto the ramp with momentum to obtain secure/capture position in the ramp.	Experiences / Trials	Technical / Qualitative
	Coxswain should be skilled and well trained.	Training / Experiences	Human / Qualitative
2&3) RHIB manoeuvring in propeller wash and in stern wake	The actual wave amplitudes in the stern wake and propeller wash should be as small as possible.	Model tests: Measurement of relative wave in sill	Technical / Consistent
	RHIB should be able to maintain directional control and good seakeeping performance in the ramp approach area.	Experiences / Trials	Technical / Qualitative
	Coxswain should be skilled and well trained.	Training / Experiences	Human / Qualitative
3) Ship motion in seaway	Ship motions should be as small as possible, in particular relative vertical and transverse displacements of stern.	Strip-theory programs	Technical / Consistent
4) Wave sheltering and reflection	Comment: Relatively small effect at the stern of larger ships.		

One of the most essential ramp design parameters is sill depth. Most projects tested at MARINTEK have sill depth in the magnitude of 1m (3 ft.). The PTO analysis (Fig. 12) shows the effects of variable sill depth for an Lpp=122m (400ft) frigate-type mother ship. What would be the design sill depth for the National Homeland Security Cutter?

As the performance of the RHIB and the coxswains ability to navigate the boat and skill to decide the timing of the entry are most essential for the effectiveness and safety of stern ramp recovery operations, are the authors confident that human factor aspects like selection of personnel, simulation-based training and drills would be given the highest attention?

While the authors present a state-of-the-art assessment of stern ramp systems, design parameters, model test techniques, analytical tools and design criteria, they are robust and objective in their approach. In particular the last sentence of the paper, "The authors (USCG-ELC) are in the process on developing a detailed design procedure for boat stern launch and recovery system construction", should be appreciated by the potential operators and industry.

Jan O. de Kat, Member

I would like to commend the authors for presenting a thorough study on the rather rare research topic of small boat deployment. The paper is successful in bridging the gap between the practical operational side at sea and the research environment, where model tests and computations are used to simulate reality. It would be appreciated if the authors could expand on some topics addressed below.

First, it would be interesting if the authors could provide more detail on the actual physics of the boat launching and recovery process. For instance, does the coxswain decide to enter the ramp when the sill submergence is at a maximum (i.e., maximum relative motion is anticipated before re-entry), or does the coxswain make use of quiescent periods in the sea state (in which case the process would be governed by wave groupiness). Also, how does the water typically behave inside the ramp – sloshing, wave run-up, wave breaking, etc.

From the discussion of available computational tools it is clear that such tools are not able yet to predict all of the combined aspects of the relevant physics involved in boat deployment. I was wondering if the authors have considered coupling a VoF (CFD) code to a 6 DOF ship motion code to simulate the internal fluid motion inside the ramp area of the ship in waves.

In the absence of suitable computational tools, the authors resort – rightly so – to model testing techniques. However, I find it puzzling that on the one hand the authors recommend carrying out tests at scale 1:10 to 1:12.5, while on the other hand the majority of tests were carried out at scale 1:22.88 with only a limited number of tests with the large cutter model. Also, could the authors discuss whether there were any differences between the large and smaller scale tests as regards boat recovery in sea state 6. One would expect some differences in boat handling ability by the coxswain in the model basin, especially if short duration events have to be judged at smaller model test scale.

Could the authors provide information on how many recovery tests were carried out for each test condition to arrive at the PTO estimates as in Table 6? Presumably the repeat tests were done in different random wave realizations. In view of the human element involved, it would be interesting to hear whether the recovery model tests were carried out always with the same coxswain, and with which skill level.

In the boat deployment application example the authors provide a list of criteria; could they comment on the selected values, such as for limiting roll and pitch. Furthermore, it would be interesting to hear to what extent such criteria might depend on stern ramp configuration. For example, presumably a wide stern ramp would allow a higher level of sway motion at the stern than a narrow ramp entrance.

Woei-Min Lin, Associate Member

I would like to congratulate the authors of this comprehensive study. This is a very timely paper to address critical design and operation issues of stern boat deployment system. In particular, the authors have done an excellent job illustrating the key hydrodynamic considerations to operability and design. The discussion presented here are comments rather than questions.

I am particularly interested in the possibility of using physics-based approach to study the design of stern boat deployment system and to develop the guidelines for small boat launch and recovery operations. As the authors correctly pointed out, the hydrodynamic phenomena in the stern region are extremely complicated. None of the advanced computational tools currently available can capture all aspect of the phenomena. However, I believe that the current physics-based tools can be very valuable for certain aspects of the design and operation study as long as we understand the assumptions and limitations of the tools. In particular, the prediction of the local relative motion problem at the stern helps to provide an evaluation of the conditions in which the small boat must operate.

At SAIC, we are continuing the development of the Stern Ramp Model (SRM) that links with the Large Amplitude Motion Program (LAMP). In the past year, we have added the radiation and diffraction waves generated by the mother ship and a local time-domain sloshing model to predict the flow over stern ramp, and are in the process of including the propeller effect by simulating rotating propellers with vortex lattice method.

In addition, we are developing a more accurate planning boat model as part of the simulation. There are certainly other hydrodynamic phenomena such as flow turbulence which are not likely to be modeled by the simulation tools in the near future. However, we feel that the physics-based simulation tools available today have sufficient fidelity to be useful for design and operation study.

Once again, I would like to congratulate the authors on their significant achievements of this study.

David W. Byers, Visitor

The science of ship design continues to become more rigorous and truer to a "first principles" approach, which accurately reflects what really happens in the full-scale physical world. These advances are in response to the steady evolution of design tools and methodologies made possible by ever-more capable computers. At the same time it is encountering challenges posed by the increasing interest in more radical hull form types, such as high speed catamarans, trimarans, etc. for naval or military applications, which require validated design tools and techniques beyond those used in the commercial world, if in fact they exist at all. There is accordingly a critical need to apply a true ship systems engineering methodology to areas of ship design that have historically been based on empirical or "rule-of-thumb" approaches. These historic methods, which frequently combined a large number of uncertainties into safety factors, margins, etc, can now be improved as more and more of these previous uncertainties can be more accurately assessed.

The authors of this paper have done a great service to the profession by providing an excellent example of how to apply systems engineering principles to one of these historically "rule-of-thumb" design processes: that of developing a satisfactory means of deploying small boats from the stern of relatively small "mother ships". Their approach to the problem, including breaking it down into its component elements, doing an international survey of existing smaller ships with stern deployment systems, identifying the hydrodynamic phenomena which affect stern boat deployment operations, assessing the state-of-the art in prediction tools, developing criteria for safe operations and establishing a method for ultimately determining the key metric of percent time operability, are all elements of a rigorous, system-engineering based approach to problem-solving. Particularly noteworthy is the attention paid to the critical human systems component of the total ship system, i.e., ensuring that the role of the Sailor in small boat deployment operations is defined from the start and reflected throughout the design evolution. As the U.S. Navy moves increasingly to optimally-manned ships where functions historically performed by a number of Sailors are now performed by just one who relies partially or totally on automated subsystems, it is critical that the remaining human functions and the interfaces with the mechanical components be clearly defined.

While this paper has focused on the manned small boat operations, the work can be extended to the even more challenging problem of handling an unmanned small boat or other vehicle.

In this respect, the U.S. Navy has already benefited from the work presented in this paper. One of the co-authors, Mr. Peter Minnick, is an employee of the U.S. Coast Guard's Engineering Logistics Center (USCG ELC). He was a Team member of a ship system concept development project recently completed by the Naval Sea Systems Command Surface Warfare Center Carderock Division's Innovation Center, which I head. The project, conducted between Oct 2002 and April 2003, was entitled "Surface Combatant Optimized for Unmanned Vehicle Operations" or "SCOUVO" for short. One of its challenges was to accommodate a variety of unmanned vehicles (air, surface and underwater) on a ship platform capable of achieving a speed of 45 knots or more. This resulted in the development of three ship system concepts, each based on a different advanced hull form type, specifically a high-speed monohull, catamaran and trimaran. All three incorporated a stern ramp for unmanned vehicle handling. The U.S. Coast Guard ELC work described in this paper directly influenced the design of the SCOUVO stern ramp deployment systems.

We are pursuing follow-on work to the SCOUVO project leading up to the point of prototype evaluation of some of the subsystems, including the variable cradle and another promising concept, the "homing crane." If we are successful, and as an outgrowth of USCG ELC cooperative involvement with the U.S. Navy's Innovation Center project, the Coast Guard has expressed a willingness to be partner with the Navy in the evaluation of any such systems of interest to them.

Again, I thank the authors for an excellent piece of work.

AUTHORS' CLOSURE

We would like to thank the many discussors who have given this paper their attention. One of the most gratifying aspects of presenting a paper is that it generates thought and discussion amongst the members. It is truly encouraging to see so much interest in this technical area.

Several discussors have brought up the need for coxswain training. We totally agree with Mr. Allan's comments on keeping well-trained coxswains, and admire the training program implemented by the Canadian Coast Guard aboard the *Gordon Reid*. Additionally, Mr. Werenskiold mentioned the need to consider human factor aspects like selection of personnel, simulation-based training and drills. In our comparative analysis of different stern configurations as well as in considerations leading to definition of the operability criteria for the stern ramp deployment, the human factor was purposely filtered out. This was mostly done since procedures for qualitative evaluation of the coxswain abilities and experiences have not yet been established. However, we do not underestimate the weight of this problem. A well skilled coxswain is a necessary condition for highly efficient stern ramp boat recovery. The U.S. Coast Guard is a military organization, and so when it comes to the development of highly skilled coxswains, we really have to explore novel ways to provide as much effective training as we can. We are looking at possibilities for simulation-based training and guidance systems.

The authors thank Mr. Allan for his insight on the use and handling of water-jet propelled RHIBs particularly with regards to using the bucket to control speed when operating in confined spaces. At the present time, the Coast Guard is considering using a training simulator to acquaint coxswains with the proper handling of the small boat for stern ramp operations and certainly to familiarize coxswains with the use of water-jet propelled craft. During our survey, our observation was that at low speed all of the coxswains complained of poor coursekeeping with standard water-jet arrangements. It showed that these boats might be directionally unstable in a wake of another ship. We believe that there are several approaches that could be employed to resolve this issue. The Swedish Coast Guard implementation of a modified coxswain control console to include "motorcycle" type controls appears to lessen this coxswain control problem.

Mr. Allan's elaboration of the rail system and the hinged ramp feature on the *Gordon Reid* are most informative and helpful. Employing a hinged ramp to remove a docking RHIB up and out of the way from the waves is an important consideration for the speed, safety and operability of the recovery operation. While this feature may not be incorporated into every stern ramp design, it certainly should be considered.

We fully agree with Mr. Allan's comments on the importance of avoiding the use of overhead structures over a stern ramp. We have given some thought to this problem previously, and take the opportunity to present a tentative design approach where overhead clearance must be considered. This is given in an appendix to this discussion.

On the issue of relative heading of the mother ship for boat recovery, we understand the use of beam seas on the *Gordon Reid* for stern ramp operations, however, from our model test results for a frigate-type hull operating in different sea headings, we found head and bow quartering seas to produce better results more consistently within our criteria limits. The *Gordon Reid*, to which the Mr. Allan referred, has a trawler shape hull that was designed to achieve low wave induced motions in the specified region of operation. The seakeeping characteristics of the two mentioned hull types differ significantly, and we may expect that an optimal wave heading for the stern boat recovery could be different for these ships. Our observations done on *Gordon Reid* confirm that on this vessel the beam swell condition is a benefit for the boat recovery.

We agree with Mr. Allan that model tests in the open ocean could be an alternative solution to the indoor testing. However, as the discussor pointed out, such outdoor experiments are usually quite difficult in the post-test analysis. Since the objective of our study was comparative assessment of the effectiveness of various configurations of the ramp arrangement, comparison of different configurations and an optimization of the ramp particulars require performing tests in controlled, repeatable environmental conditions. In an indoor model test you can always generate the desired sea state spectra. In our opinion, the outdoor tests are best suited for final testing of the complete stern ramp arrangement (including, for example, the capture mechanism).

The authors appreciate Mr. Werenskiold's opening discussion and proposed priority list of problems that should be solved in designing a stern ramp of the highest efficiency. This is a complex problem that depends on many factors including ship mission, area of operation, and ship principal characteristics, that may be different for each particular stern design. In general, the stern ramp operability is a function of several elements, design as well as human factors. We believe that design elements such as water management system, sill depth, capture of the boat without human intervention need to be considered in order to optimize stern ramp operability. Each of the four groups of problems listed in Table 9 can be related to different phases of the ship design process:

1. Complete design of the stern ramp interior (including design of the entrance form, water management system and capture mechanism) is an issue that concerns a detailed construction of the whole stern part of a hull. Though this part of a ship hull is traditionally "overloaded" with other mechanisms (propeller shafts, rudder mechanism, etc.), nevertheless in this phase of the hull design process, the designer has usually the largest possibility to influence the final level of stern ramp operability by selecting optimal ramp particulars and arrangements. The interior design of the stern ramp may therefore be treated as the first priority.

2. Optimization of the RHIB maneuvering ability is addressed to the RHIB design, especially with regards to selection of its propulsion system.

3. The ship motion characteristics at the stern are mostly decided by the ship main parameters and characteristics that are selected with respect to many other operational criteria (as, e.g., they are mostly decided with respect to the ship mission to be accomplished). Therefore, reduction of the ship vertical motion and sway at the stern to the minimum level, as is desirable for higher stern ramp operability, may seldom be fully

fulfilled. However, selecting an optimal wave heading and ship speed can minimize the ship responses at the stern at any considered environmental situation. This could be achieved through implementing on board an operator guidance system (that could be considered as a part of the ship design).

4. The area behind the ship stern where the effects of the wave sheltering and reflection are perceptible is defined mostly by three parameters: ship breadth (that usually may not be changed too much from that selected early in the ship design process), wave heading relative to the ship, and ship speed. For a safe and effective deployment via a stern ramp, it is desirable to provide shelter from waves of as large an area as possible close to the stern ramp. Such extension of the sheltering area can again be obtained by selecting an optimal ship heading and speed by applying an effective operator guidance system.

Concerning Table 9, in the row on "Ship motion in seaway", the prognoses of the relative vertical motion at the stern obtained from the strip theory are usually rather poor. Model tests (for verification and calibration) should therefore be added as an available and recommended tool. In the same table for RHIB maneuvering, we suppose that the final approach (after the coxswain's decision to start entry) is mostly affected by wake that is strongest at an area close to the stern ramp. Furthermore, maneuvering to approach the mother ship at safe distance from a ship may be hindered due to the propeller wash that is the strongest at some distance from the stern. Mr. Werenskiold in his table listed numerous issues and raised a question of their relative importance. The authors believe that the order they are listed in the table reflect the reasonably correct level of importance.

Finally, in response to Mr. Werenskiold's direct question as to whether the sill depth on the National Security Cutter will be greater than that used in the model tests, we can say that it will be in the range of 0.45 to 0.6 m (18 to 24 inches).

Dr. de Kat asks for clarification and elaboration on a number of issues. Starting with the coxswain's decision-making process at the onset of boat recovery, the optimal point of the ramp entry is when a vessel is in its lowest vertical position during the motion cycle (maximum water level over sill). Indications are that the best timing to accelerate a boat is when the mother ship starts to move down from its highest position. We have observed in those ships where there was sufficient sill depth, so that timing ceased to be the prime concern of the coxswain, the recovery process was smoother as the coxswain concentrated on maneuvering and aiming instead.

With respect to the characteristics of the water motion inside of the ramp, these depend strongly on the ramp main particulars and employed arrangements. Water management inside the ramp is an important factor in the design of the effective boat recovery system for large ships. During our studies we have learned that the maximum amount of water in the ramps of a large vessels is significantly larger than in a smaller vessels. While water sloshing is the main problem for a docking type ramp, wave run up and drainage are problems for ramps without a damping system. There are number of methods which could be utilized to reduce this problem. Some of the larger vessels (75 m (250 ft) in length and above) recently built or under construction, use variations of perforated plates, with the perforation ratios varying between 40 to 60 percent. For a stern ramp constructed with perforated plates, the correct management of water running out of the ramp is considered a main challenge.

At the time the survey of applicable hydrodynamic simulations was performed, we were not aware of a suitable and ready-to-use VoF CFD code coupled with a 6 DOF code. If such a code could provide insight to how the water behaves inside the ramp, it would improve our understanding of this complex phenomenon. Conclusions drawn after analyzing the available computational tools directed us to search for computer programs that could readily be applied with minor modifications to solve some of the ramp design problems. As an example, a CFD program for simulation of the water motion inside of the ramp that will adopt pre-computed relative motion of a mother ship and the wave field close to the ramp defined from the model tests was discussed.

As a part of our review of analytical tools that might prove helpful in evaluating ramp configuration design, the USCG participated in an international study on the hydrodynamics of LPD stern wells. The project had the specific goal of exploring the feasibility of developing and using a coupled CFD code with a 6-DOF ship motion code to model the wave action inside the well. For a LPD well, as compared to a stern ramp, there is a longer internal distance before reaching a beach or "ramp", the recovery operation takes place at a slower speed, and different hydrodynamic effects predominate, but if a coupled analytical tool could be developed that addresses hydrodynamics within the well, then there would be great potential for that tool to be useful to stern ramp configuration design. The investigation was conducted at the Institute for Marine Dynamics (IMD) and only recently completed.

Unfortunately, while the relatively simpler geometry of the LPD well allowed 2-D modeling to be employed, the double-sloped surface of a stern ramp prohibited this. In spite of this complication, a stern ramp model was developed and compared to some of our model test results. The results obtained from the simulations did not match the observations from experiments as well as those obtained for the LPD well. It was concluded by Molyneux and Bass (2003) that, "Based on the current state of numerical models and associated computer hardware, it does not seem practical to use CFD simulations for detailed design studies of stern ramps.

Whilst the benefits of water management systems are predicted, other geometric factors, such as ramp width are not predicted with sufficient accuracy. As a result, physical model experiments are the only practical engineering option at the present time."

Dr. de Kat inquires why we used a relatively small-scale model for our first model test when we ultimately recommend the use of much larger scale models. Two model test programs were conducted. The first one used an existing model of a frigate of 1:22.88 scale modified to include stern ramp located at the centerline. The purpose of the study was to evaluate overall operability for recovery via a stern ramp in varying headings, speeds and sea conditions. This model test used only one stern ramp configuration. At the time of this initial model test, the Coast Guard desired to demonstrate within a short timeframe if stern ramp boat deployment was truly feasible from frigate-sized ships operating in the sea conditions envisaged, and to identify the main hydrodynamics phenomena that influence the stern ramp design. It was concluded after these tests that the scale of the model must be larger to allow investigation not only of phenomena inside of the ramp but also to assess an effect of the different ramp designs on the recovery efficiency. The second model test, which occurred simultaneously with the writing of this paper, used a larger scale model (scale 1:12.5) of a similarly sized frigate and was more focused on ramp configuration while holding mother ship heading and speed constant. Both sets of model tests involved about the same amount of model basin time, however, since the second model test involved changing between four different ramp configurations within the same mother ship, a fewer number of test runs could be obtained. Results from both these tests converged; however, results of the test with a large model allowed us to distinguish differences in performance between different construction configurations (e.g., with and without water management system) that were not possible on a small-scale model. In addition, model tests with a larger model allow the installation of more measurement equipment that contributes to more valuable and complete experimental results.

The authors believe there were two advantages to using the larger model for the second set of tests. The first is that the time scale for the tests with the larger model was less, allowing the operator of the small boat more time to react to what the mother ship was doing. The second advantage to using the larger model is that it removed some of the uncertainty of water dynamics in the stern well, which are affected somewhat by model scale.

Dr. de Kat desires to know how many recovery tests were carried out for each test condition to arrive at the PTO estimates as in Table 6. There were from 10 up to 30 repeat test runs for each defined condition. They gave reasonable statistics for the random sea condition. In the tests we tried to eliminate any effects related to the "human factor" and all the tests were therefore performed with one coxswain that may be defined as "having a good skill". A few tests with other coxswains were done, but these results were not applied in the post-test analysis.

With regard to the criteria used for determining stern ramp operability, the roll, pitch and vertical and lateral acceleration criteria were developed from full-scale trials in the Bering Sea in 1995 for side davit launch and recovery. These criteria were then used for the mother ship stern ramp launch and recovery as well. These criteria refer to the working conditions on a deck of the mother ship. They were coupled with the ramp availability criterion developed for stern ramp operation to obtain percent time operability for various ocean basin wave environments. This was a first cut at determining the operability of the stern ramp in a gross sense.

The stern ramp operability criteria that applied the mother ship motion (relative vertical motion and sway at the stern) were derived for one stern ramp configuration. The limiting value of these mother ship responses depends on the ramp configuration and further research in this direction is needed to define the limiting sway and relative vertical motion in terms of the stern ramp main particulars.

The authors appreciate the comments provided by Dr. Lin and Mr. Byers particularly with respect to the implication of ever-more capable computers on the steady evolution of design tools and methodologies. We also recognize that further development has occurred with the LAMP stern-ramp model. However, at the time we undertook the work, none of the computational tools were fully capable for accurate simulation of recovering the boat from the stern. There is much work remaining to be done in the area of stern ramp design in terms of understanding the underlying physics of the recovery process and attempting to model the process analytically in order to affect the design for greater operability.

ADDITIONAL REFERENCE

Molyneux, David, and Don Bass, "Report on Wave Field in and around the Stern Ramp of a Coast Guard Search and Rescue Vessel", Institute for Marine Dynamics (IMD) report TR-2003-22, St. John's, Newfoundland, October 2003. (Limited Distribution)

APPENDIX. STERN RAMP OVERHEAD CLEARANCE

On a mother ship with a stern ramp constrained from above by any overhead construction such as hinged stern gates, transom bulwark, overhead deck, etc., the vertical clearance between the highest element of the small boat and the overhead elements of the stern ramp is of great concern to members of the small boat crews. Such stern ramp configurations could significantly reduce operational effectiveness of the stern ramp system. This has been observed during the survey on existing ships with overhead obstructions. Therefore, in a stern ramp design, the overhead clearance must be considered as one of the system design and operational constraints, and it should be evaluated with respect to the limiting sea condition. What follows is a proposed approach for evaluation of stern ramp overhead clearance against expected sea conditions.

The required overhead clearance can be divided between "static" and the "dynamic" allowances. The static overhead clearance is referred to the calm water condition, while the dynamic allowance is added due to the relative motion between a boat and the mother ship in waves. The ramp vertical dimension should be designed with some minimum clearance between the boat and ramp overhead constraint to give a coxswain the confidence to enter the ramp entrance gap with the required speed.

The vertical static clearance depends on the entrance speed; higher entrance speed will require a larger vertical clearance. In a seaway, a small boat moves vertically due to wave-induced motions, which will require that the height of the ramp entrance be additionally enlarged. During FRC retrieval, a coxswain often anticipates a moment when the wave top reaches the ramp entrance position because such timing guarantees a safer and softer landing. Such timing means, however, that the boat's vertical motion relative to the mother ship position will reach its maximum when a boat is partially inside of the ramp. In addition, this is also the point at which the ramp sill immersion will be close to its maximum (the optimum condition for the small boat entry). Due to all these effects a dynamic vertical clearance should be added in order to avoid a collision between a small boat and the ramp overhead constraint. The magnitude of the required dynamic allowance of the ramp will be a function of the mother ship speed, wave heading and sea condition.

The following equation can be used to determine the required height of the ramp entrance:

$$H_{ramp} = H_{boat} \cos\alpha + (a - T_{boat} \cos\alpha) + C_{static} + C_{dynamic} \qquad (3)$$

Since a small boat might pitch when entering the stern ramp, we may conservatively assume the most critical position of a boat against the deck construction (i.e., no trim with respect to the ramp angle). Thus an effect of the stern ramp inclination could be omitted.

$$H_{ramp} = H_{boat} + (a - T_{boat}) + C_{static} + C_{dynamic} \qquad (4)$$

where $(a - T_{boat}) > 0$ or equal to zero as only positive values should be considered.

The static vertical clearance is assumed to be equal to 0.2 m (8 inches) for zero speed and linearly increasing to 0.4 m (16 inches) when the boat speed is 10 knots over the speed of the mother ship. In other words, it varies with the relative approach speed. This assumption is based on the civil engineering approach for a clearance in land construction. By assuming the vertical motion of a boat corresponds to changes in wave elevation, the dynamic vertical allowance is computed as the maximum of the relative motion (single amplitude) of the mother ship at the ramp entrance position. The maximum of this ship response could be estimated by applying the wave statistics for a relatively short period of time (e.g., 30 minutes).

Additional Nomenclature

a	=	Ramp sill immersion in calm water.
α	=	Ramp inclination angle.
C_{static}	=	Static vertical clearance.
$C_{dynamic}$	=	Dynamic vertical clearance.
H_{ramp}	=	Recommended height of stern ramp at the entrance section.
H_{boat}	=	Total height of small boat from the base line to the top of superstructure.
T_{boat}	=	Draft of a small boat at midship.

Application Example

An example of the dynamic vertical allowance calculation result for four ships of different length is shown in Figure 15. All headings to the sea are considered in order to determine the maximum height for the dynamic vertical clearance.

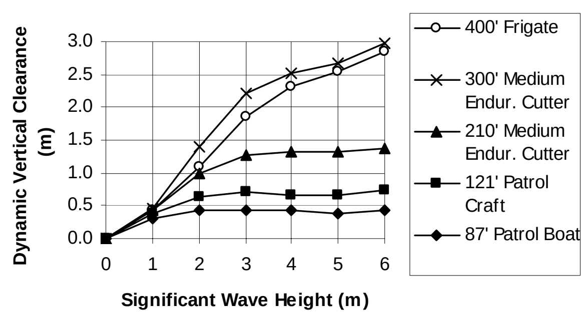

Figure 15. Example of dynamic vertical clearance for varying ship length.

Carrying out this example for a 11-m (36-ft) FRC with the total height of 2.5 m (8.2 ft) and draft of 0.46 m (1.5 ft), and by assuming a sill immersion of 0.610 m (2 ft), a boat approach speed of 5 knots over the speed of the mother ship and a limiting sea state of Sea State 5 (H_s = 3.25 m (10.7 ft)), the required minimum height of the stern ramp would be 3.4 m (11.5 ft) for a 87-ft patrol boat or 5.25 m (17.2 ft) for a 310-ft cutter.