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Technical Report

Transformation Craft (T-Craft) Concept Study

by

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14. ABSTRACT
The objective of the Transformation Craft (T-Craft) innovation team was to develop a conceptual craft that addresses the problem of transporting military vehicles at high speed from the Sea Base to troops inland. The role of T-Craft is to transfer rolling stock from a cargo transport ship at the Sea Base, carry it through the surf zone and onto the beach. T-Craft is intended to have a significantly greater payload capacity than previously developed concepts providing a "feet dry" ship-to-beach transport capability. Requirements also included a payload of up to ten M1A1 tanks, transit speeds of 20 – 25 knots and 40 knots, at ranges of 2,500 and 500 nm, respectively. The T-Craft must be operable in Sea State 6 and survive in Sea State 8. The Office of Naval Research has a T-Craft design program currently underway with four commercial contractors. None of the contracts awarded to-date are considering the use of a SWATH design. The innovation team has developed a 1,500 tonne SWATH concept design to provide an alternative approach to meeting the requirements. The concept is an aluminum-5086 structure that transforms from a SWATH ship at sea to an air-cushioned/tracked vehicle on the beach. This transformation requires that both SWATH hulls rotate vertically through 105 degrees and the deployment of an air cushion system. The vessel uses pumpjet propulsion at sea, powered by an integrated full-electric propulsion system. To improve flexibility, significant attempts to reduce onboard systems complexity were made. The final design was shown to be feasible in the critical areas of hull form, materials, general arrangements, weight, power systems, and stability.

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Abstract

The objective of the Transformation Craft (T-Craft) innovation team was to develop a conceptual craft that addresses the problem of transporting military vehicles at high speed from the Sea Base to troops inland. The role of T-Craft is to transfer rolling stock from a cargo transport ship at the Sea Base, carry it through the surf zone and onto the beach. T-Craft is intended to have a significantly greater payload capacity than previously developed concepts providing a "feet dry" ship-to-beach transport capability.

Requirements also included a payload of up to ten M1A1 tanks, transit speeds of 20 – 25 knots and 40 knots, at ranges of 2,500 and 500 nm, respectively. The T-Craft must be operable in Sea State 6 and survive in Sea State 8. The Office of Naval Research has a T-Craft design program currently underway with four commercial contractors. None of the contracts awarded to-date are considering the use of a SWATH design.

The innovation team has developed a 1,500 tonne SWATH concept design to provide an alternative approach to meeting the requirements. The concept is an aluminum-5086 structure that transforms from a SWATH ship at sea to an air-cushioned/tracked vehicle on the beach. This transformation requires that both SWATH hulls rotate vertically through 105 degrees and the deployment of an air cushion system.

The vessel uses pumpjet propulsion at sea, powered by an integrated full-electric propulsion system. To improve flexibility, significant attempts to reduce onboard systems complexity were made. The final design was shown to be feasible in the critical areas of hull form, materials, general arrangements, weight, power systems, and stability.

Acknowledgements

This report is the culmination of work conducted by students hired under the National Research Enterprise Intern Program sponsored by the Office of Naval Research. This program provides an opportunity for students to participate in research at a Department of Navy laboratory for 10 weeks during the summer. The goals of the program are to encourage participating students to pursue science and engineering careers, to further education via mentoring by laboratory personnel and their participation in research, and to make them aware of Navy research and technology efforts, which can lead to future employment.

At the Naval Surface Warfare Center Carderock Division, the single largest employer of summer interns is the Center for Innovation in Ship Design (CISD), which is part of the Ship Systems Integration and Design Department. The intern program is just one way in which CISD fulfils its role of conducting student outreach and developing ship designers.

The student team consisted of:

Cynthia Marks

Chance Phelps

Justin Ryan

Paul Sorensen

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Executive Summary

The Transformation Craft (T-Craft) is in Phase 1 of a concept design program sponsored by the Office of Naval Research. This innovation team was assigned the task of developing a T-Craft that follows the same guidelines as those set forth in the Phase 1 concept design program. The T-Craft is a multi-mode Sea Base connector that uses multiple technologies to support a craft capable of transporting wheeled and tracked vehicles through the surf zone and onto the beach.

Compared to a High Speed Sea Base-to-Shore Connector, the T-Craft will increase payload capacity 4 to 10 times, achieve speeds greater than 40 kts, and will have “feet dry” on the beach capability. The payload consists of 7 M1A1 tanks and up to 10 crewmembers. Total weight is about 1,500 tonnes. The T-Craft concept is being developed to transit at 20 to 40 knots with a range of 500 to 2,500 nm with operations at Sea State 6 and survival in Sea State 8. The multi-mode Sea Base connector’s mission has four main components:

- Fuel efficient self-deployment
- Moving the cargo off of the cargo transport ship at the Sea Base;
- High-speed transit from the Sea Base to the beach; and
- Moving the cargo through the surf zone and onto the beach.

The T-Craft must complete each of these processes in a reasonable amount of time and complete the final transport from the Sea Base to shore in less than 24-hours.

The team was instructed to follow the Broad Agency Announcement, as well as meet several other guidelines. The overall design concept was developed from the specified aspects of the design brief, namely a SWATH Hullform of 1,500 tonnes displacement, a hover barge as the means of supporting the vessel’s mass on land, and the use of a traction based system such as wheels or tracks for land based propulsion. Another assumption is that the primary method of loading and offloading all cargo would be through roll-on, roll-off (ro-ro) capabilities.

The design incorporates a combination of technologies such as aluminum structure, fully integrated electric power distribution, hover barge air cushion systems, and tracked amphibious vehicle drives that have been used in existing marine vehicles. In addition, a novel hinge/connector/actuation system is introduced to rotate the side hulls outboard to transform the craft from a buoyantly supported displacement craft into an air-cushioned amphibian. A complex transformation mechanism was required to transition from sea to land, as well as a method of developing propulsion power in each mode, without independent propulsion systems. This required the use of hinges and locking pins, winches and cables, and a ballast system to allow the transformation to occur. Six substantial arches were required to mitigate the effects of plying loads on the hulls. The hullform was specified to exploit available model test data and the displacement was fixed to eliminate design iterations.

Section 1 - Introduction

Mission Statement

The Transformation Craft (T-Craft) Team was asked to develop an effective vessel for transporting rolling stock from a cargo transport ship at the Sea Base through the surf zone and onto the beach. T-Craft is intended to have a significantly greater payload capacity than current vehicles providing a "feet dry" ship-to-beach transport capability. The T-Craft must also receive or deliver the cargo in Sea State 4, operate in Sea State 6, and be able to survive in Sea State 8.

Background

Seabasing

Seabasing is an operational concept that responds to the growing need for mobile bases that will make combat resources available wherever and whenever needed. The Center for Innovation in Ship Design (CISD) started a Seabasing Innovation Cell at the CISD charter signing ceremony in October 2002. Since February 2003, the CISD team has been working to identify the challenges of seabasing to provide future naval capabilities.. There is a need to identify both evolving and mature technologies that can demonstrate the capabilities required to fill the technological gaps in the seabasing model.

As imagined today, a Sea Base will be able to deploy up U.S. Marines and their equipment entirely from the sea. Although the exact composition of a Sea Base is evolving, many envision it as a virtual floating base composed of many ships, including amphibious assault ships, auxiliary vessels and connector vessels. Design and acquisition teams both inside and outside the Navy are currently examining many Sea Base models and foresee the full development of a Sea Base squadron in the next 10 to 15 years.

One of the many challenges of the T-Craft is the impact of seabasing constraints. There are three major design challenges presented in the process of seabasing:

- the method of mooring to a neighboring craft in rough Sea States;
- developing a ramp capable of operating in rough seas as well as being capable of withstanding the loads from a M1A1 tank; and
- the interaction between the two crafts during cargo transfer.

Introduction to the SWATH Hull

The design brief specified the use of a SWATH hull design. SWATH is an acronym for Small Waterplane Area Twin Hull. SWATH ships provide significant benefits in ride quality, comfort, operational efficiency, and speed in higher Sea States as compared to conventional monohull and catamaran vessels. Twin hulls located considerably below the waterline provide buoyancy. The top structure is connected to the submerged twin hulls by two relatively small struts. The submerged lower hulls provide the majority of the buoyancy, while the relatively small waterplane area of the struts contributes to significant reduction in ship motions. The design of the struts and the lower hull shape is critical in achieving a balance between good seakeeping and minimum hull drag. An additional benefit to a SWATH hull is a high proportion of deck area for their displacement. Little is known about the interaction of a SWATH hull with other vessels while transferring cargo.

Figure 1: T-AGOS 19 (SWATH ship) Crane Launch

T-Craft Concept Team

The T-Craft Concept Team is a group of three interns and one full-time employee of Naval Surface Warfare Center Carderock Division (NSWCCD) under the direction of Dr. Christopher Dicks and Dr. Colen Kennell. The group includes:

Name	**School**	**Degree**
Cynthia Marks	Auburn University	Mechanical Engineer
Chance Phelps	Maine Maritime Academy	Marine Systems Engineer
Justin Ryan	Florida Atlantic University	Ocean Engineer
Paul Sorensen	University of New Orleans/NSWCCD	Naval Architect

The interns worked under the Naval Research Enterprise Intern Program (NREIP), funded by the Office of Naval Research (ONR). The team is based at the CISD, a part of the NSWCCD. CISD develops innovative ship concepts, assesses future ship and ship design technology needs, and focuses on the Navy of the future. The following report illustrates the team's research and conclusions with respect to the T-Craft.

Assumptions

Payload

The assumed cargo to be moved is the surface element of a projected 2015 Marine Expeditionary Brigade (MEB) developed by the Marine Corps Combat Development Command. This includes personnel, wheeled and tracked vehicles, and other equipment. The cargo listed in Table 1 is currently transported by the Landing Craft, Air Cushion (LCAC). Based on a study conducted by the Center for Naval Analysis (CNA), it was determined that it would take 96 LCAC sorties to transport the cargo to the beach. It was also determined that it would take approximately 20 LCAC vehicles to deliver the MEB from the Sea Base to the shore in eight hours. The cargo listed in Table 1 has an approximate weight of 5,800 tonnes(t) and a footprint area of 17,000 m^2.

Table 1: Marine Expeditionary Brigade (MEB)

Ground Combat Element (GCE)	Aviation Combat Element (ACE)	Logistics Combat Element (LCE)
Marine Regiment	Marine Air Group (MAG)	Combat Logistics Regiment (CLR)
17 M1A1 Abrams Tanks	40 AV-8B	1 medium girder bridge
47 AAV	24 F/A-18	6 cranes: 1 30-t crane 5 7.5-t cranes
27 LAV	4 EA-6B	2 600k-gal fuel systems
24 M198 Howitzer	6 KC-130	44 100-kW generators
24 81-mm mortars	32 CH-53D/E	75 5-t trucks
36 60-mm mortars	12 AH-1W	9 Water purifying units
24 TOW missile launchers	48 CH-46E	116 forklifts
	12 UH-1N	5 bulldozers
	45 Stinger missile teams	3 road grades

Current Method

As previously mentioned, the MEB surface element is currently transported by the LCAC. The LCAC is a high speed, fully amphibious, air cushion landing craft capable of carrying a 60 t payload (up to 75 t in an overload condition). With a full payload, it can exceed speeds of 50 knots in Sea State 2, and 40 knots in Sea State 3. Ashore, it has the capability to cross 20-foot beaches and five-foot vertical obstacles, overrun small trees, and climb 10-degree gradients. These capabilities allow the LCAC to assault 70% of the world's beaches versus only 17% for conventional landing craft.

Although the LCAC is versatile, it does have many limitations. As previously mentioned, it takes 96 LCAC sorties from 20 LCAC vehicles operating between the Sea Base and the shore to complete the mission in eight hours. This is not satisfactory. The LCAC also has high acquisition and operational costs, high fuel consumption, and Sea State limitations.

Figure 2: LCAC offloading ashore

Assessment Procedure

The T-Craft Concept Team followed an unrestricted approach using the ship design spiral[iv] as a guideline. The ship design spiral captures the basic principles in ship design and is a widely accepted approach. The initial focus of the ship design spiral is on determining the ship's payload. From there, the shape of the hullform and displacement are considered. Once the hullform is established, basic powering is determined. Subsequently, machinery and fuel efficiency must be considered, along with stability. Many of these tasks can be completed simultaneously.

The next step in the process is concept development. The information derived from the conceptual analysis will identify the solutions that should be further investigated. Worthy concepts will then be examined and developed in greater detail. Finally, a single preferred design configuration is selected, with associated systems and major equipments determined. A baseline general arrangement drawing will be available.

The T-Craft team completed the first iteration of the design spiral. It is believed that the design is feasible and further work will result in an optimal design. As shown in the proceeding discussion, several risk areas have been identified. In subsequent design iterations, high-risk aspects will be reduced to an acceptable level, but minor changes in the design concept may result. Efforts in all areas should provide a successful design.

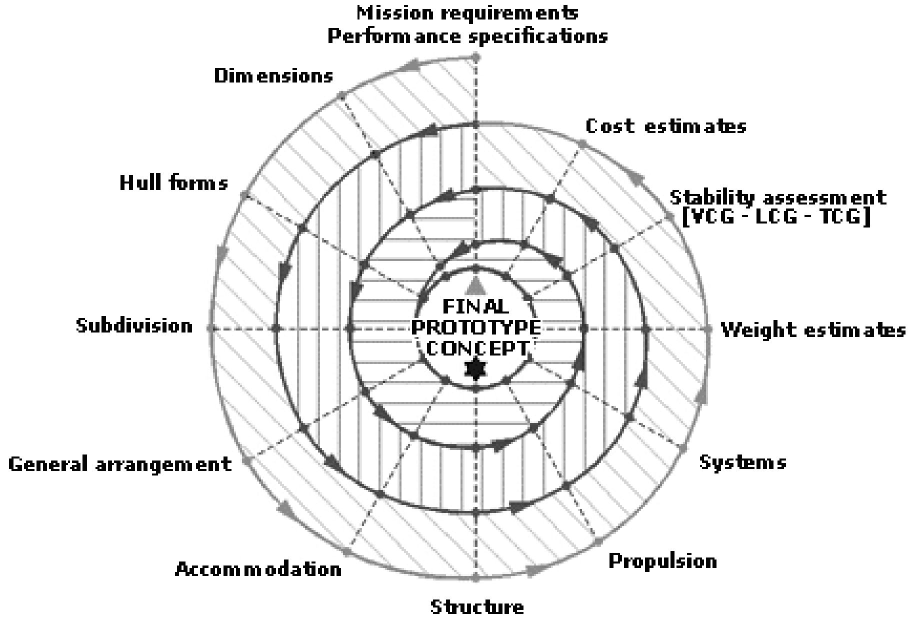


Figure 3: Design Spiral

Brainstorming

The T-Craft mode of operation is a radical idea and forces one to think outside the box as conventional solutions will not work. The first strategy in determining an initial design was to brainstorm. Brainstorming is a process of open-ended idea generation. Early in the design process the team allowed for the free flow of ideas. The team did not finalize particular designs too early, so as not to impede innovation. Periodic brainstorming sessions allowed the team to look at each system in the T-Craft design differently, and thus achieve improved solutions.

Evaluation Criteria

Once a complete list of ideas was compiled, the team selected and eliminated ideas. The T-Craft team narrowed the ideas generated in the brainstorming sessions into six major categories. These included structures, weights, powering, propulsion, auxiliary systems, and arrangements. After these design categories were established, a Gantt Chart was formulated to determine the project schedule. At this point, ideas generated through brainstorming were subjected to the design review process to ensure that these ideas were sufficiently developed and appropriately scheduled.

Section 2 - Mission

T-Craft Mission Requirements

As stated in the Broad Agency Announcement, the T-Craft is required to deploy in an unloaded condition (range of 2,500 nm) from the intermediate support base to the Sea Base and then be used as a Sea Base connector, transporting wheeled and tracked vehicles through the surf zone onto the beach. The craft is envisioned to have three modes of operation:

- A fuel-efficient, good seakeeping mode (open ocean transits);
- A high-speed, shallow water mode (~40 knots); and
- An amphibious mode to traverse sand bars and mud flats, thereby providing a "feet dry on the beach" capability.

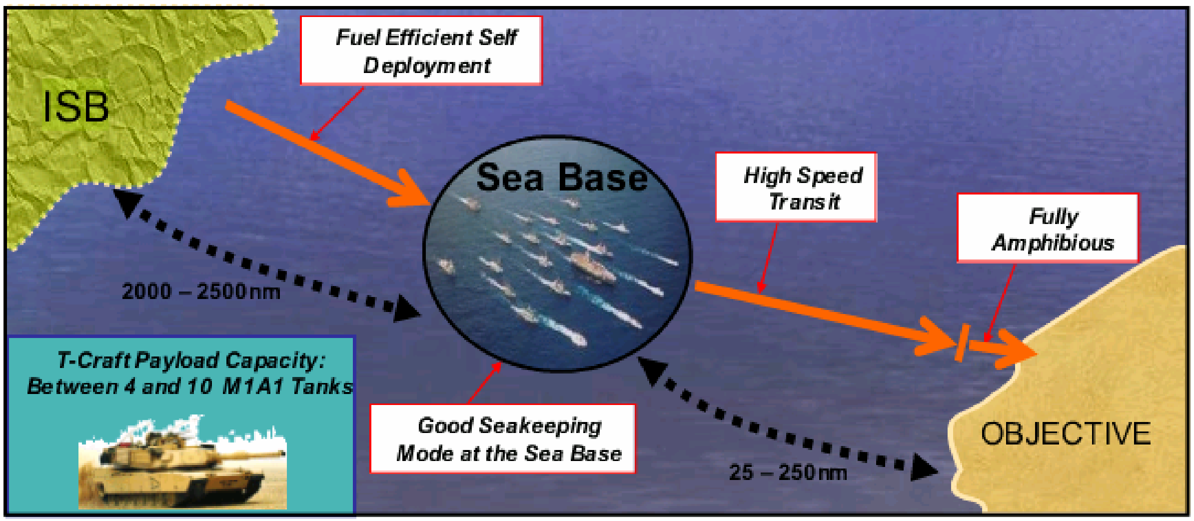


Figure 4: T-Craft Mission

Threshold T-Craft Requirements

ONR had previously identified the following list of desired capabilities for the T-Craft:

- Un-refueled range, in a no cargo conditions, of 2,500 nautical miles in a fuel efficient/good seakeeping mode (20 knots, through Sea State 5)
- Open ocean operations through Sea State 6 (through Sea State 4 in High Speed/Shallow Water Mode) and survival in Sea State 8
- Maximum Speed, full load condition in High Speed, Shallow Water Mode ~40 knots through top end of Sea State 4
- Amphibious capability, in amphibious mode, to traverse sand bars and mud flats
- Ability to convert between modes at-sea without any external assistance
- Maximum un-refueled range in High Speed/Shallow Water Mode ~500-600 nautical miles (40 knots, through Sea Sate 4)
- Ability to mitigate wave-induced motions in Sea State 4/5 to enable rapid vehicle transfer (loading/unloading) between the T-Craft and a Maritime Prepositioning Force (Future)/Sealift Ship
- To be used as an assault connector and a logistics connector.

T-Craft Design Goals

The threshold and objective goals stated by ONR in the BAA are compared with the values realized in this design (Table 2). The threshold goal in each category was met, and in some cases, the objective was exceeded.

Table 2: T-Craft Metrics

Capabilities	Threshold	Objective	Achieved
Cargo Payload Weight	300 long tonnes	750 long tonnes	517 long tonnes
Cargo Payload Area	2,200 ft^2	5,500 ft^2	5,224 ft^2
Watch Size	3	2	3
Beach Slope Climbing	0.5%	2%	2%
Vehicle Ramp Angle	15.0°	12.5°	12.0°
Un-refueled range (no-cargo)	2,500 nm, 20 kts		2,500 nm, 25 kts with 384 tonnes cargo
Un-refueled range (loaded)	500 nm, 40 kts	600 nm	550 nm, 40 kts
Sea State Operations Survivable	 SS6 (14-20 ft waves) SS8 (45-60 ft waves)		
Vehicle Deck Loading	350 lb/ft^2	550 lb/ft^2	530 lb/ft^2

Supplementary T-Craft Attributes and Capabilities

The student team was given several requirements in addition to those in the BAA. The design brief specified the use of a SWATH hull form, which is different to the other T-Craft designs. A SWATH hull has good powering at 20 to 50 knots. Model test data is available[iii]. The craft also was required to transition to a barge at the landing site, similar to a hover barge. It should have retractable skirts, a retractable traction system for crawling ashore.

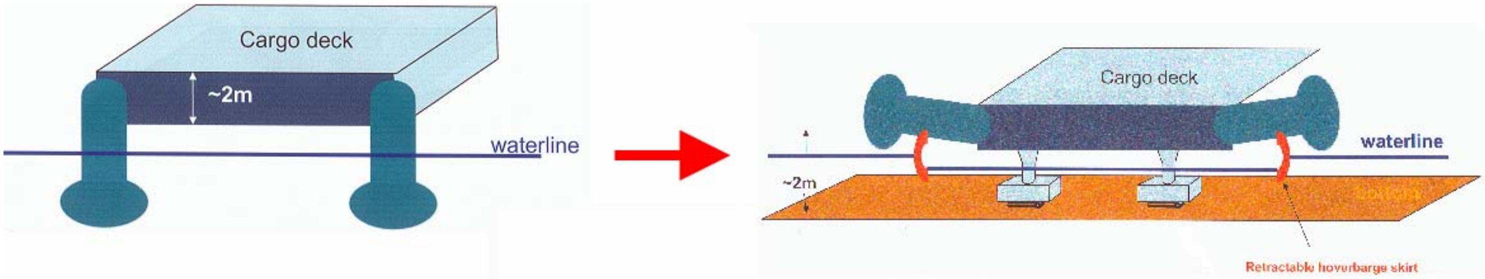


Figure 5: T-Craft Transition Process

The design brief also specified the use of a basic arch structure as the basis of the structure design. The original design started with five arches; through the design process, it was determined six arch supports were needed. The details of the structural design are discussed in

Section 3 – Ship Design and Engineering.

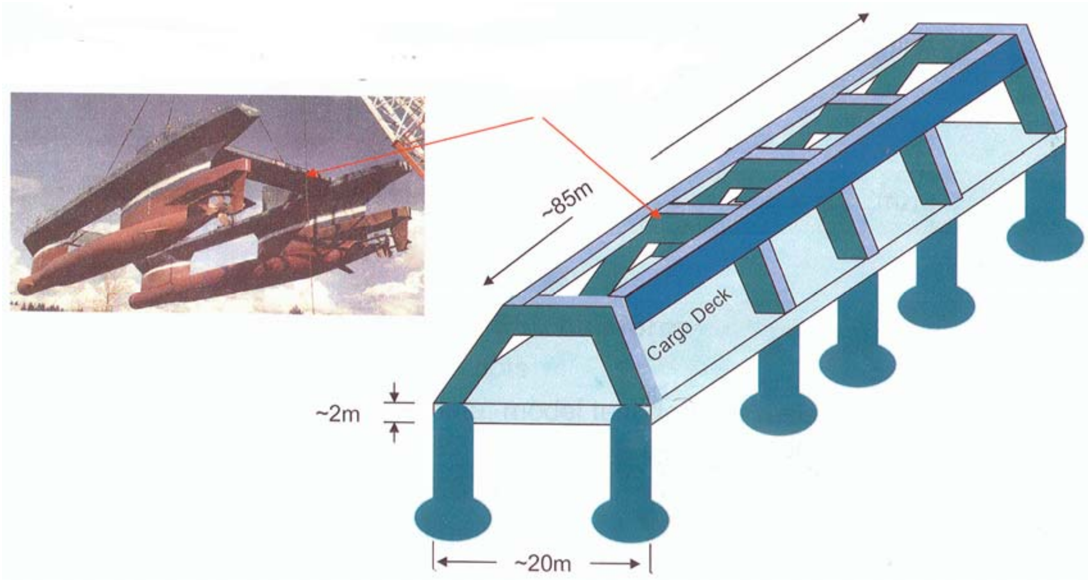


Figure 6: Initial T-Craft Structure

Other T-Craft Concepts

The ONR T-Craft project is currently in Phase I of a Prototype Demonstrator Program, in which there were four T-Craft Phase I contract awards. In this phase, technologies will be identified, a preliminary prototype design developed, technology and risk assessment performed, and during this 9-month period development, Phase II plans will be written.

The four other concepts are either a combination surface effect ship (SES), an air cushioned vehicle (ACV), or a mother/daughter design. The student T-Craft design is very different from these. It is unique in that it is a SWATH hull, with rotating hulls that transform the ship into a powered hover barge in the amphibious mode. There are many technology development areas in the student design that make this an innovative concept.

Section 3 – Ship Design and Engineering

Overall Design

The overall design concept was developed from the specified aspects of the design brief, namely a SWATH Hullform of 1,500 tonnes (t) displacement, a hover barge as the means of supporting the vessel's mass on land, and the use of a traction based system such as wheels or tracks for land based propulsion. The designers' intention was to create a conceptual design, which provided the minimum amount of non-essential systems and focused on the difficulties of transition, cargo transfer, and vehicle offload. Hence many compromises were made to allow the design intent to be met.

The hullform was developed from the parent hullform design of the High-Speed Sealift (HSSL) SWATH developed by Bath Iron Works. This hullform has, in model tests[iii], demonstrated exceptional high speed and good low speed resistance characteristics, in a low draft and a stable hull. This was fully in accordance with the design requirements.

The SWATH design also allowed a relatively simple mechanism to physically alter the hullform so that the draft could be reduced; firstly to a shallow draft in the vicinity of the beach and secondly to remove the hulls from the water in order to climb the beach. Other hullform concepts would not have easily allowed this. The space below the cross structure also provides a unique platform for the mounting of the required land support and traction system.

The need to provide vehicle and cargo access led to the decision to use an open superstructure concept in which the cargo is fully exposed to the elements. This allows flexible access and stowage. The superstructure deckhouses and equipments are fitted around the cargo handling. This benefited from the very flexible deck area introduced by the SWATH concept.

A complex transformation mechanism was required to transition from sea to land, as well as a method to develop propulsion power in each mode, without independent propulsion systems. The first of these issues was resolved by use of a complex system of winches, ballast procedures and rotating mechanisms to allow the SWATH hulls to rotate, under precise control, on demand. The mixed mode propulsion issues took advantage of the full electric propulsion system so that the three main prime movers all can provide propulsion and domestic loads at any point in the operation, reducing system complexity and reducing the amount and hence weight of machinery installed. Across the entire design weight minimization and control was a significant design driver and the intention was to remove as many traditional ship services as possible from the vessel to allow safe operation at minimum weight.

Given expected impact of additional weight on the ability to transform and also to meet the required speeds in the different modes, it was intended to minimize weight. Wherever possible, the amount and style of installed systems were reduced to a minimum and reflect a large craft, rather than small ship style of equipment.

In areas where a parent design was required to assist the development of the concept, the X-Craft was used as a design parent. Even though this design is not similar in many ways to T-Craft, there are several similarities; notably the size, aluminum construction, twin hull form and the use of minimal systems. In summary, the unique nature of the T-Craft design is driven by the requirements of the role and the synergy induced by the SWATH hullform, the requirements for transformation and the land propulsion.

The design has several main modes of operation. The student design operates as a 1,500 t SWATH ship for long range, fuel-efficient voyages and shorter-range high-speed transits from the Sea Base to near shore. Amphibious capability is accomplished by ballasting then deploying a hover barge cushion system before rotating the side hulls to a near horizontal position. Once the tracked land drive system is deployed, the hover barge "crawls" through the surf zone and onto the beach to offload cargo. Principal characteristics of the design are summarized in Table 3.

Table 3: T-Craft Principal Characteristics

Displacement, tonnes:	1,500 full load
Dimensions, meters:	85.6 Length
Beam (m):	21.5 (Transit/sprint), 32.0 (amphibious)
Draft (m):	3.72 (transit/sprint), 2.80 (shallow water), and 0.0 (amphibious)
Main engines:	3 gas turbines (General Electric LM1600, each at 14MW) 3 high temperature superconductor electric generators 2 permanent magnet motors 2 shafts (pumpjets)
Power Required	12 MW (transit), 36 MW (sprint) 2 air cushion lift fans caterpillar tracks
Range, nautical miles:	2,500 (transit), 500 (sprint)
Speed, knots:	25 (transit), 40 (sprint)
Complement:	10
Payload:	7 x M1 AFV or similar rolling cargo; 40 troops
Design:	SWATH ship that transforms into fully amphibious hover barge

The main technologies introduced into the concept are shown in Table 4 with a discussion as to the mode and reasoning. All significant technologies are explained further in this section.

Table 4: T-Craft Technologies

Notable Technologies	System Concept and Role
Full Electric Propulsion	A three prime mover based system, intended to propel propulsors at sea, generate power for the lift fans and also the tracked system.
Hinge / Locking pins	Six hinges and six locking pins to allow the relative rotation of the hulls and cross structure with locking possible in three angular locations.
Winch / cables	Twelve winches able to control the motion of the SWATH hulls by tensioning the cables connected to the hulls.
Ballast	Ballast is used to reduce the requirement for the cable to bear the mass of the hulls. By flooding the hulls the net load is reduced.
Tracks	A derivative of the main battle tank track system, scaled to allow propulsion of 1500 tonne vessel on land.
Hover Barge	An air cushion system scaled from industrial use, to support the weight of the vessel on land, while on a beach.
Arches	Six aluminum arches designed to resist transverse prying forces induced in the hulls.

Transformation

With the SWATH ship in about 7.5m of water, it will deploy the hover barge system and ballast down until the ship is fully supported by the cushion. The side hulls will then be rotated outward. Main propulsion will then propel the ship into water depths of about 2 to 2.5 m. At this point the tracked land propulsion will be lowered and it will contact the bottom. The side hulls will then be rotated further to raise them above the water and beach obstacles. At this point, the T-Craft is a self-powered hover barge. The tracked drive system will then propel the hover barge through the surf and onto the beach.

In order to meet the “feet dry on the beach” requirement, the T-Craft must transform from a sea-going SWATH ship to an amphibious vehicle. There are two stages of transition; from seagoing to littoral mode and from littoral to beach mode. The student design originated from a basic hover barge design. It will ballast down until it is supported by air. Then while rotating its hulls, it uses a combination of track and skirt systems to maintain proper ground pressure. The hulls rotate 105°, which allows the T-Craft to creep ashore.

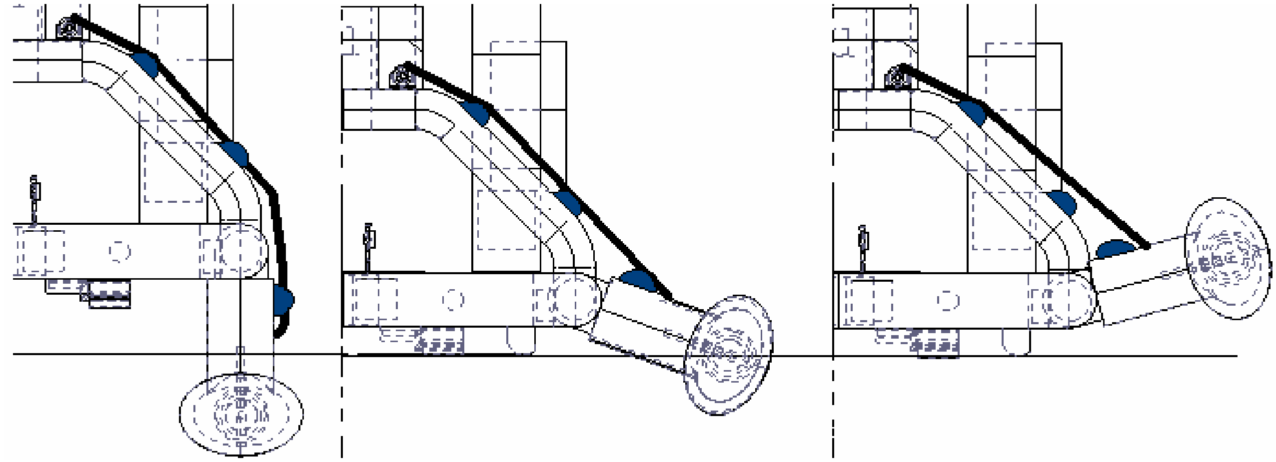


Figure 7: Transformation Process

Ballasting Process

The ballasting system consists of one ballast tank in each hull to offset the inherent buoyancy of the machinery space; the rest of the hull will be allowed to free flood so that it does not contribute in either buoyancy or weight. The purpose of the ballasting process is to minimize the moment needed to rotate the hulls during transition between phases.

There are three main phases that T-Craft must transition through. The first phase is the sea-going phase in which the hulls are vertical and locked in place. This is the phase that T-Craft will spend most of its operational life. To transition to the second phase, the first step is to fill the ballast tank in order to offset the machinery space.

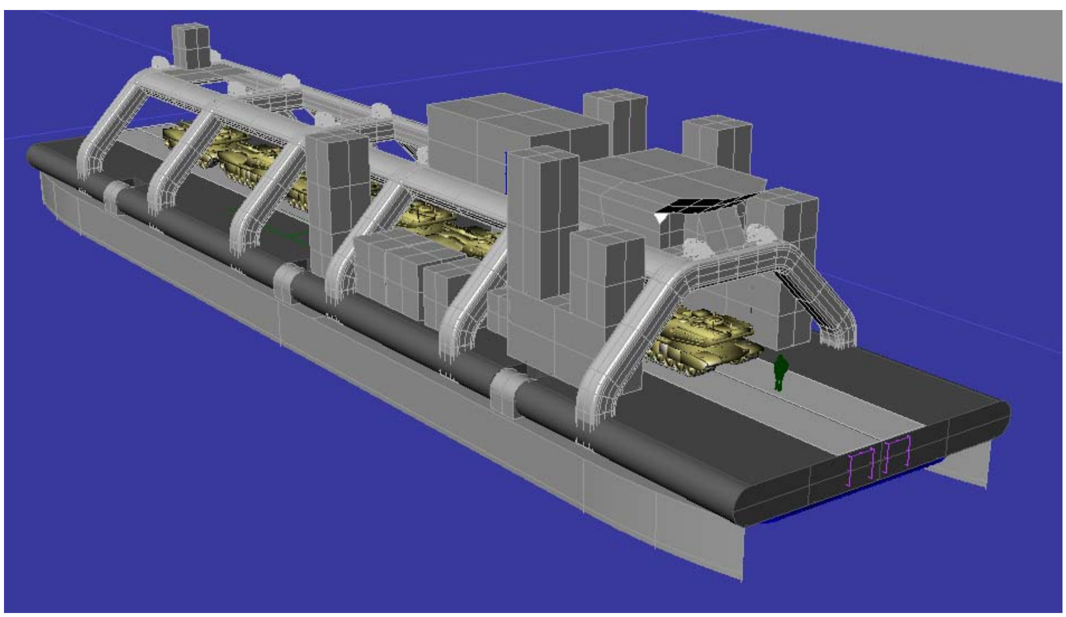


Figure 8: Step 1, T-Craft Ballasting Process

The skirt is then deployed in preparation for supporting the craft once it's fully ballasted. The hulls are free flooded to lower the craft to the skirt. Air pressure must be built up in the skirt at this time so the craft will become supported more by the air cushion and less by the hulls. Once the hulls are fully flooded, the entire craft will be supported by the air cushion and the hulls will be suspended; the hulls can then be unlocked and rotated using 12 lifting winches. As the hulls rotate out, water in the hulls will be regulated and pumped out as needed to minimize loads on the winches. Once the hulls reach a point where the pumpjets are about halfway submerged, the lifting will stop and the hulls will be locked in this position. This position is phase two, Figure 9, and is where T-Craft will advance into shallower water under power from the pumpjets.

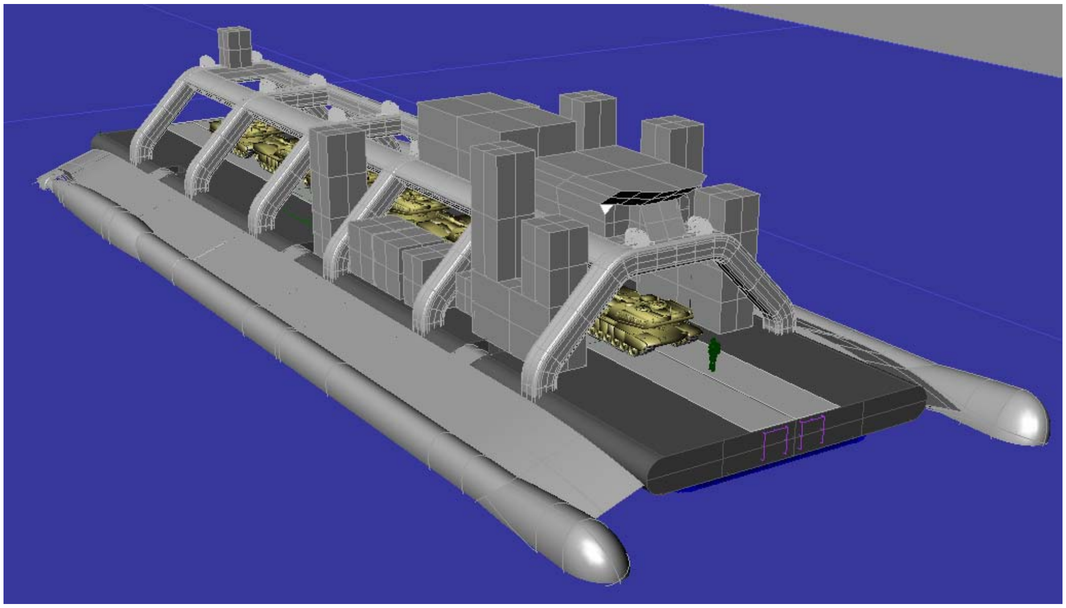


Figure 9: Step 2, T-Craft Ballasting Process

At an appropriate distance from the beach, the tracked land propulsion will be extended to achieve traction on the bottom. This is the beginning of the transition from phase two to three. The first step in this process will be to shut down the propulsion motors. The hulls will then be unlocked and the winches will pull the hulls completely out of the water. As the hulls are raised out of the water, ballast water and floodwater will be pumped out or drained out at the appropriate rate so as to minimize tension in the lifting cables. Once the hulls are completely out of the water and the tracks have been deployed, T-Craft will be in phase three, Figure 10, and will be ready to land on the beach.

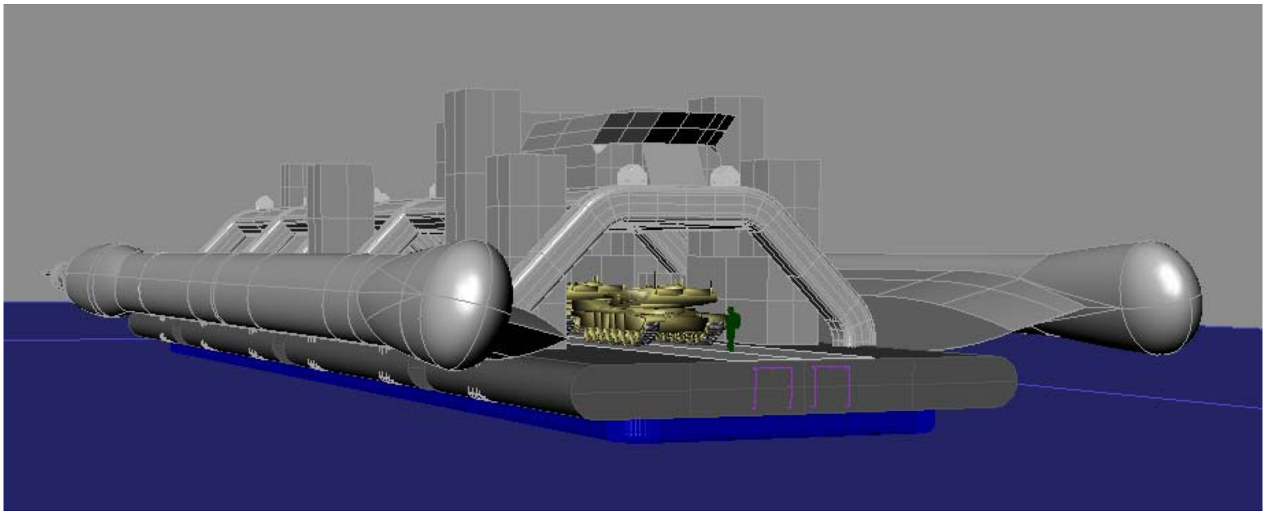


Figure 10: Step 3, T-Craft Ballasting Process

In each transition between phases, a simultaneous monitoring and control of the ballast system, air cushion system, and winch system is required. The technology capable of handling this task is available, but a system would need to be designed in detail to fit this application.

Hinge Mechanism

The hinge mechanism on board T-Craft is the key component in the transformation process. If the hulls are not allowed to rotate, then this T-Craft concept becomes infeasible. Each hull is supported by three hinge connections. The three hinge pins on each side, each 1.5m diameter by 4.0 m length, are constructed of solid aluminum. Basic shear stress calculations revealed a stress of 1.8 MPa per pin. This is significantly lower than material's yield strength of 131 MPa.

In addition to connecting the side hulls and cross-structure during rotation, the hinge mechanism must be equipped with pin connectors to allow transfer of loads between the side hulls and cross-structure. Design details of the connectors were not developed during this design.

Winch System

The mass of each side hull is 100 t. In order to rotate and lift the hulls, a force of 1,470 kN is needed on each side. Refer to Appendix D: Rotating Hull and Ramp Analyses for this analysis. Six winches are needed to support the weight of the hulls on both port and starboard sides. The winches used on the T-Craft were modeled from the Pull Master M75 Equal Speed winch. These winches provide enough force so that if one winch fails, the remaining five are still fully capable of rotating the hulls.

Cushion and Skirt Design

Part of the original concept requirements included a hover barge-like skirt system. An existing 900 tonne hover barge with the T-Craft's proportions creates a ground pressure of approximately 1 psi. In order to achieve a low ground pressure comparable to the hover barge, it was initially determined that the T-Craft skirt must be stored and deployed from its rotating hulls. Because this type of system requires substantial complexity, ground pressures created by other hovercraft designs were evaluated.

A search was performed and it was found that pressures of most hovercraft approach 2 psi[x]. LCAC data indicated that its air gap was 0.01 m. This research confirmed that a T-Craft ground pressure of 1.85 psi creates an air gap of 0.023 m, which is proportional to the air gap created by the LCAC. The airflow required to create this air gap height and ground pressure is quite low. See Appendix E for supporting calculations. These findings resulted in a smaller cushion area than originally suggested, thus allowing the skirt to be entirely located between the hulls (underneath the cross-structure), rather than in the hulls themselves. Thus, these findings resulted in a skirt system similar to a modern hovercraft.

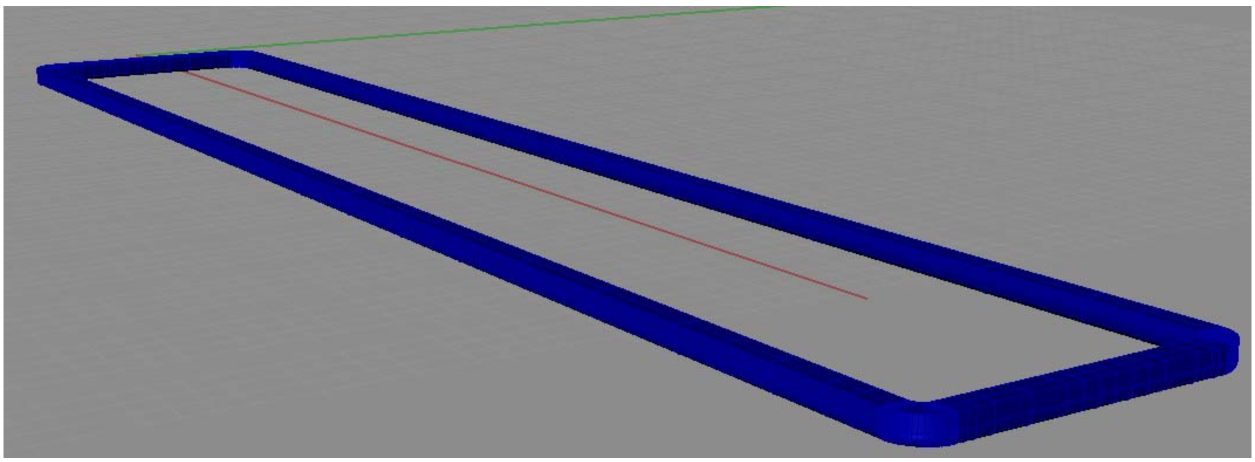


Figure 11: T-Craft Air Cushion Support (Deployed)

Track Design

The land propulsion scheme of the T-Craft is one of the more complex and difficult design challenges. Because of the need to minimize prime movers, increase fuel efficiency, and minimize maintenance, airscrews were not an option for this vessel. Instead, the design focused on incorporating some form of wheeled and/or tracked propulsion system. As such systems are currently used on self-powered hover barges, it can be assumed that this type of land propulsion is feasible. Several options were developed and researched. These options included:

inflatable air tracks that would undergo modification to use current azipod technology;

very large motor driven air-cushioned wheels (e.g. Pneumo-Wheel) placed on each side of the ramp anchored to the main box on the bow and stern; and

a track system similar to that of an M1A1 tank.

Due to the high ground pressures created in the first two systems, along with an increased risk due to new technologies, a track system (Figure 12) nominally based upon an M1A1 tank was selected, although with additional road wheels and a much wider track. Calculations were based upon information found in two references, one on Armored Fighting Vehicle Design[ix] and the other from a research report on an air-cushioned/caterpillar track combination transporter concept; these results can be found in Appendix D: Rotating Hull and Ramp Analyses. The team determined that the ground pressure created by the track system must be equal to the skirt pressure to avoid excessive track ground pressures and sinkage in soft and muddy ground conditions. The road wheels are taken from a proposed composite road wheel alternative for the M1 Armored Fighting Vehicle[ix].

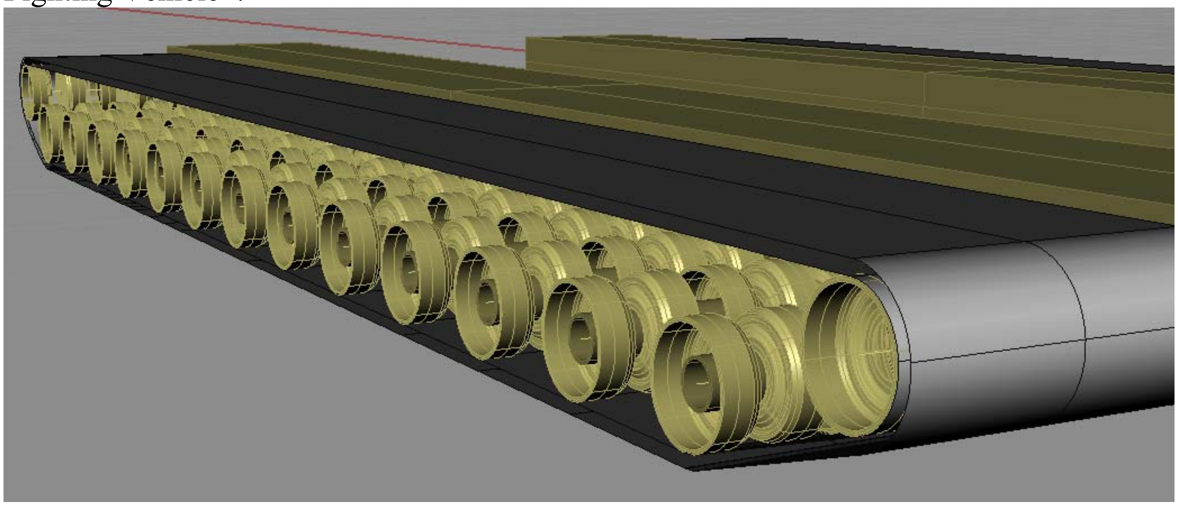


Figure 12: T-Craft Traction System

Ramp and At-Sea Cargo Transfer

One of the T-Craft requirements is that it must transfer rolling stock, including an M1A1 tank. These tanks can weigh upwards of 70 tonnes. Also, the vehicle ramp angle objective is 12.5º. A ramp length of 15m was selected, which exceeds the ramp angle by 0.5º.

The next task in creating the ramp for the T-Craft is to design one that is suitable for the transfer of wheeled and tracked cargo. Many types of military bridges and ramps were reviewed and ribbon bridges and modular bridge designs were found to be the most suitable. Ribbon bridges can adapt to banks up to 2m high, have an integral structure with floating supports, and can support up to 96 tonnes. Modular bridges can be found on various military vehicles, are electronically controlled, and can support up to 100 tonnes. A modular bridge design is the most practical application for the T-Craft. The T-Craft ramp will be constructed of aluminum and the weight was scaled from several aluminum modular bridge designs. Details of these estimations can be found in Appendix D: Rotating Hull and Ramp Analyses.

Structural Design

Structural Analysis

The T-Craft is a 1,500 t displacement aluminum hull craft that follows American Bureau of Shipping (ABS) High Speed Naval Craft (HSNC) Rules. It is similar to the X-Craft, which is a 1,400 t displacement aluminum hull craft that follows ABS High Speed Craft Rules. Because of this similarity, X-Craft scantlings were used as a basis for the T-Craft design. A plate thickness of 8.0 mm was used throughout the entire ship. The maximum loads on a SWATH ship are the side loads; therefore the transverse stress tend to be considerably less than the longitudinal stress for the principal cross-structure members. Side loads were estimated based on Navy SWATH algorithms. A basic I-beam approach was used in the calculations of the stresses. The transverse stresses are listed in Table 5.

Table 5: Transverse Bending Data

Element	Bending Moment (kN·m)	Bending Stress (MPa)	Yield Stress (MPa)
Arches	97,806	39.5	131
Deck 2	97,806	3.27	131
Deck 1	97,806	15.5	131

Payload and Machinery

All main components of machinery are located on the main cross-structure. The only components located in the hulls are the propulsion motors, steering gear, and ballasting system. All remaining machinery is located on the main cross-structure. This minimizes the complications associated with system interface between the cross-structure and the rotating hulls. Power cables feeding the propulsion motors, propulsion motor controls, and ballast controls will be the only components necessary to pass between the cross-structure and the hulls.

Space available for the remaining machinery on the cross-structure will be dictated by where it is more suitable to store payload. The current design has a lane wide enough for one vehicle across the entire length of the craft. Therefore, the space available for machinery is on the sides of the cross-structure and above the cargo deck supported by the arches. The single lane through the center of the craft was chosen for its simplicity during loading and unloading of the payload. During loading operations at the Sea Base, the payload will drive onto the craft at the stern. During offloading operations at the beach, the payload will drive-off the bow, thus avoiding the need for vehicles to turn.

Propulsion System and Weight Estimates

A fully integrated electric propulsion system was selected to minimize the number of prime movers on board and in the hulls while meeting the substantial power requirements for the propulsion motors in transit mode as well as winches, lift fans, and tracked propulsion needed to operate as an amphibian. The idea is to have all components on the craft electrical. The reduced number of prime movers as well as electric machinery for all auxiliaries should reduce the maintenance burden on the austere crew. All-electric propulsion plants have been fully developed, tested, and fielded, and so has proven a reliable choice. The alternatives are to have either an engine in the hulls, or on the cross structure driving a complex arrangement of shafts and right angle drives. This would be impractical due mostly in part to the rotation of the hulls. The main components in an all-electric plant are the generator prime movers, generators, a distribution bus, transformers if needed, power converters/variable frequency drives (VFD), and the electric propulsion motors. T-Craft has three 14 MW LM1600 gas turbines driving three high temperature superconducting (HTS) generators, two variable frequency drives, two permanent magnet (PM) propulsion motors, and two pumpjets. Shown below is a table of the estimated weights of the major components in the propulsion system.

Table 6: Propulsion Weight Summary

Item	Quantity	Weight Per (t)	Total (t)
LM1600 Gas Turbine	3	19	57
HTS Generator	3	18	54
Variable Frequency Drive	2	2	4
PM Motor	2	22	44
Pumpjet	2	28	56
		Total Propulsion Weight	215

The total estimated propulsion weight as seen above is about 14% of the total ship displacement. Section Propulsion Plant covers each component in more detail.

Electrical Power Generation

The three LM1600 GTs provide electrical power generation on board T-Craft. They provide all the power necessary for every mode of operation. The turbines are discussed in more detail below in Section Propulsion Plant, as are the generators.

Emergency power generation will be provided by a 320 kW CAT 3406C diesel generator set. The required generation capability was determined by scaling from a SWATH survey vessel. The survey vessel has a displacement of 540 t and has an emergency diesel generator (EDG) rating of 110 kW. From scaling by displacement, it was found that the emergency power generation capability of T-Craft may be 306 kW. By using the above-mentioned EDG, it results in a 4.6% margin and is sufficient.

Propulsion

Powering Estimates

Power for the T-Craft was determined using test data of a 70th scale model of the HSSL SWATH hull. The test provided resistance data as well as effective horsepower (EHP) at various speeds. The propulsive coefficient (PC) was then used to determine the shaft horsepower (SHP) needed by using the relationship PC = EHP/ SHP. The PC was obtained from a pumpjet expert who determined the PC for a 12,000 t and 15,000 t displacement ship. Pumpjets designed for these ships were estimated to have a PC of 0.74. This value was then said to be constant and was used in the T-Craft power calculation. A power margin of 6% was added to the EHP value before determining the SHP. A 5% and 1% margin was then added to the SHP value to account for appendage drag and transmission efficiency respectively. Figure 13 illustrates the relationship between EHP and speed using the data obtained from the tow test.

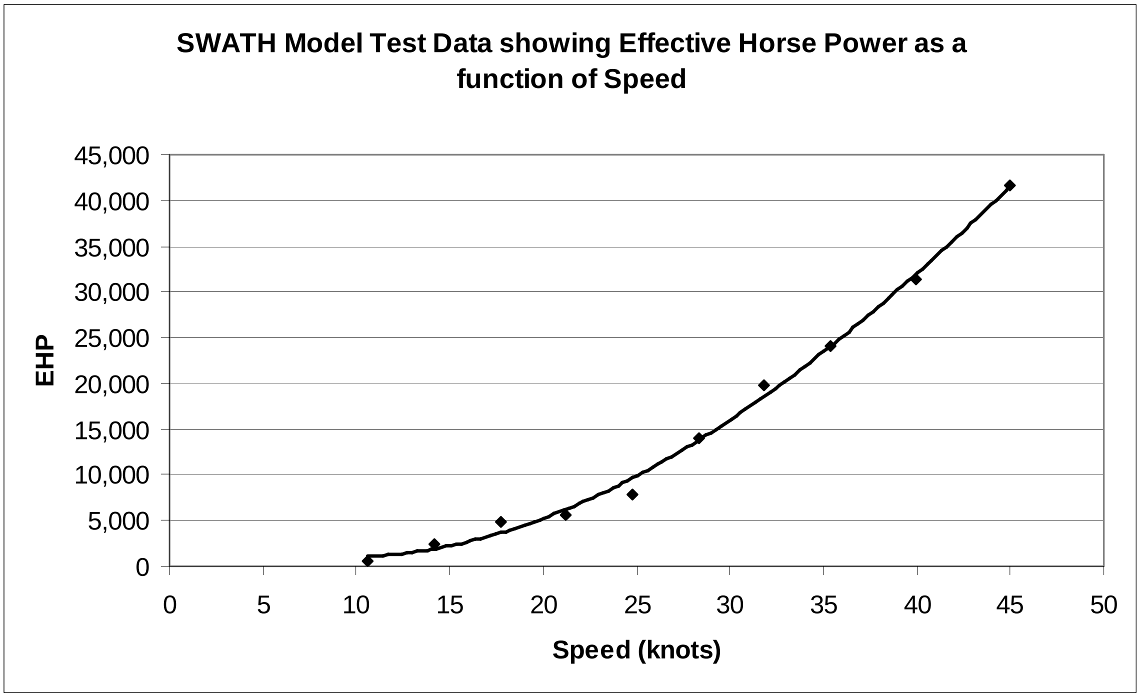


Figure 13: SWATH model test data showing power as a function of speed

Propulsor

The propulsor chosen for the initial design concept was the pumpjet. The water jet was considered but proved less desirable when compared to the pumpjet due to the intake's penetration into the hull. The water jet intake adds an unnecessary appendage to the hulls as well as weight from the body of water flowing through. A pumpjet is essentially a waterjet with an annular inlet and a submerged discharge. Consequently, much of the waterjet technology is directly applicable to pumpjets.

The pumpjet is a fully developed and fielded technology principally used on submarines and torpedoes. There are pumpjets in use today that deliver substantially more power than is required for T-Craft. However, there are no commercially available pumpjets meeting the T-Craft's power requirement. Therefore some development will be needed to properly design a pumpjet for T-Craft.

There is little data on the high-powered pumpjets in use today. So in its place, data from water jets in the same power range as T-Craft was used to estimate the size and weight of the pumpjets needed. For T-Craft, an estimated 18 MW per shaft is required to reach the 40 knot requirement. From the water jet algorithms, this corresponds to two pumpjets each having a 1.7 m diameter impeller, weighing 28 t, and operating at 442 rpm.

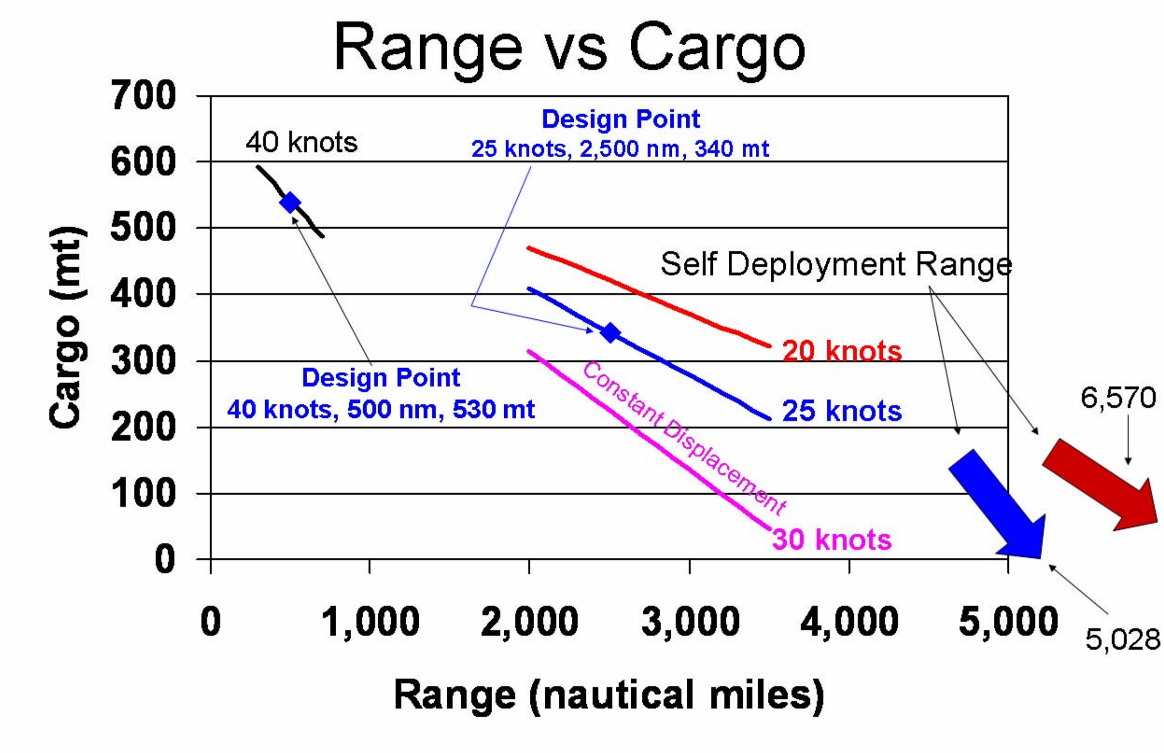


Figure 14: T-Craft Range as a function of Payload

Propulsion Plant

The initial machinery concept was to have two LM2500 gas turbines driving two high-temperature superconducting (HTS) generators. The LM2500 turbines were chosen for their high power. Each turbine is rated at 22MW, which provides enough power for the 40-knot sprint as well as the hotel load and any auxiliaries. The current concept however, has three 14 MW LM1600 GTs equipped with the same type of generator. The reasons for this change was (a) during the 25-knot transit to the Sea Base, the power needed is about half of one LM2500's rated power, which results in poor fuel economy, and (b) three LM1600 GTs are about 13 tonnes lighter than two LM2500 GTs. It is much more fuel efficient to run one LM1600 during transit; and because there are three generators to share the load, they do not have to be quite as large thus saving weight. Below is a basic electrical diagram showing the major components of the propulsion plant.

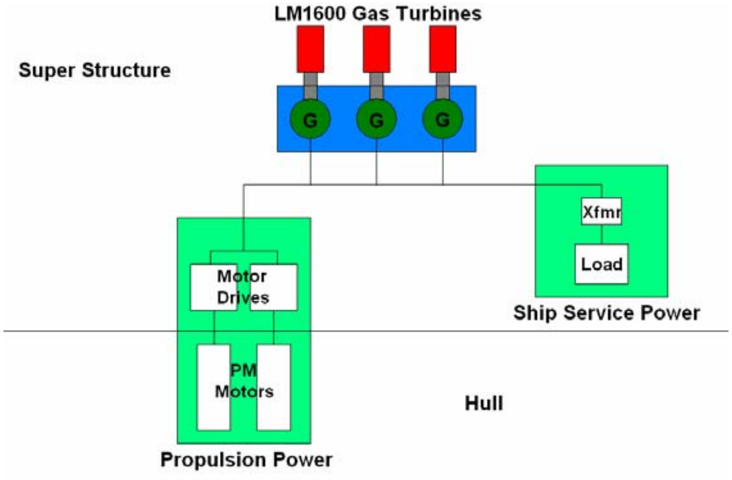


Figure 15: Propulsion Electrical Layout during the 40-knot Sprint

The HTS generators are much smaller and have a higher power density than conventional generators. Preliminary sizing data was obtained from American Superconductor for a 15 MW, 17.5 MW, and 20 MW generators. From these data points, a linear algorithm was constructed and used to estimate the weight of each generator on T-Craft. Each generator is rated at 14 MW and weighs 18 tonnes.

An alternative to HTS generators is permanent magnet (PM) generators. PM machinery is a relatively new and developing technology. PM generators are also a viable option. There are two types of PM generators, the cylindrical-type and the disc-type. A conceptual study on permanent magnet machinery for ship propulsion concluded that the cylindrical-type generator is impractical but that the disc-type is a prime candidate. The cylindrical-type generator was said to be impractical because "The stresses developed in the rotating portions of the generator exceed the materials capabilities for fabricating high-performance rotors at the high drive-turbine speeds considered"[vi]. The disc-type was only looked at briefly and no data was available. In further development, a more detailed comparison between an HTS generator and a disc-type PM generator must be completed to determine the appropriate equipment for T-Craft.

From the generators, power is fed to a distribution bus where it then fed through power converters that supply power to the motor at the proper frequency depending on desired speed. The cycloconverter, when compared to other variable frequency drives (VFDs), such as the multilevel and series connected low voltage, is smaller, lighter, and more efficient. Pulse width modulation (PWM), or synchroconverter, is also a viable option; however, the most notable difference between a synchroconverter and a cycloconverter is that the synchroconverter needs a DC link between the supply and load side[ii].

A cycloconverter drive was selected to avoid this DC link. The weight of the cycloconverter was estimated based on a previous study on variable speed electric drive options[v]. Three different types of VFDs were evaluated for a 36.5 MW propulsion motor were compared and contrasted. The estimated weight for the cycloconverter used in this study was used to make a single-point linear algorithm. Cycloconverters are a fully developed and fielded technology. The USCG icebreaker *Healy* is one example where they are used for motor drives.

For propulsion, two PM motors were chosen. The motors will be mounted in the SWATH hulls. They will be the only major propulsion components in the hulls and will be directly connected to the pumpjets. The motors operate at the same RPM as needed by the pumpjets thus eliminating the need for reduction gears. PM motors have a higher power density and deliver more torque than a conventional induction motor. When compared to HTS motors at T-Craft's power range, the HTS motor is heavier. Two data points, from the same conceptual study on permanent magnet machines as stated above, were used to create a linear algorithm to obtain a rough estimate on PM motor weight (See Figure 16). In order to compare to HTS motors, three preliminary sizing data points from American Superconductor were used to create a similar linear algorithm[v]. Figure 17 shows the two algorithms that were used to estimate motor weight. T-Craft's design point of 18MW and 442 RPM per shaft was used to determine torque and is represented on each graph.

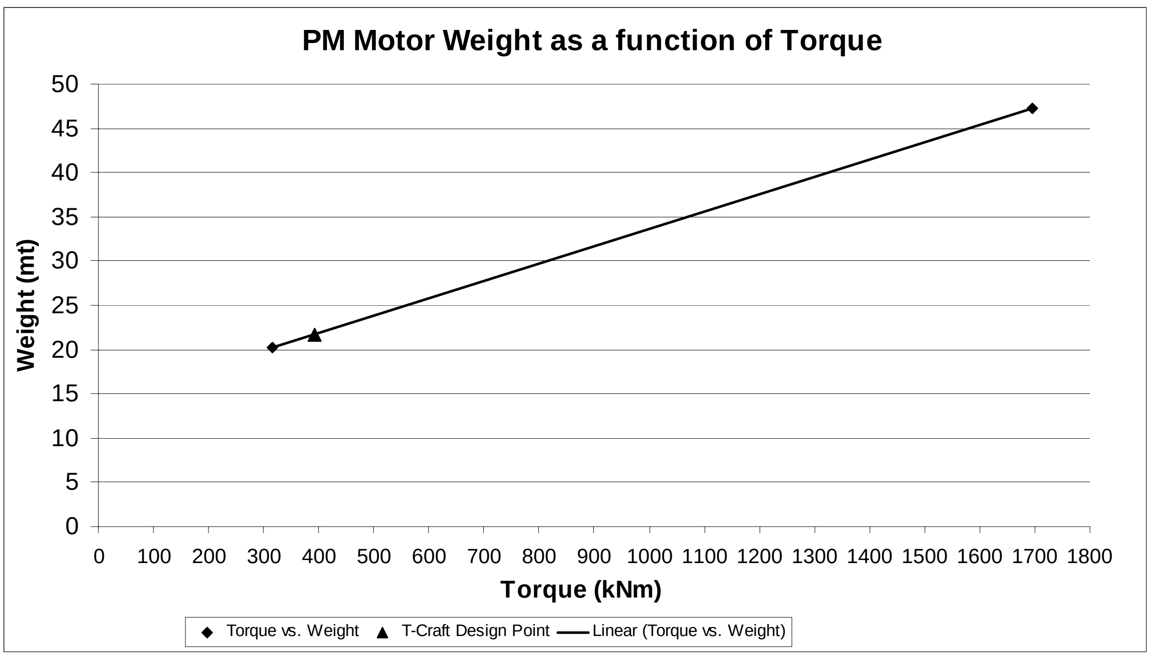


Figure 16: Permanent Magnet Motor Weight

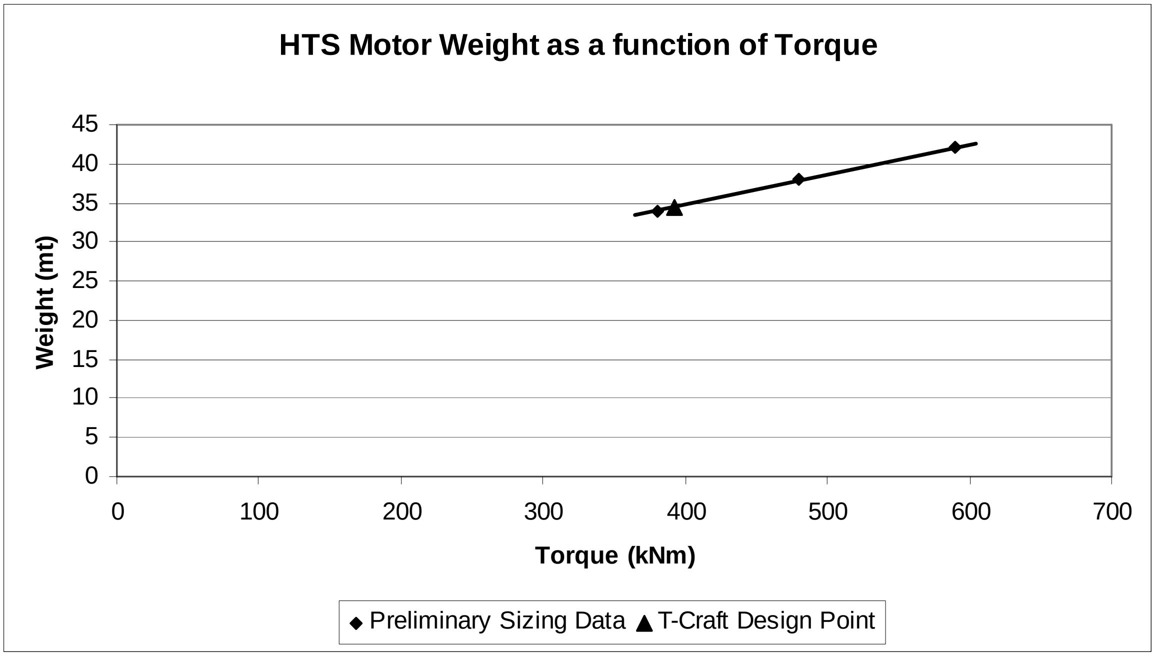


Figure 17: High Temperature Superconductor Motor Weight (data provided by American Superconductor)

After evaluating Figure 16 and Figure 17, it is important to note that although these data points do not represent "built motors." T-Craft's design points lie within the bounds of developing technology. The highest risk components in the electrical system are the generators and motors. Both HTS and PM machinery are currently under development. All other components are technology in use today and so have very little risk.

Ship Design

General Arrangements

The T-Craft is based upon a one-half scale of the parent High Speed Sealift Ship (HSSL) SWATH hull, as directed by the project's mentors; therefore, the length, breadth, depth, shape, and separation of the demi-hulls were scaled from the parent hull form. The main driver of the arrangements were the placement and sizing of the integrated above deck arches; bulkheads supporting the hinge system; the large concentrated weights and locations of the primary powering, drive, and propulsor machinery systems; and the weights and locations of the main fuel tanks required to meet the speed and range requirements. One of the major design goals was to eliminate as many systems from the demi-hulls as possible to reduce operational maintenance issues due to the anticipated limited access into the demi-hulls and facilitate side hull rotation. The other major design goal was for a totally electric ship, which provided for quite a bit of flexibility in locating major systems.

The initial configuration placed all the powering and propulsion machinery far aft to minimize cabling and shafting length; however, this resulted in unacceptable trimming by the stern. The next general arrangements configuration, presented at the mid-term review, reflected the down selection to a pump-jet propulsor and a permanent magnet drive motor in the aft portion of the demi-hulls, and two LM2500 Gas Turbine generator sets (port and starboard) on the main deck cross structure a bit aft of amidships. While balanced transversely, there was still an unacceptable amount of trim by the stern.

The final configuration reflected a powering change to three LM1600 Gas Turbine generator sets, which resulted in a significant amount of heel due to an imbalance in weight from two gas turbine generator sets located to port and only one starboard. A corridor on the centerline of the vessel needed to be kept clear for straight-thru roll-on/roll-off vehicle cargo. The transverse heel was corrected by locating machinery and tanks symmetrically about the centerline where possible. To balance the large weight of the pump-jet propulsor and permanent magnet motors at the far aft of the ship, the gas turbine generator sets were moved quite far forward (to directly behind the most forward arch) to balance longitudinal trim.

Auxiliary Systems

Several alternatives were evaluated for the T-Craft fire-fighting system, including traditional sea water systems, aqueous film-forming foam (AFFF)[viii], carbon dioxide, and FM-200.

Three basic seawater fire main systems were evaluated: single-main, horizontal loop, and the vertical offset loop systems. The fire main system receives water pumped from the sea. It distributes this water to fireplugs, sprinkling systems, as well as secondary systems such as those used for flushing, machinery cooling-water systems, wash down systems, and other systems as required. It is primarily used to supply the fireplug and the sprinkling systems. Fire mains were not selected for T-Craft because they could not function while on land.

Aqueous film-forming foam (AFFF) is one of the most widely used fire-fighting agents. The Navy uses AFFF to suppress combustible and flammable liquid fuel fires resulting from shipboard accidents and battle-induced damage. However, despite its wide and effective application, long-term continued use of AFFF creates cause for environmental concern. Subsequently, since this T-Craft is to be designed with the year 2015 in mind, AFFF raises questions to its toxicity and resistance to biodegradation. In addition, the only reliable method to remove AFFF from wastewater is a combination of existing and emerging technologies. Additionally, it should be noted that AFFF may be delivered through both portable and installed equipment.

Carbon dioxide (CO_2) is a colorless, odorless gas that is naturally present in the atmosphere at an average concentration of 0.03%. Because it reduces the concentration of oxygen in the air to the point where combustion stops, it is used in the extinguishing of fires. Before operating an installed CO_2 system, all openings in the area must be closed and the ventilation system for the space must be secured. This is necessary to prevent the loss of CO_2. This creates an unwanted and extra step in fire fighting and was quickly eliminated as a viable option.

The T-Craft design will use FM-200 in all fire-fighting applications. FM-200 was originally developed to replace ozone-depleting fire suppressants such as Halon 1301.

Effective on Class A, B, and C fires, Stored as a liquid in pressurized cylinders, FM-200 flows through a piping network to a discharge nozzle where it is deployed as a gas. FM-200 is waterless and is a clean agent, meaning that there is no residue, particulate, or collateral damage. It penetrates with three-dimensional capability, and is non-conductive and non-corrosive. This is an advantage given that the T-Craft is a full-electric ship.

A ten-day mission was assumed to evaluate potable water alternatives. It was estimated that for a ten-day mission, a crew of ten will use approximately 6,000 gallons of freshwater. A freshwater treatment facility weighs much more than the freshwater supply. Consequently it was determined that there would not be able to make freshwater, but would only require water in tanks, options for the water holding tanks were evaluated. Because payload weight is a critical issue, it was initially determined that two 3,000 gallon potable water pillow tanks should be used. The tanks are compact and can fold down when not in use. Although these pillow tanks result in a substantial weight reduction, it was later determined that fiberglass tanks are needed to meet stability criteria.

The same type of pillow tank was also evaluated for gray and black water collection. Because there may not be the ability to pump-out the onboard waste, it was concluded that a waste treatment plant is the most viable option. The need to address the impact of the waste discharge on the environment is an increasing concern. The Orca IIA and the Hamworthy Super Trident sewage treatment systems were compared. The Orca IIA has a slightly smaller footprint and replaces the need for a gravity feed system. However, it uses 5% chlorine solution as a disinfectant, thus requiring the need to carry additional chemicals onboard. The Super Trident is highly efficient, minimizes size and weight and can be automatically controlled, thus needing minimum maintenance and allowing unattended operation. It is unaffected by the craft's motion and is suitable for use with the vacuum sewage collection system. It meets IMO Regulations for the quality of black water discharges.

Once the sewage treatment plant was chosen the decision between vacuum and gravity sewage collection had to be determined. A vacuum collection system uses only a small amount of flush water compared to conventional gravy systems and because of this, there is a reduction in peak loadings, which allow the use of a smaller sewage treatment plant than for gravity systems. The Hamworthy vacuum collection system that was selected uses differential air pressure to transport sewage from the toilet bowls and other sanitary fixtures to the Super Trident sewage treatment plant.

Weight Estimation

In order to create a cohesive ship design a comprehensive weight estimate must be developed. In the case of T-Craft this is especially important because of the specified 1,500 tonne displacement and also the penalties in performance for weight growth. Any increase in weight correlates to a decrease in payload or performance. Because of this a comprehensive Ship Weight Breakdown Structure, or SWBS weight estimate, was maintained throughout the design process and the final version is presented below.

SWBS 100 – Hull Structures

The 100 group of the SWBS contains estimates for the weights of all structural components. The shell and supports, deckhouse structure, and foundation groups were directly scaled from the X-Craft SWBS estimate using a volumetric scaling factor of 0.62. The mast weight assumed for T Craft that of X-Craft. The source data for X-Craft had no separate estimates for bulkheads or hull decks. T Craft specific estimates were developed in this case with the strengthening needed to support the hinge system and the increased local stresses accounted for. A representative hinge weight was included in the 100 group. The 190 group consists of welding and structural fastenings and is a percentage of the overall 100 group weight. In this case the percentage was calculated from X-Craft's data to be six percent.

Table 7: SWBS 100 Group

Group	Category	Weight (t)
110	Shell + Supports	134.79
120	Hull Structure Bulkheads	20.0
130	Hull Decks	40.0
150	Deckhouse Structure	7.9
170	Masts	0.05
180	Foundations	2.42
190	Special Purpose Sys	12.31
	100 Group Total	217.46

SWBS 200 – Propulsion Plant

The 200 group contains weights for all propulsion equipment. As this design has fully integrated electric propulsion the weights for the gas turbines has been included under the electrical category. Weights for the vessel's main propulsion equipment were been obtained from manufacturer's data while other components such as shafting, supports systems, and fuel service systems have been obtained from scaling X-Craft data. Operating fluids were assumed to be 4.5% of the total 200 group weight. The land propulsion system is also included in the 200 group and its weight was calculated by extrapolation from the M1A1 tank's current land track system.

Table 8: SWBS 200 Group

Group	Category	Weight (t)
230	Propulsion Units	98
240	Transmission + Propulsor Units	59.87
250	Support Systems	21.17
260	Prop Sup Sys- Fuel, Lube Oil	9.90
290	Special Purpose Systems	8.50
	200 Group Total	145.45

SWBS 300 – Electrical Plant

The 300 group is heavier for this design than most other ships of the same size. This is due to the inclusion of an all electric propulsion arrangement which introduces significant extra electrical equipment.

The 310 group is based on data obtained from manufacturer specifications. The 340 group is based on the support system needed for the X-Craft's diesel engines, and the 590 group is 0.6 percent of the total group weight. Remaining weight was scaled from X-Craft data.

Table 9: SWBS 300 Group

Group	Category	Weight (t)
310	Electric Power Generation	117.6
320	Power Distribution Sys	15.86
330	Lighting Sys	2.54
340	Power Generation Support Sys	0.88
350	Special Purpose Sys	0.82
	300 Group Total	137.71

SWBS 400 – Command and Control

The 400 group includes all navigation and communications equipment aboard a ship. The values given in the following table are X-Craft based values with certain features omitted where applicable. Features omitted include search and passive sonar, as well as unnecessary data display capabilities.

Table 10: SWBS 400 Group

Group	Category	Weight (t)
410	Command and Control	0.15
420	Navigation Sys	2.59
430	Interior Communications	0.95
440	Exterior Communications	1.16
	400 Group Total	4.85

SWBS 500 – Auxiliary Systems

Most 500 group weights have been estimated by volume scaling from X-Craft except as follows. The 560 group includes the entire lift system, notably skirt weight to lift fans. These values were obtained through a review of various skirted vessels. The 540, and 570 through 590 groups are directly transferred from X-Craft, while the 530 group is scaled by the ratio of T-Craft and X-Craft personnel.

Table 11: SWBS 500 Group

Group	Category	Weight (t)
510	Climate Control	15.49
520	Sea Water Systems	1.69
530	Fresh Water Systems	0.13
540	Fuels/Lube, Hand. + Sto.	1.98
550	Air, Gas + Misc Fluid Sys	6.64
560	Ship Central Sys	7.23
570	Underway Rep. Sys	2.00
580	Mechanical Handling Sys	56.33
590	Special Purpose Sys	4.87
	500 Group Total	136.30

SWBS 600 – Outfit and Furnishing

All values for outfitting and furnishings have been obtained by scaling X-Craft data. For the 610 through 630 groups a volume scaling approach was taken. For group 640, a scaling factor on crew size was used.

Table 12: SWBS 600 Group

Group	Category	Weight t
610	Ship Fittings	2.54
620	Hull Compartmentation	12.46
630	Preservatives + Coverings	31.52
640	Living Spaces	5.06
650	Service Spaces	1.68
670	Stowage Spaces	0.13
	600 Group Total	53.40

Summary of Weight Estimates

The overall lightship weight of the T-Craft is 822 tonnes, including a 10% design & build margin. A 10% margin was used because it has previously been used for similarly advanced and unique ships designs, such as X-Craft. This margin may be pessimistic, as the X-Craft values used are the final (build) weight estimates. However, in its current stage of development, the degree of risk in the T-Craft concept is higher than that of the X-Craft.

The only significant variable load is a weight of water and fuel required is 162 t and the cargo as previously specified.

Stability Assessment

Static Stability

The Static Stability analysis was performed against the ABS Guide for Building and Classing High-Speed Naval Craft, 2007, 3-3-1, which incorporates the IMO international code of safety for High Speed Craft. The results of the static stability analysis are reported in Appendix F: Stability Analysis.

Results from the analysis indicate that this T-Craft concept meets the following applicable standards for Intact and Damaged Stability:

IMO A.749(18) Code on Intact Stability

- A.749(18) Code on Intact Stability,
    - Ch3 – Design criteria applicable to all ships
- SOLAS, II-1/8
- MSC.36 (63) HSC Code, Annex 7, Multihulls
    - HSC multi. Intact
    - HSC multi Damage

Seakeeping

The Naval Academy Hydrodynamics Laboratory (NAHL) has previously conducted Seakeeping model tests of the 12,000 LT HSSL SWATH. The test data indicated good motions qualities at high speeds. These tests indicate good performance at T-Craft size and speeds. Unfortunately, motions tests were not conducted at zero speed to assess performance during critical cargo transfer operations at the Sea Base. While the testing done to date is very encouraging for T-Craft, more extensive analyses are recommended for further development of the T-Craft design.

Risk Assessment and Management

Risk assessment is a major building block in the entire process of risk management. Risk assessment is important to reliably assume that systems will effectively operate. It is also critical when systems lack historical data, as in the T-Craft design. Risk engineering seeks to apply engineering analysis to eliminate and reduce hazards. Although a detailed risk assessment of the T-Craft was not performed, risk areas were noted as areas of uncertainties in planning, design, operation and maintenance arose. There are many risk control options, including designing out the risk, reducing the likelihood of the occurrence, transfer of the risk, and retain the risk. Table 13 lists the risks identified.

Table 13: Risk Management

Issue	Discussion	Class
Hinge	Conduct a trade-off study of various hinge designs.	High
Connectors	Conduct a detail design of locking pins, cables, and pulleys.	High
Actuators	Conduct a study of the uses of linear motors versus winches.	High
Sea Base Interface	Model the interaction of the SWATH hull and various platforms.	High
Track System	Based on M1A1 track system; design retractable mechanism.	Moderate
Structure	Complete a detailed structure design, while incorporating FEA.	Moderate
Control Systems	Integrate and automate all components involved in transition.	Moderate
Pumpjet	Technology to be further developed	Moderate
Ballast System	Integrate with the hinge, track, and lift fan systems.	Low
Skirt System	Based on hover barge system	Low

Section 4 – Conclusion

Project Summary

The objective of this project was to determine what parts, and to what degree, the student T-Craft concept could fulfill T-Craft BAA threshold requirements. This concept succeeded in completing the first iteration in the ship design spiral, as well as presenting alternatives while meeting the initial design constraints.

The T-Craft can travel 2,500 nm when moving at 25 knots, and has the capability to travel up to 6,570 nm when traveling at 20 knots. Using full-electric propulsion, the T-Craft will carry 384 tonnes of cargo during the open ocean transit and then carry a payload equal to seven M1A1 tanks during the high-speed sprint from the Sea Base to the shore.

Design Variations for Consideration

This SWATH design provides an excess amount of static stability. A trade-off study to assess the aspect of moving the power plant machinery (the three gas turbine/generator units) to an inline configuration on top of the arch structure should be completed. This will provide more available deck space and reduce the possible impact of heavy seas impinging on the machinery. Because the crew would only need to work primarily on the one deck level, it also allows for the possibility of further reduction in manning. This will result in integration of both the pilot house/bride and the powering machinery.

Recommendations for Future Work

The T-Craft concept team concluded that the original concept is feasible. Although several risk areas have been identified, efforts in the following areas should provide a successful design:

Mission Design Refinement
Finite Element Analysis
Detail Hinge Design
Hull Locking System
Retractable System for Track
Sea Base Interface
Ramp Deployment System
Auxiliary Control System
Seakeeping Analysis
Material Trade-Offs

References

[i]Amyot, J.R. Hovercraft Technology, Economics, and Applications. Amsterdam: Elsevier Science Publishers, 1989.

[ii]Arrington, Jess W. Naval Post Graduate School. The Analysis of Components, Designs, and Operation for Electric Propulsion and Integrated Electrical System. Sept. 1998.

[iii]Beaver, Bill. United States Naval Academy. Effective Horsepower and Seakeeping Tests on a High Speed Sealift (HSSL) SWATH Model. Mar. 2007.

[iv]Brown, Alan and Thomas Laverghetta. "Dynamics of Naval Design: A Systems Approach." Naval Engineers Journal, Vol 111 (1999): 307-324.

[v] Gritter, David et. al. United States Office of Naval Research. Variable Speed Electric Drive Options for Electric Ships.

[vi] Levedahl, William J. United States Department of the Navy, Office of Naval Research. Integrated Electrical Power Supply System for Propulsion and Service Control. 16 Aug. 1996.

[vii] Marshall, R.A. et. al. General Electric. Conceptual Study of Permanent Magnet Machine Ship Propulsion Systems. 31 Oct. 1977.

[viii] Taylor, Robert G. Morristown Fire Bureau. Compressed Air Foam Systems in Limited Staffing Conditions. Dec. 1997.

[ix]Terry, T.W. et. al. "Land Warfare: Brassey's New Battlefield Weapons Systems and Technology Series." Fighting Vehicles. Vol. 7. London: Brassey's. 1994.

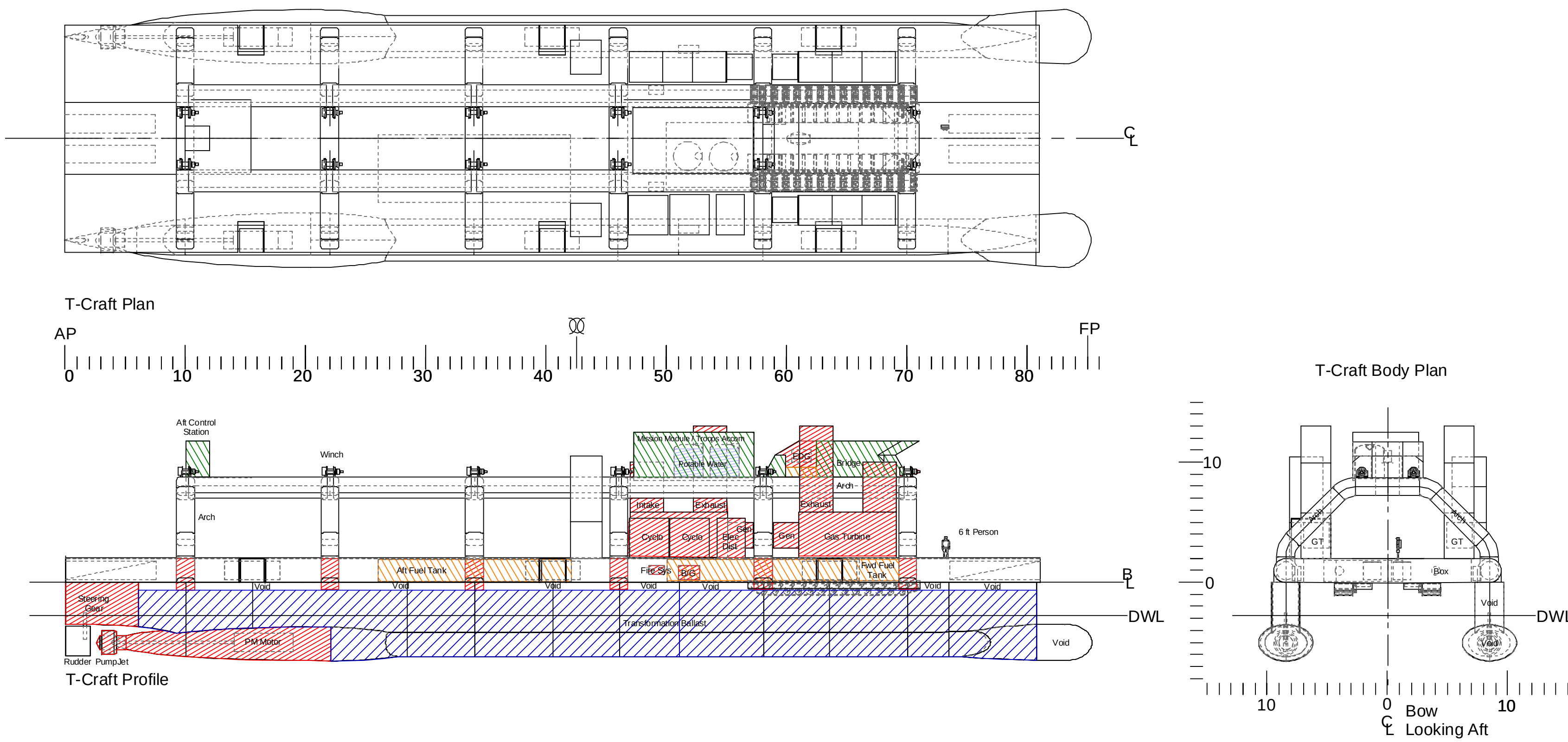
[x]United States Army. Belvoir RD&E Center. Amphibious Vehicle Technology Development for U.S. Army Amphibious Air Cushion Vehicle — Final Report. Contract No. DAAK70-92-C-0055. July 1993.

[xi]"Proceedings of the Thirteenth Canadian Symposium on Air Cushion Technology", September 1979, Air Cushion Technology Society, Canadian Aeronautics and Space Institute, Ottawa, Canada.

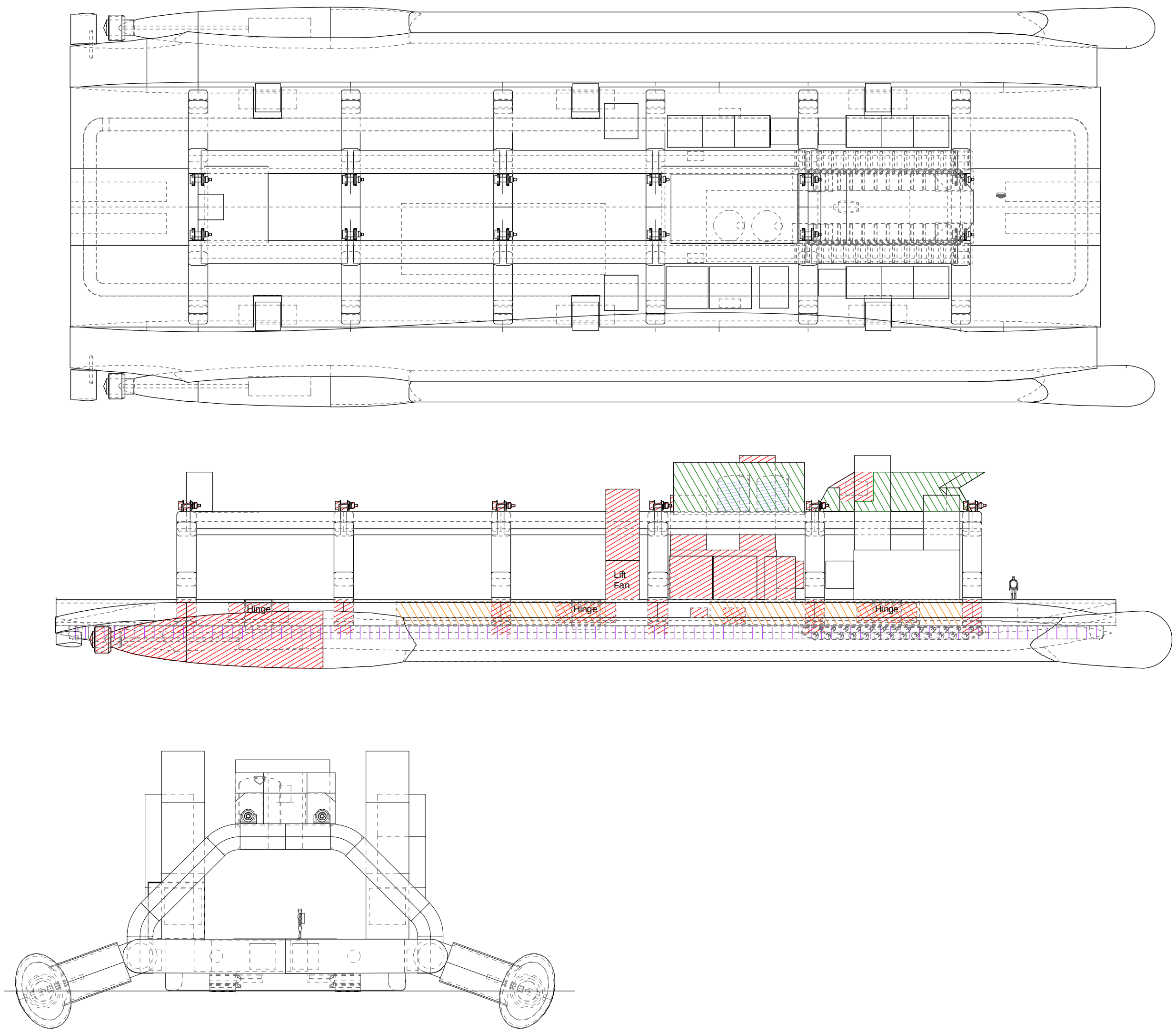
[xii]"Stability and Strength." Principles of Naval Architecture. Vol. 1. Jersey City: The Society of Naval Architects and Marine Engineers, 1988.

Appendix A: General Arrangements

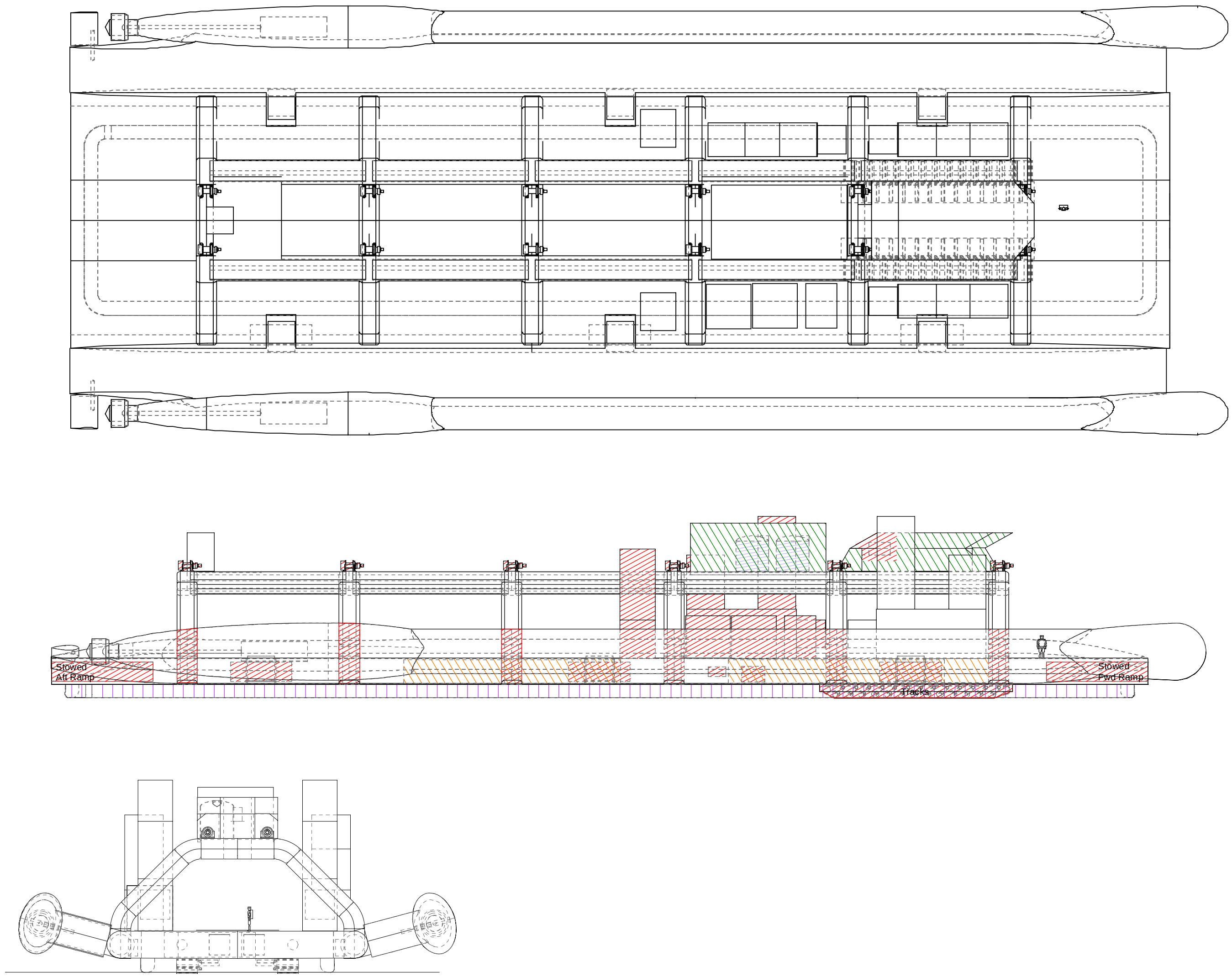
A-1 Offshore



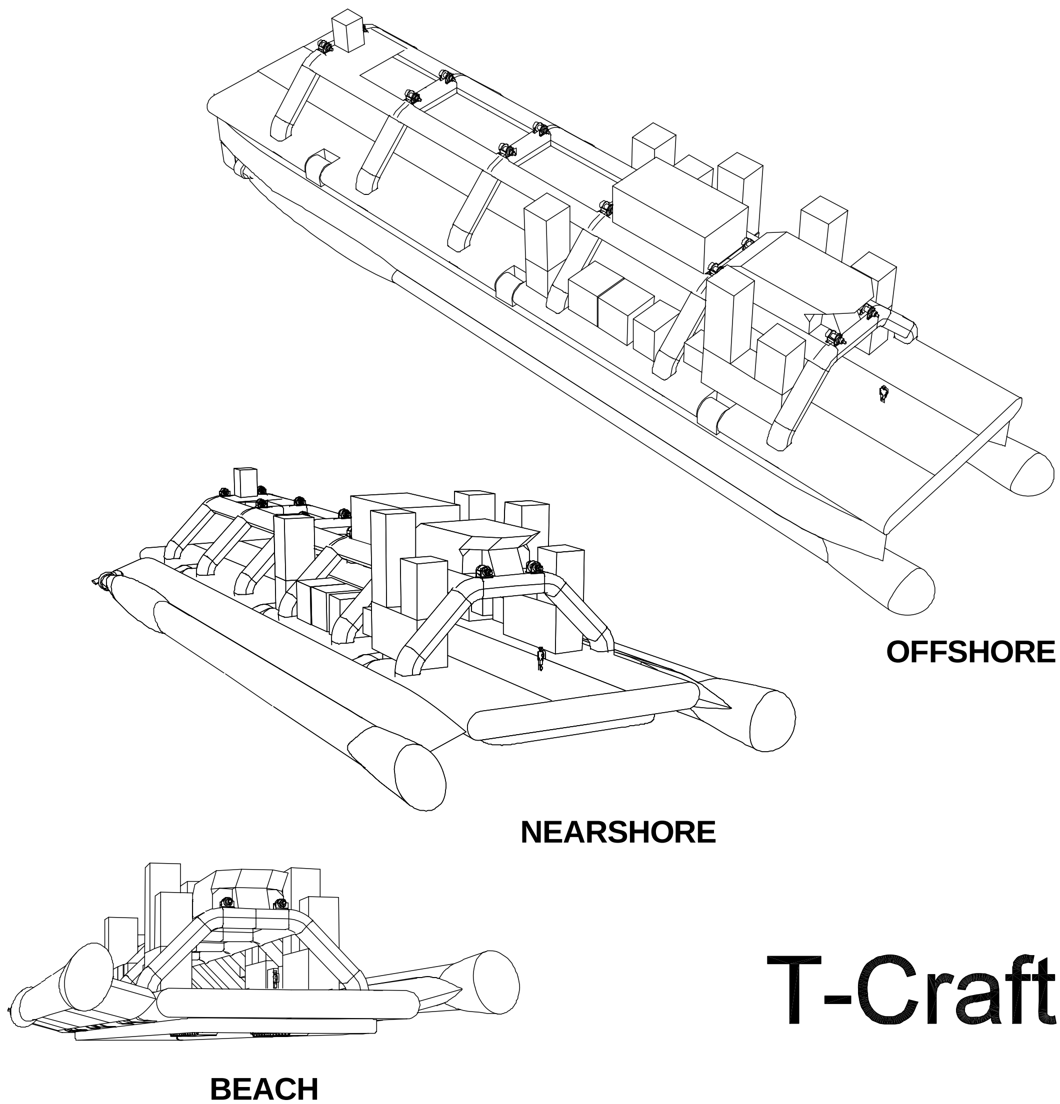
A-2 Nearshore



A-3 Beach



Appendix B: 3-Dimensional Views



Appendix C: SWBS Weight Estimates

Table A - 1: 100 HULL STRUCTURES

	Weight (t)			
	T-Craft		X-Craft	
	82.67		188.72	
110 SHELL + SUPPORTS	134.79		207.37	
111 PLATING		88.83		136.66
113 INNER BOTTOM				
114 SHELL APPENDAGES		2.64		4.07
115 STANCHIONS				
116 LONGIT FRAMING		12.74		19.60
117 TRANSV FRAMING		30.58		47.04
120 HULL STRUCTURAL BULKHDS	20.00		0.00	
121 LONGIT STRUCTURAL BULKHDS				
122 TRANSV STRUCTURAL BULKHDS		20.00		
123 TRUNKS + ENCLOSURES				
124 BULKHEADS, TORPEDO PROTECT SYS				
130 HULL DECKS	40.00		0.00	
131 MAIN DECK		40.00		
132 2ND DECK				
133 3RD DECK				
134 4TH DECK				
135 5TH DECK+DECKS BELOW				
136 01 HULL DECK				
137 02 HULL DECK				
138 03 HULL DECK				
139 04 HULL DECK				
140 HULL PLATFORMS/FLATS	0.00		0.00	
141 1ST PLATFORM				
142 2ND PLATFORM				
143 3RD PLATFORM				
144 4TH PLATFORM				
145 5TH PLAT+PLATS BELOW				
149 FLATS				
150 DECK HOUSE STRUCTURE	7.90		142.17	
151 DECKHOUSE STRUCT. TO FIRST LEVEL				
152 1ST DECKHOUSE LEVEL		7.90		137.50
153 2ND DECKHOUSE LEVEL				
154 3RD DECKHOUSE LEVEL				4.67
155 4TH DECKHOUSE LEVEL				

156 5TH DECKHOUSE LEVEL				
157 6TH DECKHOUSE LEVEL				
158 7TH DECKHOUSE LEVEL				
159 8TH DECKHOUSE LEVEL				
160 SPECIAL STRUCTURES	0.00		4.75	
161 CASTINGS+FORGINGS+EQUIV WELDMT				
162 STACKS AND MACKS				
163 SEA CHESTS				
164 BALLISTIC PLATING				
165 SONAR DOMES				
166 SPONSONS				
167 HULL STRUCTURAL CLOSURES				4.75
168 DKHS STRUCTURAL CLOSURES				
169 SPECIAL PURPOSE CLOSURES+STRUCT				
170 MASTS+KINGPOSTS+SERV PLATFORM	0.05		0.05	
171 MASTS,TOWERS,TETRAPODS		0.05		0.05
172 KINGPOSTS AND SUPPORT FRAMES				
179 SERVICE PLATFORMS				
180 FOUNDATIONS	2.42		3.72	
181 HULL STRUCTURE FOUNDATIONS		2.42		3.72
182 PROPULSION PLANT FOUNDATIONS				
183 ELECTRIC PLANT FOUNDATIONS				
184 COMMAND+SURVEILLANCE FDNS				
185 AUXILIARY SYSTEMS FOUNDATIONS				0.00
186 OUTFIT+FURNISHINGS FOUNDATIONS				
187 ARMAMENT FOUNDATIONS				
190 SPECIAL PURPOSE SYSTEMS	12.31		38.04	
191 BALLAST+BOUYANCY UNITS				
196 MILL TOLERANCE				
197 WELDING AND RIVETS (6%)		12.31		
198 FREE FLOODING LIQUIDS				38.04
199 HULL REPAIR PARTS+SPEACIAL TOOLS				

Table A - 2: 200 PROPULSION PLANT

	Weights (t)			
	T-Craft		X-Craft	
	197.44		239.25	
230 PROPULSION UNITS	98.00		64.20	
233 DIESEL ENGINES				29.28
234 GAS TURBINES				34.92
235 ELECTRIC PROPULSION (PM motors)		43.00		
236 SELF-CONTAINED PROPULSION SYS				
237 AUXILIARY PROPULSION DEVICES		55.00		
240 TRANSMISSION+PROPULSOR SYSTEMS	59.87		116.30	
241 REDUCTION GEARS				51.40
242 CLUTCHES + COUPLINGS				2.32
243 SHAFTING		5.87		5.87
244 SHAFT BEARINGS				0.00
245 PROPULSORS				
246 PROPULSOR SHROUDS AND DUCTS				
247 WATER JET PROPULSORS (pumpjet)		54.00		56.71
250 SUPPORT SYSTEMS	21.17		34.96	
251 COMBUSTION AIR SYSTEM		3.57		3.57
252 PROPULSION CONTROL SYSTEM		3.05		3.05
253 MAIN STEAM PIPING SYSTEM				
254 CONDENSERS AND AIR EJECTORS				
255 FEED AND CONDENSATE SYSTEM				
256 CIRC + COOL SEA WATER SYSTEM				5.96
258 H.P. STEAM DRAIN SYSTEM				
259 UPTAKES (INNER CASING)		14.55		22.38
260 PROPUL SUP SYS- FUEL, LUBE OIL	9.90		13.31	
261 FUEL SERVICE SYSTEM		9.90		9.90
262 MAIN PROPULSION LUBE OIL SYSTEM				
264 LUBE OIL HANDLING				3.41

290 SPECIAL PURPOSE SYSTEMS	8.50		10.48	
296 PROPULSION PLANT OP FLUIDS (4.5%)		8.50		10.48
298 OPERATING FLUIDS				
299 REPAIR PARTS + TOOLS				

Table A - 3: 300 ELECTRIC PLANT

	Weights (t)			
	T-Craft		X-Craft	
	137.71		45.87	
310 ELECTRIC POWER GENERATION	117.60		16.38	
311 SHIP SERVICE POWER GENERATION		111.00		12.13
312 EMERGENCY GENERATORS		2.60		
313 BATTERIES+SERVICE FACILITIES				2.19
314 POWER CONVERSION EQUIPMENT		4.00		2.06
320 POWER DISTRIBUTION SYS	15.86		24.41	
321 SHIP SERVICE POWER CABLE		13.64		20.99
322 EMERGENCY POWER CABLE SYS				
323 CASUALTY POWER CABLE SYS				
324 SWITCHGEAR+PANELS		2.22		3.42
330 LIGHTING SYSTEM	2.54		3.91	
331 LIGHTING DISTRIBUTION		0.10		0.15
332 LIGHTING FIXTURES		2.44		3.76
340 POWER GENERATION SUPPORT SYS	0.88		0.88	
341 SSTG LUBE OIL				
342 DIESEL SUPPORT SYS		0.00		0.88
343 TURBINE SUPPORT SYS		0.88		
390 SPECIAL PURPOSE SYS	0.82		0.30	
396 ELECTRIC PLANT OP FLUIDS (.6%)		0.82		0.30
399 REPAIR PARTS+SPECIAL TOOLS				

Table A - 4: 400 COMMAND AND SURVEILLANCE

	Weights (t)			
	T-Craft		X-Craft	
	4.85		8.29	
410 COMMAND & CONTROL	0.15		3.23	
411 DATA DISPLAY GROUP				2.04
412 DATA PROCESSING GROUP				0.55
413 DIGITAL DATA SWITCHBOARDS				0.05
414 INTERFACE EQUIPMENT				0.44
415 DIGITAL DATA COMMUNICATIONS		0.15		0.15
420 NAVIGATION SYSTEMS	2.59		2.59	
422 ELECTRICAL NAVIGATION AIDS		2.54		2.54
426 ELECTRICAL NAVIGATION SYSTEMS		0.05		0.05
430 INTERIOR COMMUNICATIONS	0.95		0.95	0.75
432 TELEPHONE SYSTEMS		0.20		0.20
440 EXTERIOR COMMUNICATIONS	1.16		1.16	0.99
441 RADIO SYSTEMS		0.17		0.17
450 SURVEILLANCE SYSTEMS	0.00		0.25	
451 SURFACE SEARCH RADAR				0.25
460 SURVEILLANCE SYSTEMS (UW)	0.00		0.11	
462 PASSIVE SONAR				0.11

Table A - 5: 500 AUXILIARY SYSTEMS, GENERAL

	Weights (t)			
	T-Craft		X-Craft	
	136.30		171.82	
506 OVERFLOWS, AIR ESC, AND SOUNDING TUBES				7.10
510 CLIMATE CONTROL	15.49		24.86	
511 COMPARTMENT HEATING SYSTEM				
512 VENTILATION SYSTEM		1.50		1.40
513 MACHINERY SPACE VENT SYSTEM		2.70		4.20
514 AIR CONDITIONING SYSTEM		10.60		18.20
516 REFRIGERATION SYSTEM		0.69		1.06
517 AUX BOILERS+OTHER HEAT SOURCES				
520 SEA WATER SYSTEMS	1.69		12.89	
521 FIREMAIN+SEA WATER FLUSHING SYS				3.88
522 SPRINKLING SYSTEM				2.09
523 WASHDOWN SYSTEM				0.26
524 AUXILIARY SEAWATER SYSTEM				1.79
526 SCUPPERS+DECK DRAINS				1.64
527 FIREMAIN ACTUATED SERV, OTHER				
528 PLUMBING DRAINAGE				1.54
529 DRAINAGE+BALLASTING SYSTEM		1.69		1.69
530 FRESH WATER SYSTEMS	0.13		0.62	
531 DISTILLING PLANT				0.42
532 COOLING WATER				
533 POTABLE WATER		0.13		0.20
534 AUX STEAM + DRAINS IN MACH BOX				
535 AUX STEAM + DRAINS OUT MACH BOX				
536 AUXILIARY FRESH WATER COOLING				
540 FUELS/LUBRICANTS,HANDLING+STORAGE	1.98		4.63	
541 SHIP FUEL+COMPENSATING SYSTEM		1.98		
542 AVIATION+GENERAL PURPOSE FUELS				4.63
543 AVIATION+GENERAL PURPOSE LUBO				
544 LIQUID CARGO				
545 TANK HEATING				
546 AUXILIARY LUBE SYS				
549 SPEC FUEL+LUBRICANTS HANDL+STOW				
550 AIR,GAS+MISC FLUID SYSTEM	6.60		26.72	
551 COMPRESSED AIR SYSTEMS		3.50		9.25
552 COMPRESSED GASES				
553 O2 N2 SYSTEM				
554 LP BLOW				

555 FIRE EXTINGUISHING SYSTEMS		3.10		3.36
556 HYDRAULIC FLUID SYSTEM				14.11
557 LIQUID GASES, CARGO				
558 SPECIAL PIPING SYSTEMS				
560 SHIP CNTL SYS	47.23		8.55	
561 STEERING+DIVING CNTL SYS		0.20		0.20
562 RUDDER		2.54		2.54
565 TRIM+HEEL SYSTEMS				
567 LIFT SYSTEMS		44.50		5.82
568 MANEUVERING SYSTEMS				
570 UNDERWAY REPLENISHMENT SYSTEMS	2.00		33.04	
571 REPLENISHMENT-AT-SEA SYSTEMS				
572 SHIP STORES+EQUIP HANDLING SYS				31.71
573 CARGO HANDLING SYSTEMS				
574 VERTICAL REPLENISHMENT SYSTEMS				
575 VEHICLE HANDLING+STOWAGE SYSTEMS		2.00		1.33
580 MECHANICAL HANDLING SYSTEMS	56.33		47.70	
581 ANCHOR HANDLING+STOWAGE SYSTEMS		5.52		11.05
582 MOORING+TOWING SYSTEMS		3.67		3.67
583 BOATS,HANDLING+STOWAGE SYSTEMS		4.54		4.54
584 MECH OPER DOOR,GATE,RAMP,TTBL SYS		24.12		24.12
585 ELEVATING + RETRACTING GEAR		18.48		4.33
586 AIRCRAFT RECOVERY SUPPORT SYS				
587 AIRCRAFT LAUNCH SUPPORT SYSTEM				
588 AIRCRAFT HANDLING,SERVICE,STOWAGE				
589 MISC MECH HANDLING SYSTEMS				
590 SPECIAL PURPOSE SYSTEMS	4.85		5.69	
591 SCIENTIFIC+OCEAN ENGINEERING SYS				
592 SWIMMER+DIVER SUPPORT+PROT SYS				
593 ENVIRONMENTAL POLLUTION CNTL SYS		0.90		0.90
594 SUBMARINE RESC+SALVG+SURVIVE SYS				
595 TOW,LAUNCH,HANDLE UNDERWATER SYS				
596 HANDLING SYS FOR DIVER+SUBMR VEH				
597 SALVAGE SUPPORT SYSTEMS				
598 AUX SYSTEMS OPERATING FLUIDS (3%)		3.94		4.79
599 AUX SYSTEMS REPAIR PARTS+TOOLS				

Table A - 6: 600 OUTFIT AND FURNISHING

	Weights (t)			
	T-Craft		X-Craft	
	53.40		81.73	
610 SHIP FITTINGS	2.55		3.49	
611 HULL FITTINGS				
612 RAILS,STANCHIONS+LIFELINES		2.55		3.49
613 RIGGING+CANVAS				
620 HULL COMPARTMENTATION	12.46		21.24	
621 NON-STRUCTURAL BULKHEADS		5.87		9.03
622 FLOOR PLATES+GRATING		1.66		2.55
623 LADDERS		0.95		1.46
624 NON-STRUCTURAL CLOSURES		3.99		6.14
625 AIRPORTS,FIXED PORTLTS, WNDOS				2.06
630 PRESERVATIVES+COVERINGS	31.53		44.34	
631 PAINTING		3.98		6.12
632 ZINC COATING				
633 CATHODIC PROTECTION				0.25
634 DECK COVERINGS		2.87		0.00
635 HULL INSULATION		24.68		37.97
636 HULL DAMPING				
637 SHEATHING				
638 REFRIGERATION SPACES				
639 RADIATION SHIELDING				
640 LIVING SPACES	5.06		8.09	
641 OFFICER BERTHING+MESSING		1.59		2.54
642 NON-COMM OFFICER B+M		0.43		0.69
643 ENLISTED PERSONNEL B+M		2.44		3.90
644 SANITARY SPACES+FIXTURES		0.60		0.96
645 LEISURE+COMMUNITY SPACES				
650 SERVICE SPACES	1.68		1.68	
651 COMMISSARY SPACES		0.98		0.98
652 MEDICAL SPACES		0.37		0.37
653 DENTAL SPACES				
654 UTILITY SPACES				
655 LAUNDRY SPACES		0.33		0.33
656 TRASH DISPOSAL SPACES				
660 WORKING SPACES	0.00		2.77	2.52
661 OFFICES				
662 MACH CNTL CENTER FURNISHING				0.25
663 ELECT CNTL CENTER				

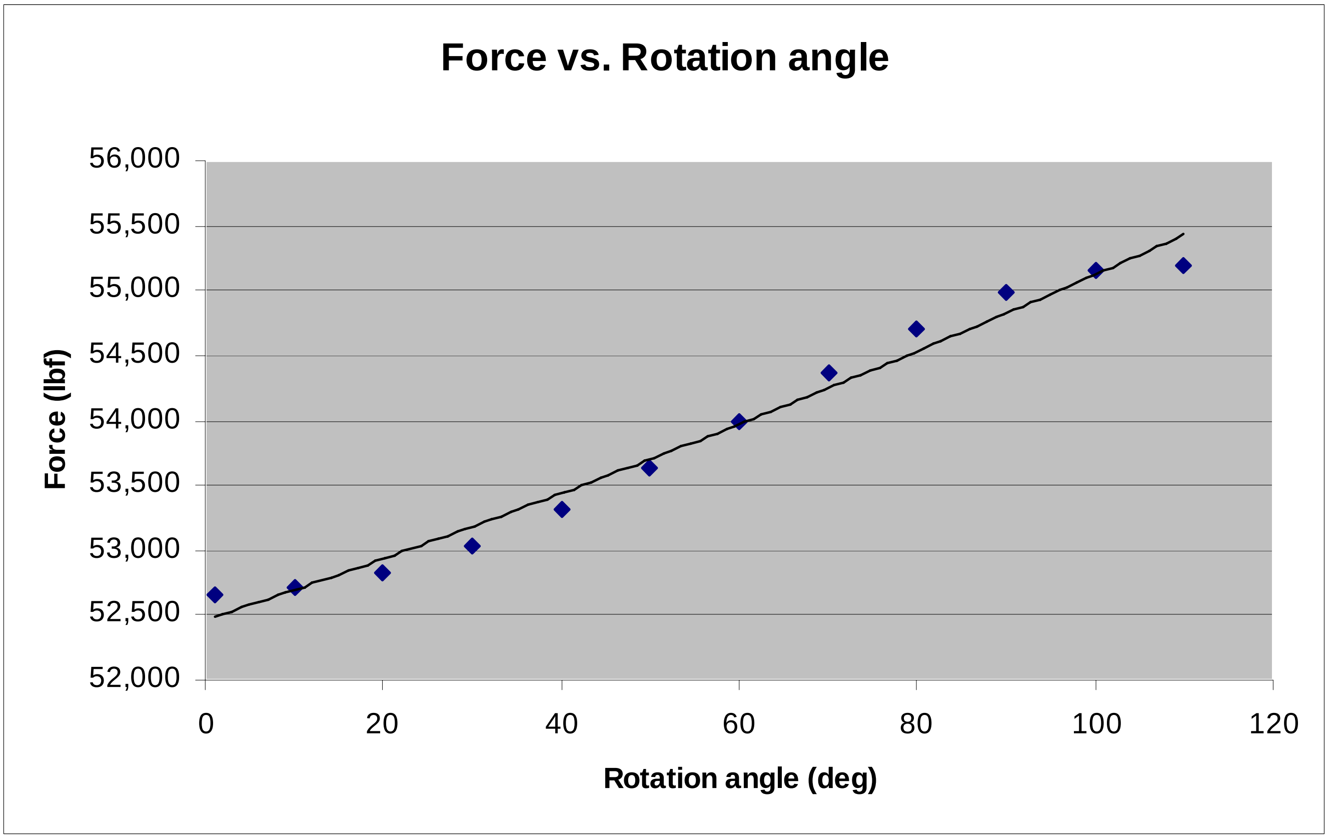
FURNISHING				
664 DAMAGE CNTL STATIONS				
665 WORKSHOPS,LABS,TEST AREAS				
670 STOWAGE SPACES	0.13		0.13	
671 LOCKERS+SPECIAL STOWAGE				
672 STOREROOMS+ISSUE ROOMS		0.13		0.13
673 CARGO STOWAGE				
690 SPECIAL PURPOSE SYSTEMS	0.00		0.00	
698 OPERATING FLUIDS				
699 REPAIR PARTS+SPECIAL TOOLS				

Appendix D: Rotating Hull and Ramp Analyses

q	0	1	10	20	30	40	50	60	70	80	90	100	110
ω	0	0.23	2.30	4.58	6.79	8.91	10.91	12.73	14.34	15.69	16.70	17.31	17.44
y	13	13.00	12.95	12.82	12.60	12.30	11.93	11.50	11.03	10.52	10.00	9.48	8.97
x1	0	0.08	0.75	1.47	2.15	2.76	3.29	3.72	4.04	4.23	4.30	4.23	4.04
x2	0	0.05	0.52	1.03	1.50	1.93	2.30	2.60	2.82	2.95	3.00	2.95	2.82

Weight (t)	100	100	100	100	100	100	100	100	100	100	100	100	100
Normal Force (t)	0	143.33	143.33	143.33	143.33	143.33	143.33	143.33	143.33	143.33	143.33	143.33	143.33
Tension (t)	0	143.33	143.45	143.79	144.35	145.08	145.97	146.95	147.94	148.88	149.64	150.13	150.24

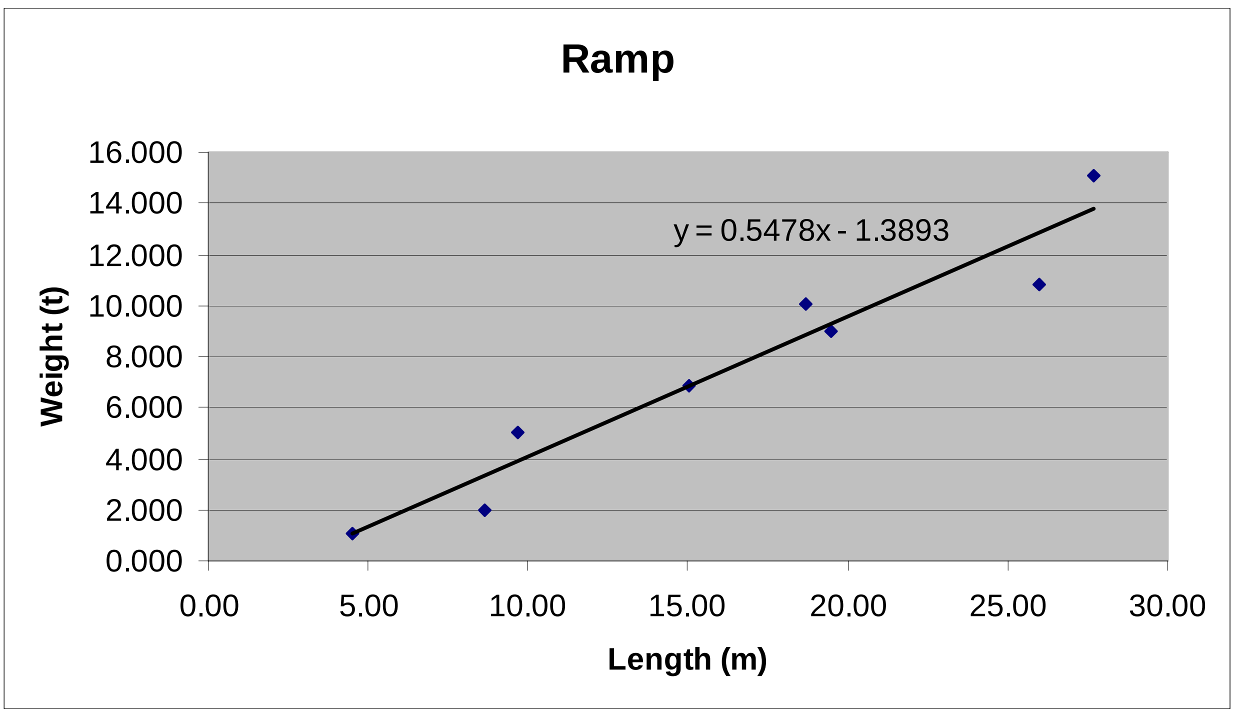
Tension in Each Arch		Number of Arches: 6											
Tonnes	0	23.89	23.91	23.97	24.06	24.18	24.33	24.49	24.66	24.81	24.94	25.02	25.
kilo-Newtons	0	234.35	234.54	235.10	236.01	237.21	238.66	240.26	241.89	243.41	244.67	245.47	24
Pounds	0	52,663.35	52,705.49	52,831.35	53,034.90	53,306.39	53,631.40	53,990.15	54,356.94	54,699.93	54,981.70	55,161.58	55,


Force vs. Rotation angle
56,000
55,500
55,000
54,500
54,000
53,500
53,000
52,500
52,000
Force (lbf)
0
20
40
60
80
100
120
Rotation angle (deg)

Ramp Analysis

Table A - 7: Scaled Ramp Data

	L (m)	W (MT)	MLC	Width (m)
LCAC stern	4.50	1.101	70	
LCAC bow	8.634	1.988	70	
PSB 2-1	9.700	5.040	70	4.00
T-Craft	15.00	6.828		
PSB 2-2	18.70	10.08	70	4.00
PAR-70	19.50	9.00	70	4.00
Leguan	26.00	10.80	70	4.01
PSB 2-3	27.70	15.12	70	4.00



Appendix E: T-Craft Air Cushion & Traction Calculations

Air Cushion

Hovering at rest:

L = cushion length
B = cushion breadth
Pc = cushion pressure
S = cushion area
h = cushion air gap

Total weight, W = Pc S
Cushion flow, $Q = 2(L + B)\ h\ (2\ Pc / \rho)^{1/2}$
Lift power, $P_L = Pc\ Q$

Air Density, $\rho = 1.2250\ kg/m^3$

INITIAL
L = 80 m
B = 20 m

L/B = 4

$Pc = W / S = [\ 1500\ tonne \times (1000\ kg / tonne) \times 9.81\ m/s^2\ ] / (\ 80m \times 20m\ ) = 9187.5\ N/m^2 = 1.33\ psi$

$Pc/L = 9187.5\ N/m^2 / 80\ m = 114.8\ N/m^3$

$h/L = 0.014\ W^{-1/3} = 0.014\ (1500)^{-1/3} = 1.22x10^{-3}$

$h = 1.22x10^{-3}\ (80m) = 0.0976\ m$

$Q = 2(80m + 20m)\ (0.0976\ m)\ [\ 2\ (9187.5\ N/m^2) / 1.2250\ kg/m^3\ ]^{1/2} = 2390\ m^3/s$

$P_L = (9187.5\ N/m^2)(2390\ m^3/s) = 21.965\ MW \Rightarrow 22\ MW$

FINAL
L = 80 m
B = 14 m
h = 0.023 m (from LCAC)

Air Cushion Only Supporting Total Weight

Pc = 13138 N/m^2 = 13.14 kPa ≈ 1.9 psi

$Q = 2(80m + 20m)\ (0.023\ m)\ [\ 2\ (13138\ N/m^2)\ /\ 1.2250\ kg/m^3\ ]^{1/2} = 633.3\ m^3/s$

Lift power, $P_L = Pc\ Q = (13138\ N/m^2)(633.3\ m^3/s) = 8.32\ MW$

Air Cushion & Caterpillar Tracks Supporting Total Weight

Pc = 1.85 psi = 12760 N/m^2 = 12.76 kPa (from air cushion combined with traction calculations)

$Q = 2(80m + 20m)\ (0.0976\ m)\ [\ 2\ (12760\ N/m^2)\ /\ 1.2250\ kg/m^3\ ]^{1/2} = 624.1\ m^3/s$

$P_L = Pc\ Q = (12760\ N/m^2)(2390\ m^3/s) = 7.96\ MW$

Add 20% margin: max(8.32,7.96)*1.20 = 9.98 => Required Lift Power, P_L = 10 MW

Traction Calculations

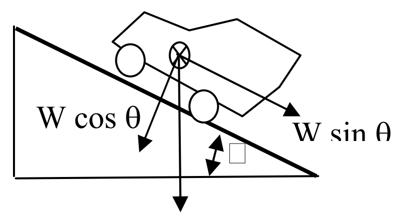
Reference: Fighting Vehicles, by Terry, et.al., © 1991, Brassey's (UK) Ltd.
Tank track resistance is 3X truck resistance
Nominal Ground Pressure (NGP) = Vehicle Weight / Area in contact with ground (FV p.177)

Resistance to Motion (FV p.184)

rolling resistance
- wheeled vehicles: 2% to 2.5% of weight
- tracked vehicles: 4% to 5% of weight

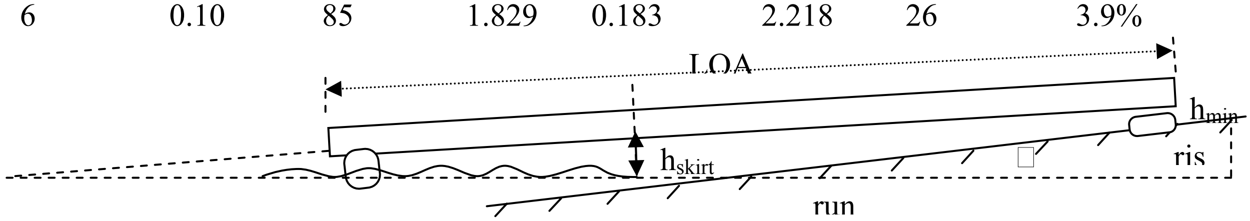
air resistance
- negligible at low speeds

gradient resistance
- W sin θ



T-Craft Slope Limits

skirt height (ft)	min skirt height factor ($h_{skirt_{min}}$,ft)	LOA (m)	skirt height (h_{skirt}, m)	min skirt height ($h_{skirtmin}$,m)	max slope (θ, deg)	max gradient (1 in *run*)	% grade
1	0.20	85	0.305	0.061	0.329	174	0.6%
2	0.18	85	0.610	0.110	0.674	85	1.2%
3	0.14	85	0.914	0.128	1.060	54	1.9%
3.28	0.14	85	1.000	0.140	1.159	49	2.0%
4	0.12	85	1.219	0.146	1.446	40	2.5%
5	0.10	85	1.524	0.152	1.848	31	3.2%
6	0.10	85	1.829	0.183	2.218	26	3.9%

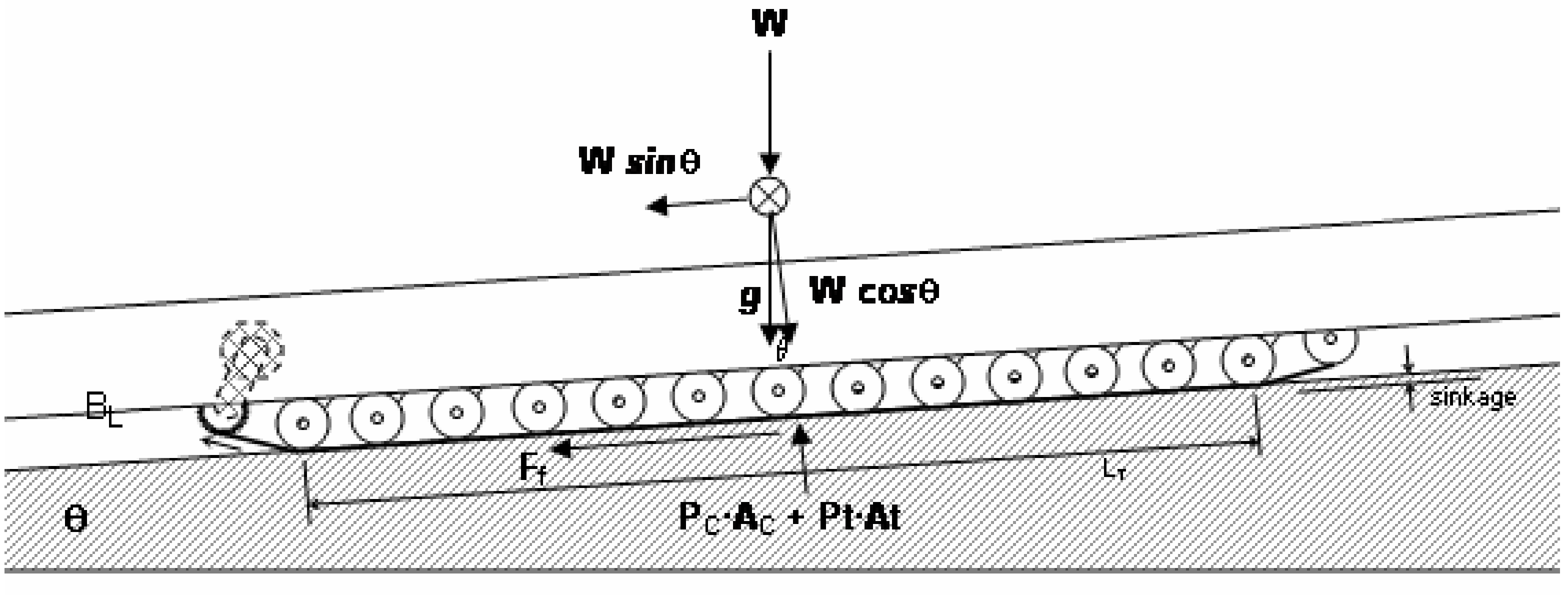


Displacement (tonnes)	Weight W (N)	Grade	Slope Angle (θ, deg)	Cushion Nominal Ground Pressure P_C (psi)	P_C (kPa)	Cushion Length L_c (m)	Cushion Width W_C (m)	Cushion Area A_C (m^2)	Track Nominal Ground Pressure Pt (psi)
1500	14708250	2%	1.146	1.85	12.76	80	14	1120	1.85

Pt (kPa)	Track Footprint Area A_T (m^2)	Num Tracks	Track Width W_T (m)	Track Length L_T (m)	Track Supported Weight Fraction	Supported Displacement (tonnes)	Supported Weight (N)	Turning Ratio (L/C) [1.5-1.8]	Distance Track Centers (m)
12.76	32.9	2	1.5	11.0	2.9%	43	419355	1.5	7.3

Road Wheel Diameter (m)	Road Wheel Stride Factor	Num Road Wheels	Drive Sprocket Diameter (m)	Idler Diameter (m)	Top Roller Diameter (m)	Num Top Rollers (located btw road wheels)	Approx. Track Circumference (m)	Track Mass / Area (kg/m^2)	Track Mass (kg)
0.548	1.75	13	1.0	0.5	0.15	6	40.2	200	12053

Wheel, Roller, Sprocket, Idler Material Density (kg/m3)	Idler Wheel Volume (m3)	Road Wheel Mass (kg)	Drive Sprocket Mass (kg)	Idler Mass (kg)	Top Roller Mass (kg)	Torsion Arm Mass (kg)	Track, Wheels, Rollers, Torsion Arms Mass (kg)	Track, Wheels, Rollers, Torsion Arms LCG (m)	Track, Wheels, Rollers, Torsion Arms VCG (m)	Track Motor & Gear Mass (kg)	Track Motor & Gear LCG (m)	Track Motor & Gear VCG (m)
2700	0.8060	251	342	228	38	200	37384	42.5	-0.6	000	35.71	0.30



Resistance (tonnes)	Force (N)	Speed (mph)	Speed (kph)	Speed (m/s)	Linear Distance (m)	Slippage (%)	Time (s)	Power (MW)	Power (hp)
30	294,241	5	8.0	2.235	40.176	5%	17.974	0.7	926
30	294,241	10	16.1	4.470	40.176	5%	8.987	1.4	1852
30	294,241	15	24.1	6.706	40.176	5%	5.991	2.1	2778

Total Traction System Mass (tonnes)	LCG (m) [from stern]	TCG (m)	VCG (m) [from BL]
55	40.29	0	-0.307

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Appendix F: Stability Analysis

The T-Craft concept 3D model was originally created in the Rhinoceros v3 solid modeling package. The authors were instructed to use the Hydromax v11 software to perform the stability analysis. The demi-hulls and main box were recreated within the MaxSurf v11 modeler as trimmed NURBS surfaces and imported into Hydromax for analysis. The recreation of the model was necessary because the installed version of MaxSurf did not support importing of trimmed IGES NURBS surfaces from Rhino 3 models (later versions of MaxSurf are reported to support the required IGES entity types.) Due to the challenge of recreating the somewhat complex shapes of the demi-hulls without access to the Pre-Fit add-on for MaxSurf, there is likely to be a fairly significant amount of difference between the Rhino and MaxSurf surface models of the demi-hulls. Also, as much of the auxiliary equipment was scaled from another vessel without benefit of information about the equipment's center of gravity information, a significant amount of extra weight representing this was added about an assumed consolidated center of gravity. Likewise, structure above the main deck was not modeled in MaxSurf/Hydromax due to time constraints and the primitive MaxSurf user interface. The cumulative effect of these assumptions leads to the possibility of a significant amount of error being introduced into the inputs to the stability calculations, thus the authors caution readers to take this into account when reviewing the static stability results.

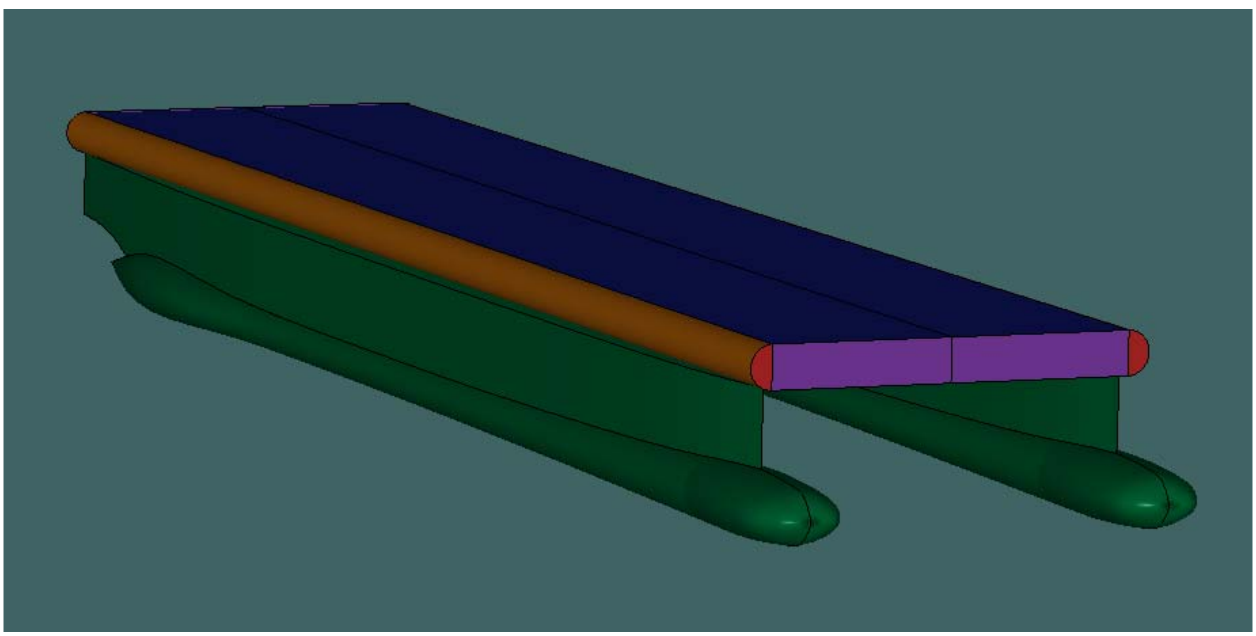

Figure A-18 MaxSurf shaded surface model in Hydromax

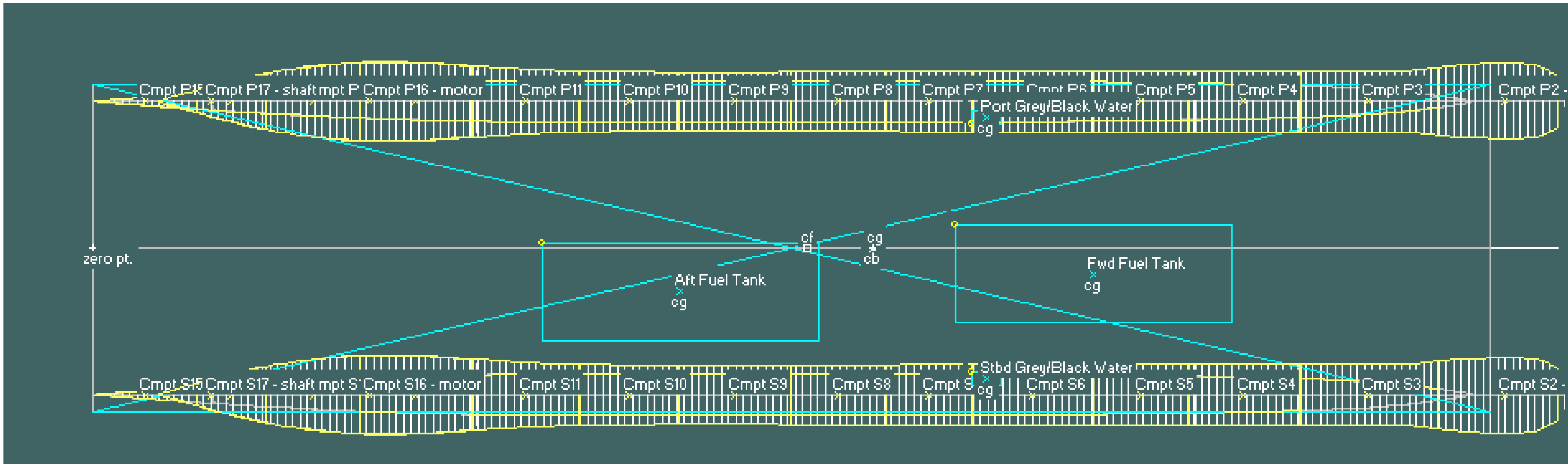

Figure A-19 Hydromax Plan - Tanks & Compartments – Fully Loaded Equilibrium Condition

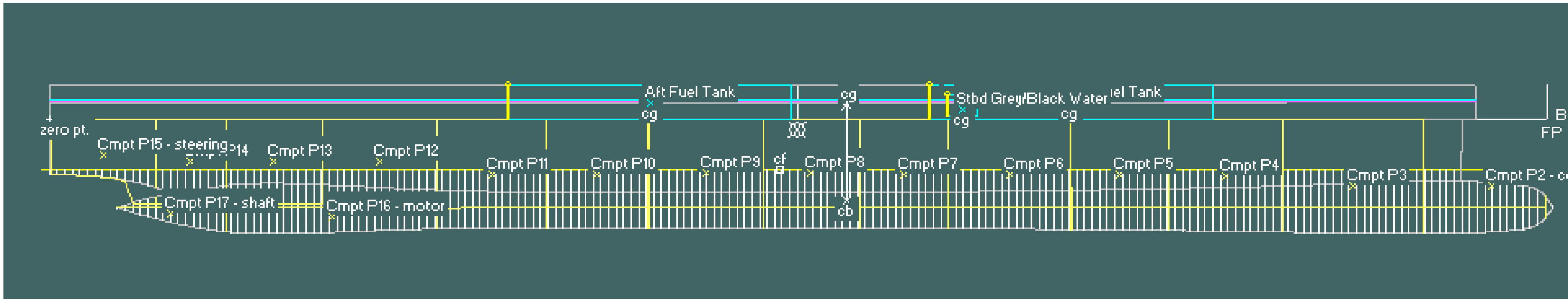

Figure A-20 Hydromax Profile - Tanks & Compartments – Fully Loaded Equilibrium Condition[1]

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[1] Note: Compartments 2 thru 11 are full height of demi-hull.

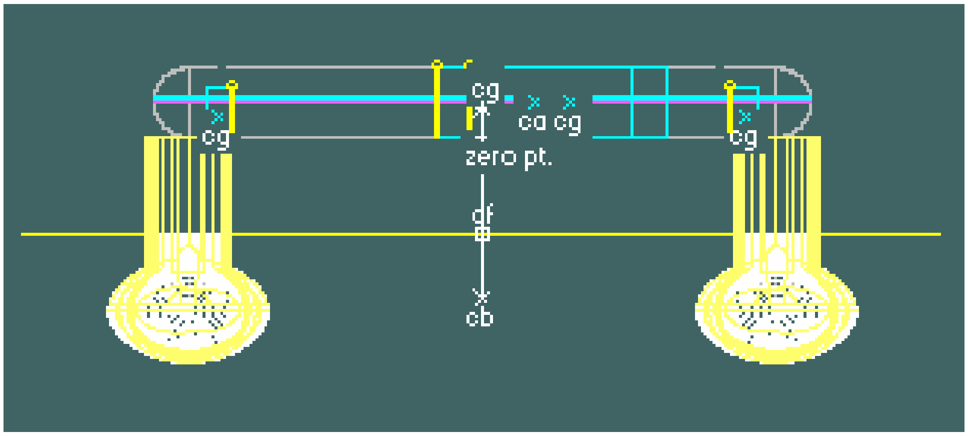


Figure A-21 Hydromax Body Plan - Tanks & Compartments – Fully Loaded Equilibrium Condition

Table A-7 Fully Loaded Condition - Weights & Centers

Item Name	Quantity	Weight tonne	Long.Arm m	Vert.Arm m	Trans.Arm m	FS Mom. tonne.m	FSM Type
Lightship	1	751.0	42.600	0.500	0.000	0.000	
Fwd Fuel Tank	98.6%	141.0	58.000	0.986	1.500	0.000	Maximum
Aft Fuel Tank	0%	0.0000	34.100	1.000	2.500	0.000	Maximum
Port Grey/Black Water	61.36%	0.8000	51.850	0.568	-7.550	0.044	Maximum
Stbd Grey/Black Water	61.36%	0.8000	51.850	0.568	7.550	0.044	Maximum
Abrams Tank 1	1	70.00	11.500	1.500	0.000	0.000	
Abrams Tank 2	1	70.00	21.500	1.500	0.000	0.000	
Abrams Tank 3	1	70.00	31.500	1.500	0.000	0.000	
Abrams Tank 4	1	70.00	41.500	1.500	0.000	0.000	
Abrams Tank 5	1	70.00	51.500	1.500	0.000	0.000	
Abrams Tank 6	1	70.00	61.500	1.500	0.000	0.000	

Item Name	Quantity	Weight tonne	Long.Arm m	Vert.Arm m	Trans.Arm m	FS Mom. tonne. m	FSM Type
Abrams Tank 7	1	70.00	71.500	1.500	0.000	0.000	
Misc. Weights	1	116.0	62.480	0.000	-1.900	0.000	
	Total Weight=	1500	LCG=45.236	VCG=0.834	TCG=-0.006	0.089	

Intact Stability

Equilibrium Calculation - t-craft maxsurf SWATH
Loadcase - Swath Fully Loaded Displacement
Damage Case - Intact
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Fluid analysis method: Use corrected VCG

Table A-14 Hydrostatics at Equilibrium - Fully Loaded Intact Condition

Draft Amidsh. m	-2.811	Prismatic Coeff.	0.776	GMt corrected m	9.682
Displacement tonne	1500	Block Coeff.	1.013	GML corrected m	74.296
Heel to Starboard degrees	0.0	Midship Area Coeff.	1.679	KMt m	10.516
Draft at FP m	-2.822	Waterpl. Area Coeff.	0.788	KML m	75.130
Draft at AP m	-2.799	LCB from Amidsh. (+ve fwd) m	2.735	Immersion (TPc) tonne/cm	3.159
Draft at LCF m	-2.810	LCF from Amidsh. (+ve fwd) m	-1.063	MTc tonne.m	13.108
WL Length m	80.179	KB m	-4.639	RM at 1deg = GMt.Disp.sin(1) tonne.m	253.397
WL Beam m	19.354	KG fluid m	0.834	Max deck inclination deg	0.0
Wetted Area m^2	1492.710	BMt m	15.155	Trim angle (+ve by stern) deg	0.0
Waterpl. Area m^2	308.168	BML m	79.769	Trim (+ve by stern) m	0.023

Hydrostatics - t-craft maxsurf SWATH
Damage Case - Intact
Fixed Trim = 0 m (+ve by stern)
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)

Table A-15 Upright Hydrostatics - Curves of Form Values

Draft Amidsh. m	-4.000	-3.700	-3.400	-3.100	-2.800	-2.500	-2.200	-1.900	-1.600	-1.300	-1.000
Displacement tonne	1108	1218	1314	1408	1503	1598	1692	1787	1882	1977	2072
Heel to Starboard degrees	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Draft at FP m	-4.000	-3.700	-3.400	-3.100	-2.800	-2.500	-2.200	-1.900	-1.600	-1.300	-1.000
Draft at AP m	-4.000	-3.700	-3.400	-3.100	-2.800	-2.500	-2.200	-1.900	-1.600	-1.300	-1.000
Draft at LCF m	-4.000	-3.700	-3.400	-3.100	-2.800	-2.500	-2.200	-1.900	-1.600	-1.300	-1.000
Trim (+ve by stern) m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WL Length m	78.003	77.581	76.091	80.177	80.179	80.181	80.183	80.186	80.188	80.190	80.192
WL Beam m	20.189	19.354	19.354	19.354	19.354	19.354	19.354	19.354	19.354	19.354	19.354
Wetted Area m^2	1138.277	1255.228	1304.427	1399.886	1495.871	1591.856	1687.841	1783.827	1879.812	1975.797	2071.782
Waterpl. Area m^2	386.884	328.289	305.652	308.168	308.168	308.167	308.166	308.166	308.165	308.164	308.164
Prismatic Coeff.	0.751	0.763	0.794	0.767	0.778	0.788	0.797	0.805	0.812	0.819	0.824
Block Coeff.	0.845	1.119	1.112	1.031	1.011	0.995	0.980	0.968	0.957	0.947	0.938
Midship Area Coeff.	1.160	1.872	1.836	1.740	1.678	1.626	1.563	1.525	1.492	1.446	1.421
Waterpl. Area Coeff.	0.758	0.868	0.824	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788
LCB from Amidsh. (+ve fwd) m	3.620	3.531	3.286	3.005	2.748	2.522	2.321	2.142	1.981	1.835	1.702
LCF from	3.369	1.620	-0.745	-1.063	-1.063	-1.063	-1.062	-1.062	-1.062	-1.062	-1.061

Draft Amidsh. m	-4.000	-3.700	-3.400	-3.100	-2.800	-2.500	-2.200	-1.900	-1.600	-1.300	-1.000
Amidsh. (+ve fwd) m											
KB m	-5.068	-4.959	-4.857	-4.749	-4.635	-4.518	-4.396	-4.272	-4.145	-4.016	-3.884
KG m	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
BMt m	25.813	19.888	17.160	16.140	15.123	14.225	13.429	12.716	12.076	11.497	10.971
BML m	183.639	119.033	88.081	84.953	79.597	74.876	70.684	66.937	63.567	60.520	57.752
GMt m	20.414	14.598	11.973	11.062	10.157	9.378	8.702	8.115	7.601	7.151	6.756
GML m	178.241	113.743	82.894	79.874	74.631	70.028	65.958	62.335	59.092	56.174	53.537
KMt m	20.744	14.928	12.303	11.392	10.487	9.708	9.032	8.445	7.931	7.481	7.086
KML m	178.571	114.073	83.224	80.204	74.961	70.358	66.288	62.665	59.422	56.504	53.867
Immersion (TPc) tonne/cm	3.966	3.366	3.134	3.159	3.159	3.159	3.159	3.159	3.159	3.159	3.159
MTc tonne.m	23.240	16.296	12.812	13.232	13.195	13.162	13.133	13.107	13.084	13.064	13.048
RM at 1deg = GMt.Disp.sin(1) tonne.m	394.860	310.265	274.510	271.834	266.408	261.478	257.043	253.106	249.664	246.719	244.270
Max deck inclination deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trim angle (+ve by stern) deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

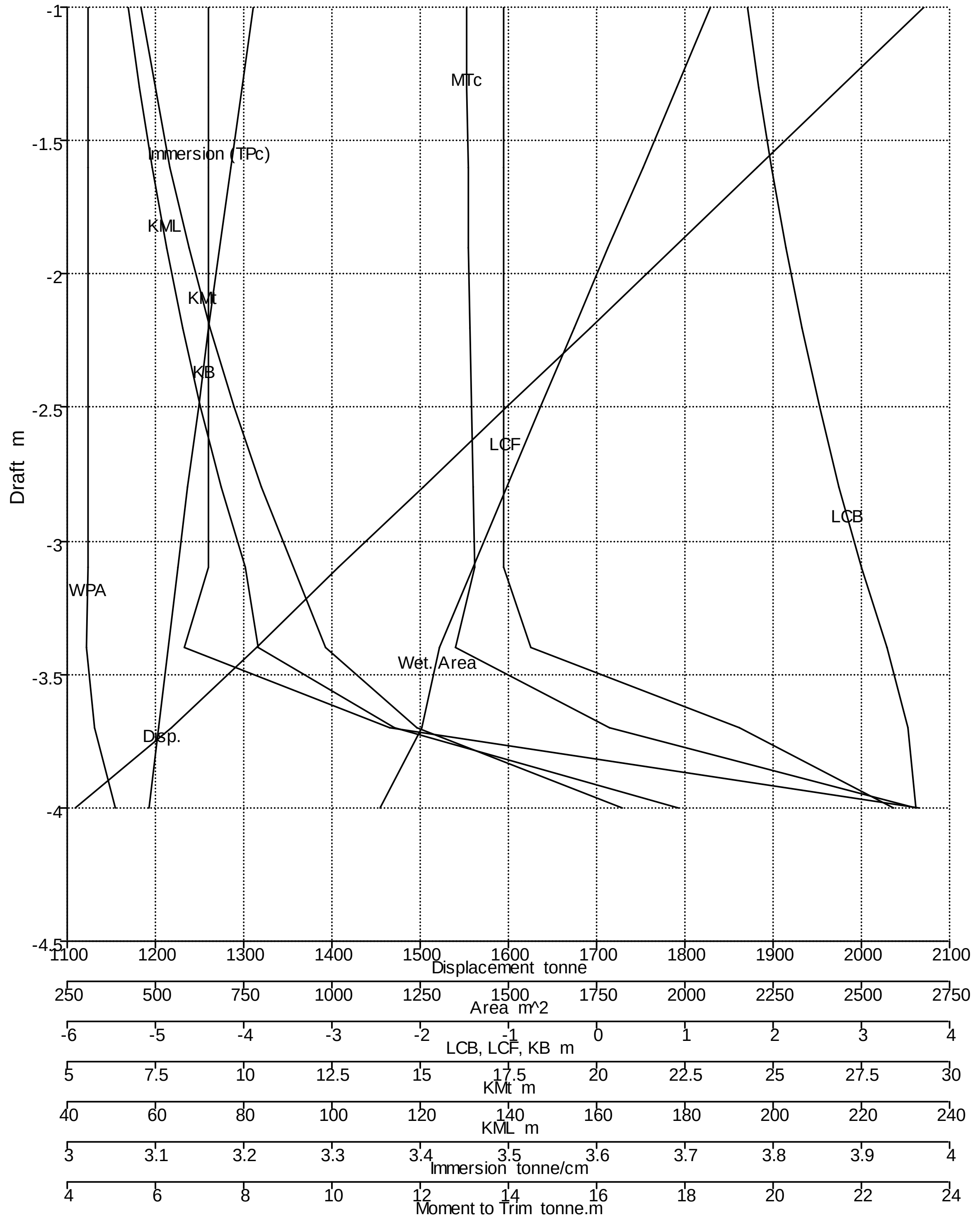


Figure A-22 Curves of Form

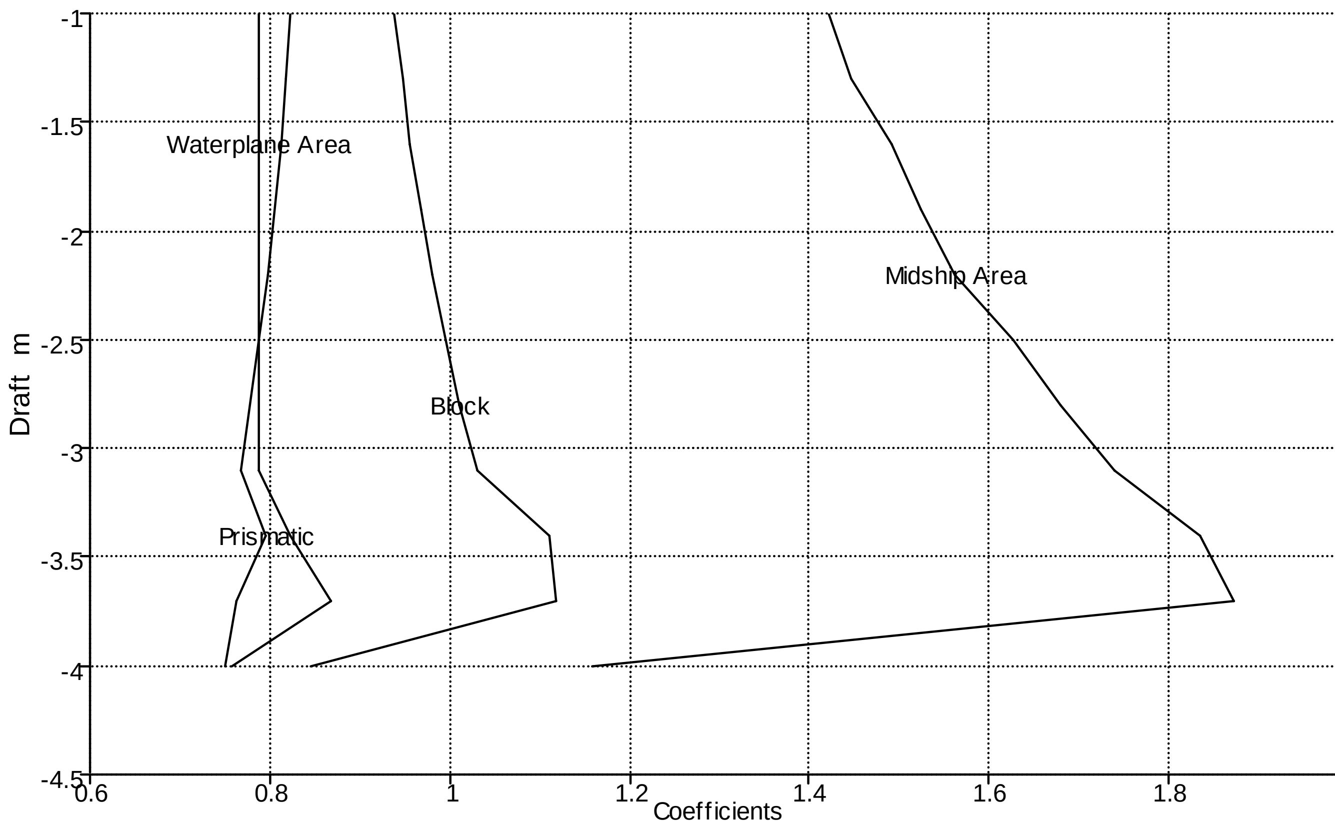


Figure A-23 Curves of Form - Coefficients

Stability Calculation - t-craft maxsurf SWATH
Loadcase - Swath Fully Loaded Displacement
Damage Case - Intact
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Fluid analysis method: Use corrected VCG

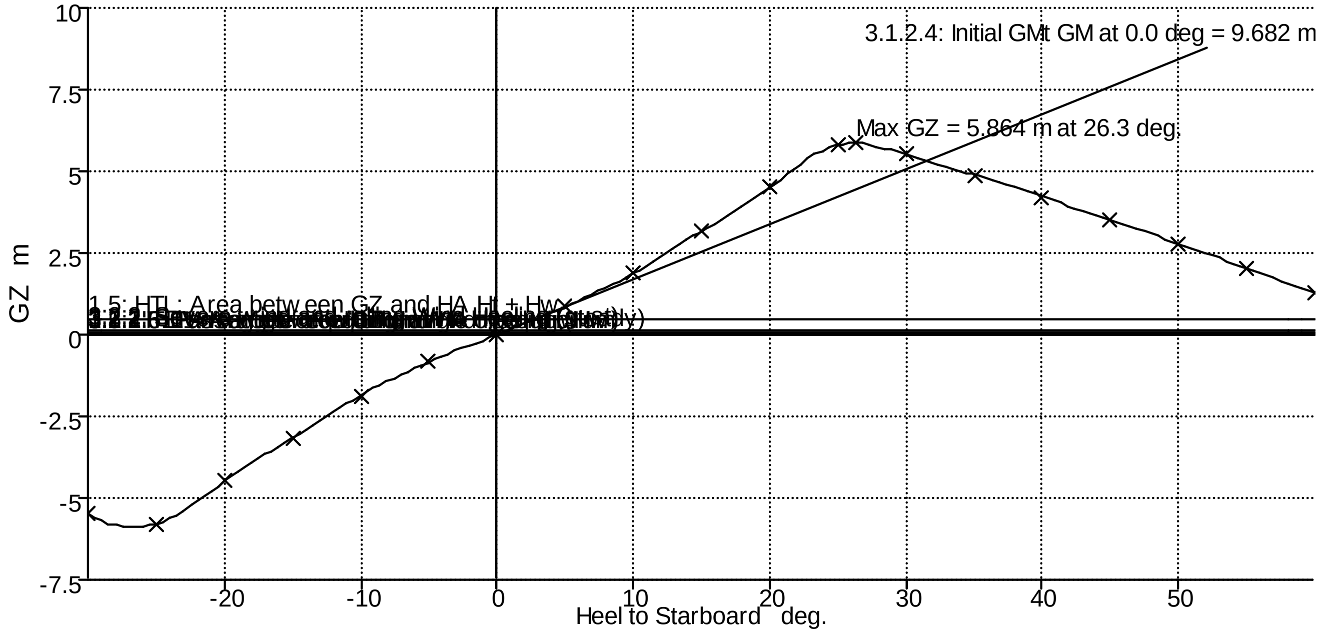


Figure A-24 Static Stability Curve – Fully Loaded Condition

Table A-16 Static Stability Curve Data - Fully Loaded Condition

Heel to Starboard degrees	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0
Displacement tonne	1499	1500	1500	1500	1500	1500	1500	1499	1500	1499
Draft at FP m	-2.218	-2.014	-2.619	-2.822	-2.618	-2.016	-2.216	-3.682	-5.624	-8.574
Draft at AP m	-4.247	-2.670	-2.849	-2.799	-2.850	-2.669	-4.249	-6.550	-9.710	-14.573
WL Length m	81.017	85.324	84.708	80.179	84.706	85.324	81.017	81.027	81.039	81.050
Immersed Depth m	8.076	7.140	5.305	3.693	2.546	4.197	8.200	8.093	7.812	7.350
WL Beam m	10.208	20.937	20.488	19.354	20.488	20.937	10.208	9.903	9.327	8.498
Wetted Area m^2	1731.489	1907.647	1571.304	1492.691	1571.393	1912.539	1728.314	1716.252	1709.640	1702.276
Waterpl. Area m^2	283.171	502.149	387.466	308.168	387.421	502.081	283.085	230.728	197.603	185.813
Prismatic Coeff.	0.864	0.825	0.762	0.776	0.762	0.825	0.864	0.863	0.861	0.859
Block Coeff.	0.559	0.300	0.548	1.013	1.142	0.510	0.550	0.717	0.885	0.887
LCB from Amidsh. (+ve fwd) m	2.878	2.782	2.746	2.735	2.749	2.777	2.883	2.935	2.994	3.059
VCB from DWL m	-3.668	-3.208	-2.120	-1.828	-2.120	-3.208	-3.668	-3.497	-3.217	-2.844
GZ m	-5.504	-4.489	-1.863	0.006	1.874	4.501	5.514	4.218	2.782	1.258
LCF from Amidsh. (+ve	1.452	3.274	1.114	-1.063	1.107	3.266	1.462	0.570	0.116	-1.448

Heel to Starboard degrees	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0
fwd) m										
TCF to zero pt. m	-6.606	1.109	2.270	0.000	-2.269	-1.110	6.605	6.120	5.391	4.432
Max deck inclination deg	30.0	20.0	10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0
Trim angle (+ve by stern) deg	-1.4	-0.4	-0.2	0.0	-0.2	-0.4	-1.4	-1.9	-2.8	-4.0

Table A-17 Intact Static Stability Criteria Results - Fully Load Condition

Code	Criteria	Value	Units	Actual	Status
HSC multi. Intact	1.1: Area from 0 to 30 shall not be less than (>=)	3.589	m.deg	74.428	Pass
	1.2: Angle of maximum GZ shall not be less than (>=)	10.0	deg	26.3	Pass
	1.5: HTL: Area between GZ and heeling arms shall not be less than (>=)... Hpc + Hw Ht + Hw	 1.604 1.604	m.deg	 21.360 23.755	Pass
	3.2.1: HL1: Angle of equilibrium due to the following shall not be greater than (<=)... Wind heeling (Hw)	16.0	deg	0.1	Pass
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30 shall not be less than (>=)	3.151	m.deg	95.358	Pass
	3.1.2.1: Area 0 to 40 shall not be less than (>=)	5.157	m.deg	144.165	Pass
	3.1.2.1: Area 30 to 40 shall not be less than (>=)	1.719	m.deg	48.807	Pass
	3.1.2.2: Max GZ at 30 or greater shall not be less than (>=)	0.200	m		Not Analysed
	3.1.2.3: Angle of maximum GZ shall not be less than (>=)	25.0	deg	26.3	Pass
	3.1.2.4: Initial GMt shall not be less than (>=)	0.150	m	9.682	Pass
	3.1.2.5: Passenger crowding: angle of equilibrium shall not be greater than (<=)	10.0	deg	0.0	Pass

Code	Criteria	Value	Units	Actual	Status
	3.1.2.6: Turn: angle of equilibrium shall not be greater than (<=)	10.0	deg	0.0	Pass
	3.2.2: Severe wind and rolling:				Pass
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.4	Pass
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.000	%	2.154	Pass
	Area1 / Area2 shall not be less than (>=)	100.000	%	260.727	Pass

Longitudinal Strength Calculation - t-craft maxsurf SWATH
Loadcase - Swath Fully Loaded Displacement
Damage Case - Intact
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Fluid analysis method: Use corrected VCG

Table A-18 Longitudinal Weight Distribution

Item Name	Quantity	Weight tonne	Long.Arm m	Aft. Limit m	Fwd. Limit m	Vert.Arm m	Trans.Arm m
Lightship	1	751.0	42.600	0.000	81.000	0.500	0.000
Fwd Fuel Tank	98.6%	141.0	57.997			0.986	1.500
Aft Fuel Tank	0%	0.0000	34.100			1.000	2.500
Port Grey/Black Water	61.37%	0.8000	51.850			0.568	-7.550
Stbd Grey/Black Water	61.37%	0.8000	51.850			0.568	7.550
Abrams Tank 1	1	70.00	11.500	6.500	16.500	1.500	0.000
Abrams Tank 2	1	70.00	21.500	16.500	27.500	1.500	0.000
Abrams Tank 3	1	70.00	31.500	27.500	36.500	1.500	0.000
Abrams Tank 4	1	70.00	41.500	36.500	46.500	1.500	0.000
Abrams Tank 5	1	70.00	51.500	46.500	56.500	1.500	0.000
Abrams Tank 6	1	70.00	61.500	56.500	66.500	1.500	0.000
Abrams Tank 7	1	70.00	71.500	66.500	77.500	1.500	0.000
Misc. Weights	1	116.0	62.480	17.480	98.480	0.000	-1.900
	Total Weight=	1500	LCG=45.236			VCG=0.834	TCG=-0.006

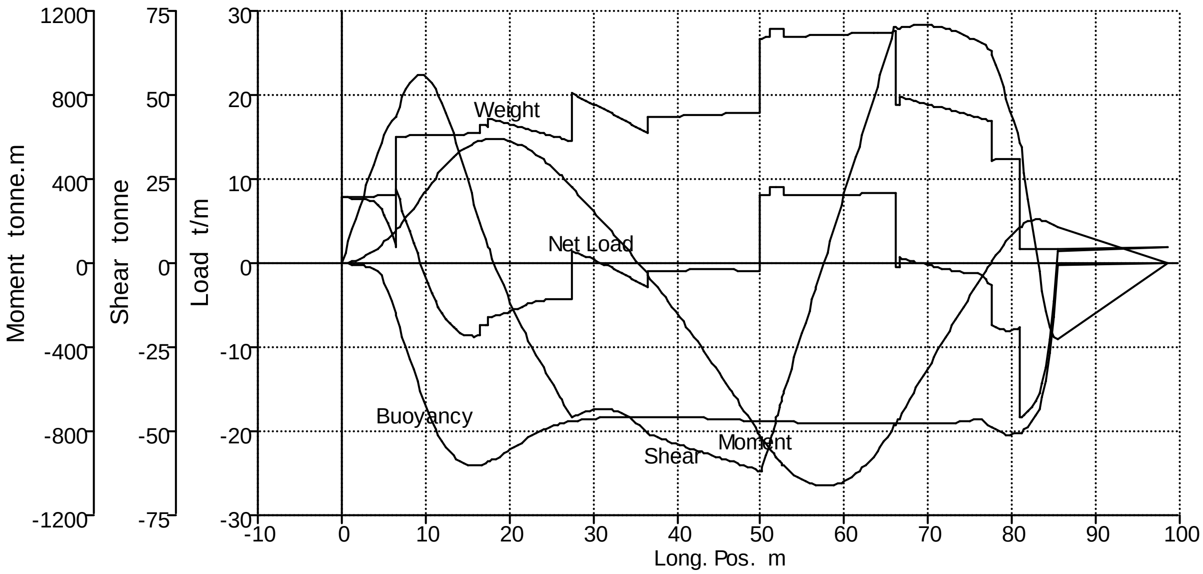


Figure A-25 Intact Logitudinal Load, Shear, and Bending Moment Diagram

Damaged Stability

Floodable Length Calculations - t-craft maxsurf SWATH
Damage Case - Intact
Initial Trim = 0 m (+ve by stern)
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
VCG = 1.4 m

Minimum freeboard of margin line shall not be less than (>=) 0.200 m

Name	Long. Pos m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m	Flood. Len m
Displacement t		1400	1400	1400	1500	1500	1500	1600	1600	1600
Permeabitily %		100	90	80	100	90	80	100	90	80

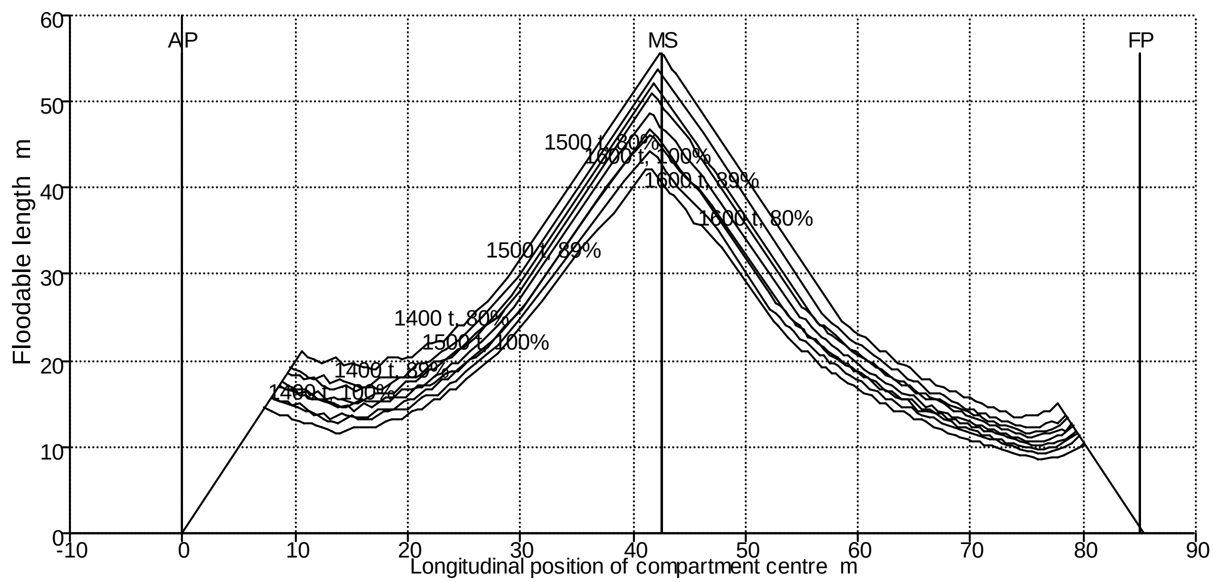
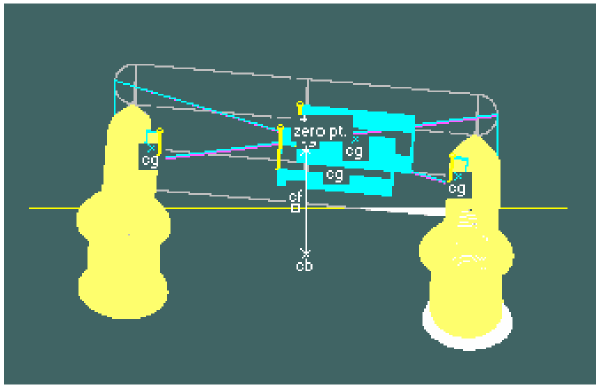


Figure A-26 Floodable Length Diagram

Equilibrium Calculation - t-craft maxsurf SWATH

Loadcase - Swath Fully Loaded Displacement
Damage Case - Two Compartment Flooding
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Compartments Damaged -
  Cmpt S2 - collision
  Cmpt S3
Fluid analysis method: Use corrected VCG



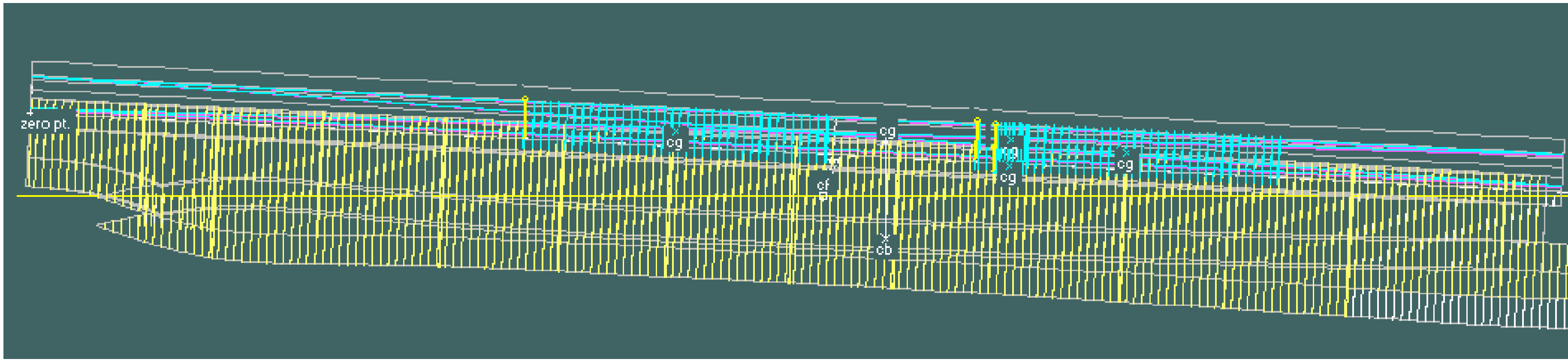


Figure A-27 Starboard Forward Two Compartments Damaged – Profile (above) & Body Plan (above right)

Table A-19 Hydrostatics at Equilibirum - Fully Loaded Damaged Condition

Draft Amidsh. m	-2.203	LCB from Amidsh. (+ve fwd) m	2.992
Displacement tonne	1499	LCF from Amidsh. (+ve fwd) m	-0.422
Heel to Starboard degrees	5.1	KB m	-4.303
Draft at FP m	-0.032	KG fluid m	0.834
Draft at AP m	-4.375	BMt m	17.112
Draft at LCF m	-2.225	BML m	111.441
Trim (+ve by stern) m	-4.343	GMt corrected m	11.982
WL Length m	77.125	GML corrected m	106.312
WL Beam m	20.118	KMt m	12.809
Wetted Area m^2	1701.738	KML m	107.138
Waterpl. Area m^2	352.527	Immersion (TPc) tonne/cm	3.614
Prismatic Coeff.	0.725	MTc tonne.m	18.754
Block Coeff.	0.536	RM at 1deg = GMt.Disp.sin(1) tonne.m	313.569
Midship Area Coeff.	1.421	Max deck inclination deg	5.9
Waterpl. Area Coeff.	0.699	Trim angle (+ve by stern) deg	-2.9

Table A-20 Damaged Stability Criteria Results

Code	Criteria	Value	Units	Actual	Status
SOLAS, II-1/8	8.6.2: Heel angle at equilibrium for unsymmetrical flooding the angle of heel shall not be greater than (<=)	7.0	deg	5.1	Pass
SOLAS, II-1/8	8.6.3: Margin line immersion: the min. freeboard of the margin line shall be greater than (>)	0.000	m	0.434	Pass

Stability Calculation - t-craft maxsurf SWATH
Loadcase - Swath Fully Loaded Displacement
Damage Case - Two Compartment Flooding
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Compartments Damaged -
  Cmpt S2 - collision
  Cmpt S3
Fluid analysis method: Use corrected VCG

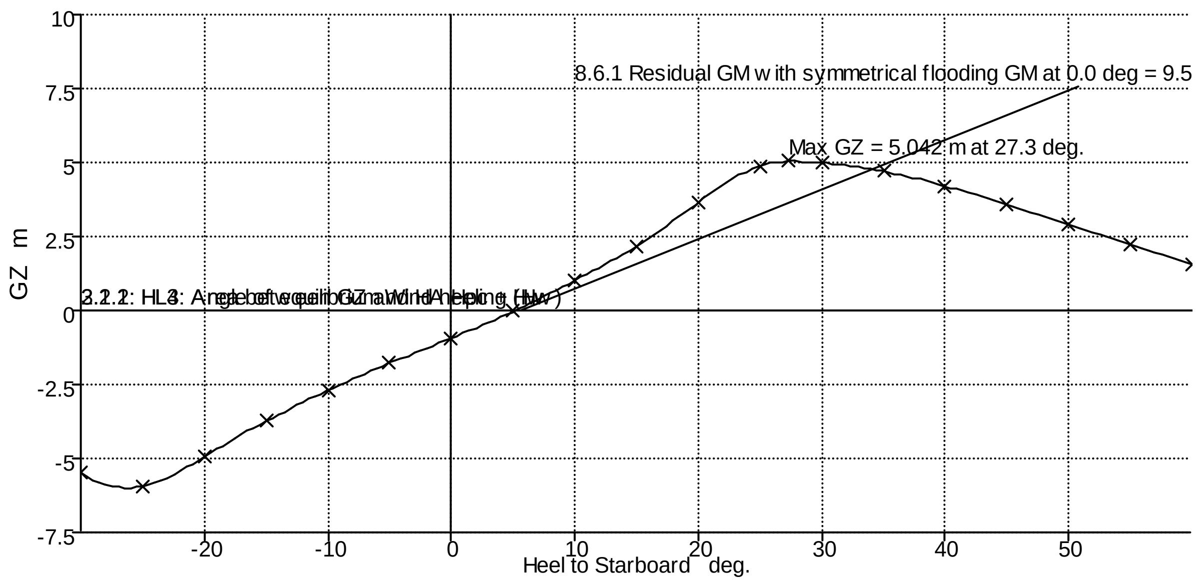


Figure A-28 Damaged Static Stability Curve

Table A-21 Static Stability Curve - Damaged Condition

Heel to Starboard degrees	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0
Displacement tonne	1499	1500	1500	1500	1500	1500	1499	1500	1500	1500
Draft at FP m	-2.218	-1.449	-0.622	0.023	-0.308	-0.868	-0.174	0.399	0.090	-0.549
Draft at AP m	-4.247	-3.003	-3.912	-4.505	-4.061	-3.367	-5.511	-9.001	-12.846	-18.471
WL Length m	81.017	85.281	81.070	73.443	81.088	84.715	85.468	84.776	81.398	79.559
Immersed Depth m	8.076	7.568	7.010	6.225	4.425	5.770	8.432	10.860	11.134	10.995
WL Beam m	10.208	20.919	20.553	19.515	20.546	20.580	16.695	12.785	9.327	8.498
Wetted Area m^2	1718.135	1962.115	1706.234	1628.669	1762.222	1997.635	1932.530	1854.511	1805.017	1786.000
Waterpl. Area m^2	283.136	461.347	358.952	300.424	394.309	516.746	324.026	222.810	199.458	194.826
Prismatic Coeff.	0.864	0.752	0.736	0.759	0.703	0.660	0.629	0.624	0.650	0.667
Block Coeff.	0.559	0.248	0.398	0.616	0.609	0.323	0.263	0.382	0.512	0.434
LCB from Amidsh. (+ve fwd) m	2.880	2.843	2.944	3.010	2.962	2.890	3.088	3.344	3.505	3.600
VCB from DWL m	-3.668	-3.315	-2.538	-2.247	-2.320	-2.862	-3.345	-3.498	-3.459	-3.338
GZ m	-5.504	-4.932	-2.706	-0.930	1.020	3.649	4.995	4.204	2.918	1.548
LCF from Amidsh. (+ve fwd) m	1.456	2.686	-2.206	-2.552	0.894	7.269	10.873	3.833	0.457	-2.013
TCF to zero pt. m	-6.606	-0.038	0.648	-0.336	-0.511	-0.630	2.343	4.423	4.182	3.357
Max deck inclination deg	30.0	20.0	10.2	3.0	10.3	20.1	30.1	40.2	50.2	60.2
Trim angle (+ve by stern) deg	-1.4	-1.0	-2.2	-3.0	-2.5	-1.7	-3.6	-6.3	-8.7	-11.9

Table A-22 Static Stability Criteria Results - Damaged Condition

Code	Criteria	Value	Units	Actual	Status
SOLAS, II-1/8	8.2.3.1: Range of residual positive stability shall not be less than (>=)	15.0	deg	54.8	Pass
	8.2.3.2: Area under residual GZ curve shall not be less than (>=)	0.859	m.deg	32.733	Pass
	8.2.3.3: Maximum residual GZ shall not be less than (>=)	0.100	m	5.042	Pass
	8.6.1 Residual GM with symmetrical flooding shall not be less than (>=)	0.050	m	9.586	Pass

Code	Criteria	Value	Units	Actual	Status
HSC multi. Damage	2.1.1: HL4: Area between GZ and heeling arms shall not be less than (>=)... Hpc + Hw	1.604	m.deg	25.465	Pass
	3.2.2: HL3: Angle of equilibrium due to the following shall not be greater than (<=)... Wind heeling (Hw)	20.0	deg	5.2	Pass

Longitudinal Strength Calculation - t-craft maxsurf SWATH
Loadcase - Swath Fully Loaded Displacement
Damage Case - Two Compartment Flooding
Free to Trim
Relative Density (specific gravity) = 1.025; (Density = 1.0252 tonne/m^3)
Compartments Damaged -
  Cmpt S2 - collision
  Cmpt S3
Fluid analysis method: Use corrected VCG

Item Name	Quantity	Weight tonne	Long.Arm m	Aft. Limit m	Fwd. Limit m	Vert.Arm m	Trans.Arm m
Lightship	1	751.0	42.600	0.000	81.000	0.500	0.000
Fwd Fuel Tank	98.6%	141.0	58.085			0.987	1.524
Aft Fuel Tank	0%	0.0000	34.100			1.000	2.500
Port Grey/Black Water	61.37%	0.8000	51.867			0.569	-7.545
Stbd Grey/Black Water	61.37%	0.8000	51.867			0.569	7.555
Abrams Tank 1	1	70.00	11.500	6.500	16.500	1.500	0.000
Abrams Tank 2	1	70.00	21.500	16.500	27.500	1.500	0.000
Abrams Tank 3	1	70.00	31.500	27.500	36.500	1.500	0.000
Abrams Tank 4	1	70.00	41.500	36.500	46.500	1.500	0.000
Abrams Tank 5	1	70.00	51.500	46.500	56.500	1.500	0.000
Abrams Tank 6	1	70.00	61.500	56.500	66.500	1.500	0.000
Abrams Tank 7	1	70.00	71.500	66.500	77.500	1.500	0.000
Misc. Weights	1	116.0	62.480	17.480	98.480	0.000	-1.900
	Total Weight=	1500	LCG=45.244			VCG=0.834	TCG=-0.004

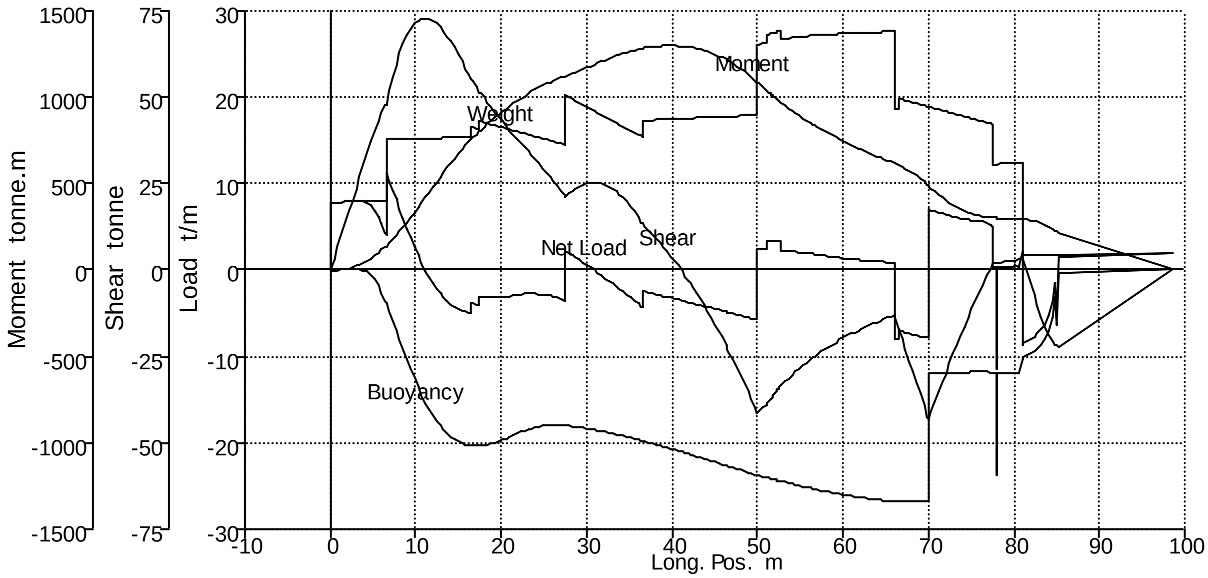


Figure A-29 Damaged Longitudinal Load, Shear, and Bending Moment Diagram