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Technical Report

Landing Ship Dock Replacement

by

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14. ABSTRACT
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NOMENCLATURE

C_B	Block Coefficient
C_M	Midships Coefficient
C_P	Prismatic Coefficient (Vertical)
C_W	Waterplane Coefficient
EFV	Expeditionary Fighting Vehicle
GM	Ship's Metacentric Height
GZ	Ship's Righting Lever
IMO	International Maritime Organization
KG	Ship's Vertical Center of Gravity
LCAC	Landing Craft Air Cushion
LCG	Ship's Longitduinal Center of Gravity
LCU	Landing Craft Utility
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
LPD	Landing Platform Dock
LSD	Landing Ship Dock
MEU	Marine Expeditionary Unit
mt	Metric Tonnes
nm	Nautical Mile
PC	Propulsive Coefficient
SSCS	Ship Space Classification System
SWBS	Ship Work Breakdown Structure
USMC	United States Marine Corps
USN	United States Navy

1. INTRODUCTION

This report details the results of a study to develop novel amphibious ship designs with the potential to succeed the LSD-41 design. The design team was detailed to develop concept designs that were not bound by historical amphibious ship design practice, especially the impact of traditional displacement landing craft. The resulting designs were to exploit the operational advances of other US Navy and US Marine Corps landing craft and amphibious vehicles. The report provides a summary of the final design details.

1.1. Problem Definition

Currently, US Navy amphibious ships are designed to operate with both displacement and non-displacement landing craft, as well as with the smaller amphibious assault vehicles operated by the US Marine Corps. This results in amphibious ships that, although they have the capability to operate a range of landing craft, are not optimized for operating any single craft type. Often the demanding implications of the ability to operate traditional displacement landing craft, such as Landing Craft Utility (LCU), dictate many of the features of the amphibious assault ships to the detriment of the ability to operate other types of landing craft or assault vehicle.

In some respects this forms an in-virtuous circle as the landing craft design is limited by the design features of the current amphibious shipping, but the features of the next generation of amphibious shipping are significantly defined by a requirement to remain compatible with the current landing craft fleet. This reduces a designer’s flexibility to innovate and develop superior solutions. Without a step change in the features of the amphibious ship, the circle will remain self-fulfilling. In particular, monohull amphibious ships are large voluminous ships, driven in beam and depth by the requirements of the well deck and in length by the storage requirements for craft, aircraft and vehicles. As a result the overall design is compromised in areas such as seakeeping and powering.

A particular challenge in the design of conventional amphibious ships is the inclusion of a well deck capable of operating LCUs. These are comparatively large craft with a deep draft requirement that can only deploy or recover into a fully flooded well deck. This requires a mother ship with a large enclosed volume as well as a large, complex, ballast system to trim vessel and flood the well deck when required. LCACs operate from a nearly dry well deck and amphibians such as the EFV (Expeditionary Fighting Vehicle) require much smaller well decks that could significantly reduce ballast system requirements. This reduction in demand could lead to more effective ship designs.

Given this, a task was set to develop concept designs for a replacement for the Landing Ship Dock 41 class, that is not limited by the demands of displacement landing craft to a modified repeat of historic designs. The new vessel design is intended to maximize the benefits of operating non-displacement craft or amphibious vehicles, from the ship. In response to this problem, several potential concepts were identified and investigated. Two were selected for further development as concept designs. These were: A ship focused on operating Expeditionary Fighting Vehicles (EFVs) (referred to as LSD

(EFV)) and a ship focused on operating Landing Craft Air Cushions (LCACs) (referred to as LSD (LCAC)).

1.2. Overview of Landing Craft

There are several different types of Landing Craft and amphibious vehicles that are used or proposed to be used in the timeframe under consideration for the concept designs. Landing Craft Data was taken from References 1 and 2.

LANDING CRAFT UTILITY (LCU)

The US Marine Corp (USMC) and US Navy currently operate LCU 1600s (see Figure 1) as troop and equipment transports. LCUs are traditional displacement landing craft with no amphibious capability (and hence require a large floodable well deck) which can carry comparatively large payloads at slow speeds over a long range and then beach. Ramps at the bow and stern are used to load and unload vehicles, equipment and personnel between the LCU, the ship and the beach.

Figure 1 - LCU Launching from LHA 4

The principal characteristics of the LCU 1600 are outlined in Table 1.

Full Load Displacement (mt)	381
Lightship Displacement (mt)	203
Length (m)	41.1
Beam (m)	8.8
Draft (m)	1.9
Trial Speed (knots)	11
Range at 8 knots (nm)	1,200
Military Lift Capability	136 mt consisting of 3 M103s or 2 M1A1s or 350 Troops

Table 1 - Principal Characteristics of LCU 1600

LANDING CRAFT AIR CUSHION (LCAC)

The LCAC (see Figure 2 and Figure 3) is a large air cushion vehicle used for amphibious assault operations and over the shore logistics support to a deployed US Marine Corps Air Ground Task Force.

LCACs require a dry well deck with between 0” and 6” of water over the sill of the deck to deploy or recover. LCACs can climb a static angle of up to 4 degrees. Unlike the LCU, the LCAC is amphibious and can cross land based obstacles of up to 4 foot. LCAC operations degrade significantly in rough seas. The principal characteristics of the LCAC are outlined in Table 2 (Ref. 1).

Figure 2 - LCAC at Sea

Figure 3 - LCAC on Land

Full Load Displacement (mt)	183
Lightship Displacement (mt)	88
Length on Cushion (m)	26.8
Beam on Cushion (m)	14.3
Draft off Cushion (m)	0.9
Trial Speed (knots)	40
Range (nm)	300 @ 35 knots
	200 @ 40 knots
Military Lift Capability	70 mt consisting of 1 M1A1 or 23 Troops

Table 2 - Principal Characteristics of LCAC

EXPEDITIONARY FIGHTING VEHICLE (EFV)

The EFV (see Figure 4 and Figure 5) is an amphibious vehicle currently in development to replace the current Amphibious Assault Vehicles used by the USMC. EFVs can carry up to 17 troops plus a crew of three but cannot carry heavy or large equipment. The EFV has a range of 300 miles on land and hence can be used to transport troops to a point inland, away from the beach. As it is amphibious, the EFV does not require a fully floodable well deck and can be operated from a ramp off the stern of a ship. However it also can be operated from a fully flooded well deck. Given the relatively small size of the EFV, a well deck dedicated to operating only the EFV well deck could be considerably smaller than that required for an LCU or LCAC. This would make a significant difference to the design features of an amphibious ship.

Figure 4 - EFV on Land

Figure 5 - EFV at Sea

The expected principal characteristics of the EFV are outlined in Table 3.

Full Load Displacement (mt)	28.5
Lightship Displacement (mt)	33.8
Length (m)	10.67
Beam (m)	3.66
Height (m)	3.28
Max Water Speed (knots)	25
Max Land Speed (mph)	45
Range on Water (nm)	65 @ 20 knots
Range on Land (miles)	300 @ 25 mph

Table 3 - Principal Characteristics of EFV

1.3. Design Requirements

DESIGN SPECIFIC REQUIREMENTS

While many of the operational and design requirements for the two ship designs were common between the designs, several of the most dominating requirements were design specific. This section introduces the operational requirements that differed between the LSD(EFV) and the LSD(LCAC).

Taking the role and features of the current LSD-41 design as a start point as well as some features of the more modern LPD-17 design, a set of design requirements for a replacement Landing Ship Dock were postulated. The LSD-41 was used to reflect the requirements of a LSD specific concept. The LPD-17 is considered to represent the state of the art in smaller US Navy amphibious shipping requirements and where those design features of a Landing Platform Dock are relevant to a Landing Ship Dock (for example medical facilities) LPD-17 based requirements have been specified.

The payloads specified for these designs were derived from a published composition for the 2015 Marine Expeditionary Unit (MEU) (as specified at Appendix A). For both concept designs, the composition of the payloads was selected to exploit the concept of designing primarily round a single surface connector. The concept specific requirements are outlined in Table 4.

	LSD (EFV)	**LSD (LCAC)**
Primary Payload	48 EFVs	3 LCACs
Vehicle Deck Area (m^2)	3,500	2,100
Troop Accommodation	1,000	454

Table 4 – Concepts Specific Requirements

The EFV variant is intended to operate in various modes but its dominant design characteristics are driven by the requirement to offload all embarked EFV's and their embarked troops during a single wave. The design is thus not equipped to undertake heavy logistics delivery tasks in support of an expeditionary strike group. These tasks are assumed to be undertaken by other amphibious ships.

In contrast, the LCAC variant is focused on the high speed delivery of larger or heavier vehicles. As the number of LCACs remains small, the design is limited in the rate at which these can be taken to shore, but the single mode of operation is intended to maximize the number of LCAC sorties.

COMMON DESIGN REQUIREMENTS

As stated previously two separate designs were developed. However, due to the common design requirements in many aspects, some common features were maintained between both ship concept designs.

Requirements applicable to both designs were derived for compatibility with the remainder of the current and future amphibious fleets and include:

- A trial speed of 22 knots
- Range of 15,000 nm at 12 knots
- Aviation, medical, combat and command and control capabilities as LPD-17
- 45 day stores endurance

Throughout this work, it has been assumed that these ships will be working as part of a task group where other, more capable, ships will provide flag officer accommodations and more extensive defensive capabilities.

Each requirement was investigated with monohull and trimaran solutions. The trimaran hullform was selected as the final hull concept for both designs due to the ability to place many of the ship systems in the side hulls. This led to the stern of the center hull being dedicated to amphibious and landing craft operations and stowage of US Marine Corps equipment, providing very flexible arrangements.

In addition, the ability to provide transverse stability without a very large main hull beam should allow a designer the freedom to deliver superior seakeeping and powering performance without sacrificing stability. The limited center hull beam also reduces the amount of ballast water required to provide the trim for the well deck immersion.

The ability to provide a cross structure with a significant beam and length, provides the designer with the flexibility to provide an open vehicle deck, allowing flexible stowage of US Marine Corps vehicles without intrusive watertight bulkheads.

The aviation facilities incorporated in both designs are identical to those on LPD-17, which has a hangar and maintenance facilities for:

- One CH-53E Super Stallion, or
- Two CH-46 Sea Knights, or
- One MV-22 Osprey, or
- Three UH –1 Hueys/AH-1 Cobras.

Both designs have a flight deck capable of being configured to land:

- Two CH-53E Super Stallions, or
- Four CH-46 Sea Knights, or
- Two MV-22 Ospreys, or
- Four UH –1 Hueys/AH-1 Cobras, or
- One AV-8B Harrier.

1.4. Powering and Propulsion

POWER GENERATION AND DISTRIBUTION

As both concept designs were developed, it became clear that the propulsion and electrical hotel load demands for both designs were very similar. As such, one system was proposed for both designs, using diesel generators to provide propulsive and ship service power via an Integrated Electric Power (IEP) system. The indicative propulsion system uses six Diesel Generators, two propulsion motors and a representative power conversion and distribution system. To maintain as much of the Trimaran main hull volume as possible for mission equipment and operational spaces, the majority of propulsion related equipment was located in the Trimaran side hulls. These key decisions, along with the propulsion power demands, were the key features in developing the propulsion concept. Consideration of the internal arrangement of both designs highlighted a significant disadvantage of locating gas turbines in the main hull. The volume required for large intakes and exhausts was in conflict with vehicle and equipment stowage in the cross-deck, hence gas turbines were not considered a desirable option. Diesel generators were selected for electrical generation as gas turbine generators were considered too large to be fitted into the side hulls.

Use of six diesels also provides the ability to operate a flexible power management system while also operating continually in a very fuel-efficient mode.

PROPULSION

One propulsor is located on each side hull. This was to provide separation between the propulsor train and the well deck to reduce wake issues during well dock operations.

Ducted propellers were selected to improve propeller efficiency and offer some protection given the outboard location on the side hulls. Preliminary investigation based on the Kaplan impeller geometry suggests that this solution is feasible, although detailed design has not been undertaken. Additional weight was incorporated in the weight calculations to account for the ducts.

It is envisioned that rudders can be located on the main hull in the aft cut up although the impact of the loss of rudder effectiveness due to being located away from the propeller wake has not been fully assessed. However, it should also be noted that the separated propellers allow the use of differential thrust to aid maneuvering should it be required.

1.5. Other Facilities

The LSD designs produced contain several other features mirroring traditional US Navy amphibious ship designs such as medical spaces and command systems. These were not considered to dramatically impact on the design style of the vessel nor on it’s specific design characteristics. It was decided to specify these simply to ensure that the overall vessel size and characteristics were representative.

Medical, command and control, and combat systems capabilities were all based on LPD-17, including the weight and space estimates. It is assumed that LPD 17 reflects current US Navy thoughts on the requirements for general small amphibious shipping more closely than the older Landing Ship Dock designs, except in the specific area of dock operations. In summary the requirements inherited from LPD-17 include:

Medical

- 2 operating rooms
- 4 isolation beds
- 24 primary care beds
- dental facilities

Command and Control

- Combat Information Center
- Ships Signals Exploitation Space
- Troop Operations and Logistics Center
- Joint Intelligence Center
- Supporting Arms Coordination Center

- Tactical-Logistical Group Center
- Helicopter Coordination Section

Combat Systems

- Mk-144 Mod 0 Rolling Air Frame missile launchers
- Mk-26 .50 Caliber machine guns
- Mk-46 Mod 1 30mm machine gun

As the Landing Ship Dock is traditionally not a command and control platform, no facilities have been provided for flag officers and their staff. It is assumed that the LSD concepts would always work as part of a task force where other ships (such as LHAs or LHDs) will provide the command and control facilities when these are required.

2. DESIGN METHODS

This section details the design methods used to develop both concepts. For each design, a manual synthesis tool was developed to allow a comprehensive weight and space synthesis to be developed with integrated analytical and estimation routines to develop indicative performance data prior to the detailed performance analysis using dedicated tools.

2.1. Volume and Weight

Internal area and volume requirements were estimated using the SSCS (Ship Space Classification System) format. This was undertaken primarily by scaling spaces from LPD-17. Spaces for the operational system outlined in the previous section were taken directly from LPD-17. Some volume groups such as well decks, vehicle decks, engine spaces and tanks the volumes required were calculated based on vehicle and equipment sizes and amount of liquids required.

Using this volume breakdown, an estimate of the volume needed in the superstructure was undertaken by considering each SSCS group individually and determining its appropriate location. This allowed the total volume calculated to be subdivided into superstructure volume and hull volume.

Weight was estimated using the SWBS (Ship Work Breakdown Structure) format. For the designs presented here, monohull amphibious ships were used as a basis for scaling weights where sensible for a trimaran concept.

SWBS group 100 (Hull Structure) was scaled at the single digit level using a structural density estimate of $85kg/m^3$ of enclosed volume. This estimate was based on current ship data for both current amphibious monohull vessels and the trimaran research vessel RV Triton.

SWBS group 200 (Propulsion Plant) was partly calculated (for specific, representative equipment) and partly scaled from current amphibious ships using the enclosed volume of the designs.

SWBS group 300 (Electric Plant) was partly scaled from current amphibious ships, based on the enclosed volume of the designs and partly calculated based on generator weights of current ships.

SWBS group 400 (Command and Control) is taken directly from the data for LPD-17 without modification or scaling.

SWBS group 500 (Auxiliary Systems) is scaled from current amphibious ships using either hull volume, manning or displacement depending on the specific system.

SWBS group 600 (Outfitting and Furnishing) is scaled from current amphibious ships using either manning or hull volume depending on the sub-group.

SWBS group 700 (Armament) is taken directly from the data for LPD-17 without modification or scaling.

SWBS group 800 (Loads) is either taken directly from LPD-17, scaled based on manning, or calculated based on payload and mission profile.

Based on these two systems, weight and volume were iterated to give a balanced design, with displacement and internal volume of the hull and the superstructure as outputs which could then be used to develop potential geometries.

2.2. Electrical Power Requirements for Propulsion and Ship Services

Propulsive power was estimated using model test data (from Reference 3). A 5% margin was included for scaling discrepancies, 3% to accommodate air drag and 15% for appendage drag. A propulsive coefficient of 0.65 was assumed and a 10% margin for electrical loses was also included. The sustained speed is considered to be the speed achievable at 80% of propulsive load.

The model test data was also used to optimize the placement of the side hulls as the data compared the resistance with different longitudinal and transverse side hull positions Although the separation of the side hulls from the main hull was primarily driven by stability requirements, the side hulls were positioned longitudinally to minimize resistance and therefore propulsive power requirements, without affecting the architectural concept.

Ship service load was estimated from data available for similar ships and scaled on displacement.

2.3. Ship Stability

An initial estimate of stability was undertaken by calculating GM based on the geometry of proposed designs. This was expanded to include different states including ballasted conditions. Additionally, when designs had been finalized and modeled, GZ curves were produced to ensure that US Navy intact stability criteria were met. In addition to the US

Navy DDS-079 criteria, an additional assessment was made of IMO's GZ curve shape characteristics to identify any areas of interest at specific angles of heel in the GZ curve due to the novel nature of this trimaran. However, these characteristics were not employed as limiting design criteria.

KG and LCG were estimated based on the weight breakdown and the general arrangement of the design. It was assumed throughout that the transverse center of gravity is on the centerline as the general arrangement was not progressed to a point to allow the transverse center of gravity to be calculated. Stability analysis undertaken did not model tanks and therefore does not take into account free surface effect and is, therefore, slightly optimistic.

No damage stability assessment has yet been undertaken. Watertight bulkheads have been placed along the length of the ship based on a 15%, three compartment flooding standard. These bulkheads extend to the cross-deck. For each design, the post damage stability performance is expected to be fully satisfactory due to the degree of sub-division in the lower hull decks, the separation of main and side hulls and the high intact stability. However a full damage stability analysis is required.

The next two sections of this report detail the specific characteristics of the two concept designs developed for this report, namely the LSD(EFV) and the LSD(LCAC).

3. LANDING SHIP DOCK (EXPEDITIONARY FIGHTING VEHICLE)

3.1. Concept Overview

The mission of this ship is to deploy 48 EFVs, with 17 troops and three crew in each, giving a total of 960 troops to be deployed, potentially as a single assault wave. This concept would also have the capability to operate two CH-53E Super Stallions. Given that this ship also has an aviation capability, accommodation has been provided for 1,000 marines including officers.

The ship is designed around the EFV deployment capability and is based on a small floodable/pumpable EFV launch area at the main hull stern with a system of internal ramps connecting to a large EFV stowage deck area in the cross-structure. EFVs would be launched from the stern from a small well deck located below the waterline. A watertight stern door is fitted to the stern opening, so that the well deck can be flooded for operations by opening this stern gate. Following operations, the well deck can be pumped dry. This minimizes ballast requirements, although, as EFVs prefer to operate with 2m of water depth to launch in a controlled manner, a modest ballast and trim system is required to maintain this sill depth in different loading conditions. The well deck is too small to dock LCUs. In addition to deploying EFVs, this design has the capability to land an LCU's ramp to load or offload troops, vehicles and equipment. The stern is also designed to allow an LCU to transfer vehicles, equipment and personnel to and from the LSD (EFV) by dropping its bow ramp onto a designated LCU operations section in the stern of the LSD. This is only intended to occur in calm conditions due to the difference in the seakeeping capabilities of the LCU and the LSD. This differs from current amphibious ships with large floodable well decks where the LCU can float into the amphibious ship. The LSD (EFV) cannot transport LCUs.

The cross-structure linking the main hull and side hulls is solely dedicated to the stowage of EFVs and has sufficient deck height to accommodate these, as do the decks between the cross-deck and the launch area. The EFV stowage deck could also be used for other vehicles and equipment either for transportation on LCUs or with the aviation capability as there is ramp access to and from both the launch area and the flight deck from the EFV stowage area. An embarkation point is located on the main deck with access to the flight deck, the EFV stowage area (by ramp) and to a stores elevator.

Sufficient fuel is carried to refuel each EFV twice.

Operationally, this ship would be able to deploy a large number of troops with their personal equipment to an inshore location very quickly. Equipment, other than personal equipment, could not be transported by EFV, but with the ability to transfer equipment to and from LCUs and with aviation capability, some heavy equipment could also be deployed from this ship. This ship would be required to work in conjunction with other amphibious ships to support the displacement or air cushion landing craft required to provide heavy equipment lift capability.

The unique properties of the design would allow for a fundamentally different mode of operation in which the LSD(EFV) was deployed with the MEB for the initial assault and once all EFVs were safely ashore, would retire to the intermediate support base for further EFV vehicles, while the remainder of the Expeditionary Strike Group supported the ashore elements. Use for alternate missions, such as a logistics shuttle ship, has not been explored.

3.2. Principal Characteristics and General Arrangement

Based on the requirements set and the design method previously outlined, the principal characteristics shown in Table 5 were determined for this concept design.

A general arrangement for this ship was developed. A schematic of the main hull inboard profile is shown Figure 6. Appendix B contains a more detailed general arrangement.

Mission orientated spaces were located in the stern to meet EFV launch area requirements and noting the convenience of locating both the flight deck and hangar at the aft of the weather deck. A large vehicle storage deck was incorporated between the flight deck and EFV launch area providing good access to both. Medical facilities were located just aft of the hangar on the top deck to allow casualties to be easily embarked by either sea or air.

All accommodation is located in the superstructure and is divided by rank with crew and troop accommodation kept separate. The galley and associated stores are located to provide easy access to all the messes and allow stores to be embarked and stowed easily.

	Displacement (mt)	23,830
Enclosed Volume	**Hull and Box Section (m^3)**	62,050
	Superstructure (m^3)	37,680
	Total (m^3)	99,730
Length	**Main Hull (Waterline) (m)**	203.6
	Side Hull (m)	61.1
Beam	**Overall (m)**	42
	Main Hull (m)	18
	Side Hull (m)	4.5
Draft	**Main Hull Draft (m)**	8.82
Depth	**Main Hull Depth (m)**	18
Speed	**Sustained (knots)**	21.4
	Trial (knots)	23.5
Power	**Propulsive (MW)**	40
	Hotel (MW)	8
	Installed (MW)	48
Endurance	**Range @ 12 knots (NM)**	15,000
	Stores (days)	45
Accommodations	**Troops**	1,000
	Crew	360
Mission Loads	**EFVs**	48
	Cargo (m^3)	5,100

Table 5 - LSD (EFV) Principal Characteristics

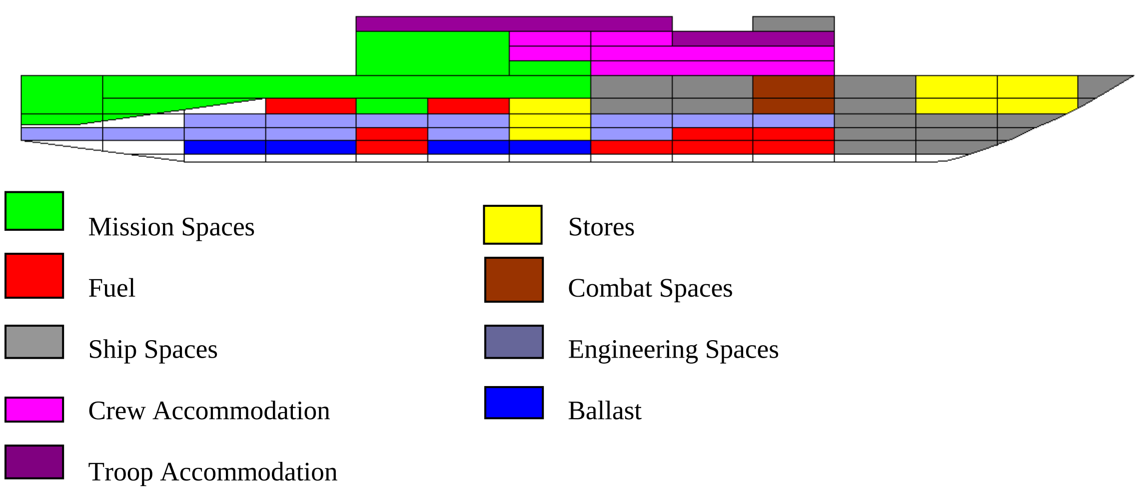


Figure 6 - LSD (EFV) Main Hull Inboard Profile Schematic

The main stores areas are located directly below the primary embarkation point with stores elevators connecting the stores and magazine to this area. Ballast is used to maintain the required water depth in the launch area to allow EFV operations. This is provided towards the aft of the ship so that trim can be induced with a minimum amount of ballast. Fuel tanks are distributed along the length of the ship to help maintain the trim as fuel is consumed, to allow fuel to be transferred between tanks to adjust trim as necessary and to reduce vulnerability so that, if one fuel tank is compromised, others can be used.

3.3. Weight and Volume

The weight summary for LSD (EFV) is shown in Table 6. The volume summary for LSD (EFV) is shown in Table 7.

SWBS Group		**Weight (mt)**
100 – Hull Structure		8,480
200 – Propulsion		840
300 – Electric Plant		870
400 – Control		490
500 – Auxiliary Systems		1,920
600 – Outfitting + Furnishings		1,250
700 – Armament		230
Lightship		**14,080**
Lightship plus 10% Margin		**15,488**
800 – Loads	Personnel	150
	Fuel	3,780
	Vehicles	1,500
	Cargo	1,970
	Misc. - Liquids	580
	Misc. – Other	360
	Total	8,340
Full Load Displacement		**23,828**

Table 6 – Weight Summary for LSD (EFV)

SSCS Group	**Total Volume (m^3)**	**Superstructure Volume (m^3)**	**Hull Volume (m^3)**
Group 1 – Combat, Control, Aviation, Magazines, Stores	28,330	6,970	21,360
Group 2 – Accommodation, Medical	23,780	11,660	12,130
Group 3 – Well Deck and Vehicle Deck, Offices, Stores, Fuel	29,690	14,750	14,930
Group 4 – Engineering Spaces	8,680	880	7,810
Total without 10% Margin	90,480	34,250	56,230
Total with 10% Margin	**99,730**	**37,680**	**62,050**

Table 7 - Volume Summary for LSD (EFV)

3.4. Hull Form

From the displacement and hull volume calculated above, parameters including beam, hull depth, side hull length and hull coefficients were adjusted to meet required criteria. These criteria included:

- Adequate but not excessive GM.
- Well deck freeboard requirements to allow EFVs to be launched.
- Layout constraints requiring a minimum main hull beam to launch EFVs and allow ramp transfer with LCUs.
- Adequate side hull beam to accommodate diesel machinery.
- Main and side hulls proportioned to avoid adverse whipping.

The coefficients in Table 8 were selected in conjunction with the parameters in Table 5.

	Main Hull	Side Hull
C_B	0.65	0.45
C_P	0.68	0.55
C_M	0.96	0.82
C_W	0.81	0.71

Table 8 - LSD (EFV) Hull Form Coefficients

3.5. Resistance and Powering

The estimated speed power curve for the LSD (EFV) is shown in Figure 7

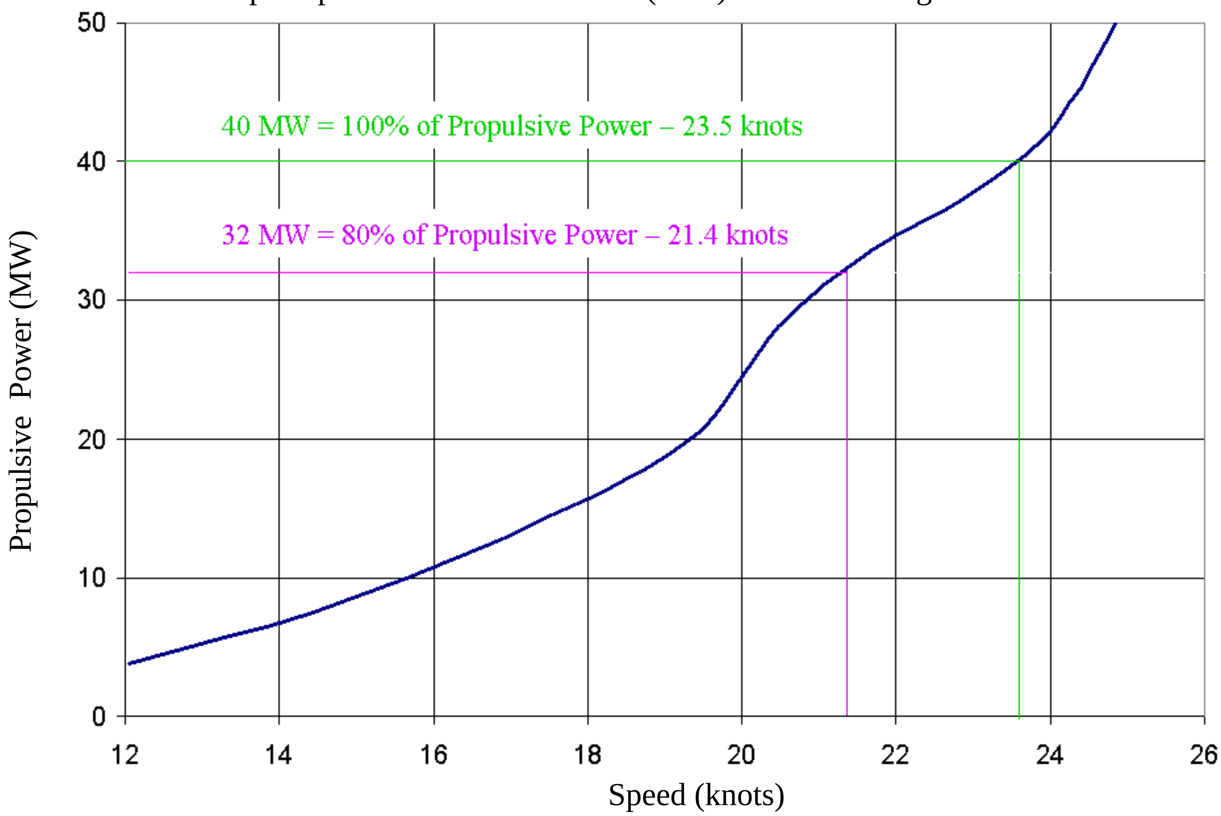


Figure 7 - Speed Power Curve for LSD (EFV)

The LSD (EFV) can maintain a sustained speed on 21.4 knots with 32 MW of propulsive load. An estimated trial speed of 23.5 knots would be achieved with 40 MW of propulsive power.

The hotel load was estimated from data for other similar ships scaled by enclosed volume. Hotel load for LSD (EFV) was estimated to be 8 MW, giving a total maximum load of 48 MW. Six Wartsila 16V32 diesel generators were selected to provide this power. Each generator has an output of 8 MW. These particular diesel generators were selected to fit into side hulls, given the narrow hull dimensions.

3.6. Stability and Hydrostatics

The ships stability was analyzed in several different conditions to find the GM of the ship and to assess if relevant stability criteria are met. The conditions assessed were:

1. Full load condition, fully laden with equipment, fuel and stores.
2. Full load condition and ballasted for well dock operations with the EFV launch bay flooded.
3. Light ship condition, with no operational equipment and 20% of fuel and stores.
4. Light ship condition, with no operational equipment and 20% of fuel and stores, ballasted to allow the EFV launch bay to be flooded.
5. Light ship condition, with no operational equipment and 20% of fuel and stores, ballasted and with the EFV launch bay flooded.

These conditions were used to provide an overview of the ships hydrostatics and stability. Further conditions will need to be analyzed to fully understand the different conditions experienced particularly during EFV offload and ship ballasting operations. Hydrostatic curves can be found in Appendix D.

The hydrostatic details of these conditions are outlined in Table 9. Note, the draft at aft perpendicular is quoted as this must be kept as near constant as possible for offload operations to be undertaken.

	1	**2**	**3**	**4**	**5**
Displacement (mt)	23,831	24,070	19,011	19,976	20,215
Draft (Midships) (m)	8.82	8.92	7.56	7.70	7.80
Draft (Aft Perpendicular) (m)	9.12	9.63	6.16	8.18	9.56
LCG from Midships (m, + to bow)	-0.54	-1.28	3.13	-1.04	-1.90
KG (m)	11.35	11.30	12.05	11.04	10.98
GM (m)	2.49	2.60	3.55	4.65	2.67
Trim (m, + by the bows)	-0.30	-0.71	1.40	-0.48	-1.90
Moment to Change Trim by 1 cm (mt-m/cm)	426	431	426	427	362

Table 9 - Hydrostatic Data for LSD (EFV)

These results suggest that operations could be undertaken at a range of conditions between the full load and lightship conditions analyzed here, although further analysis of each condition would be required to confirm this. Righting arm curves were calculated for all cases. The GZ curve for the full load condition is shown in Figure 8.

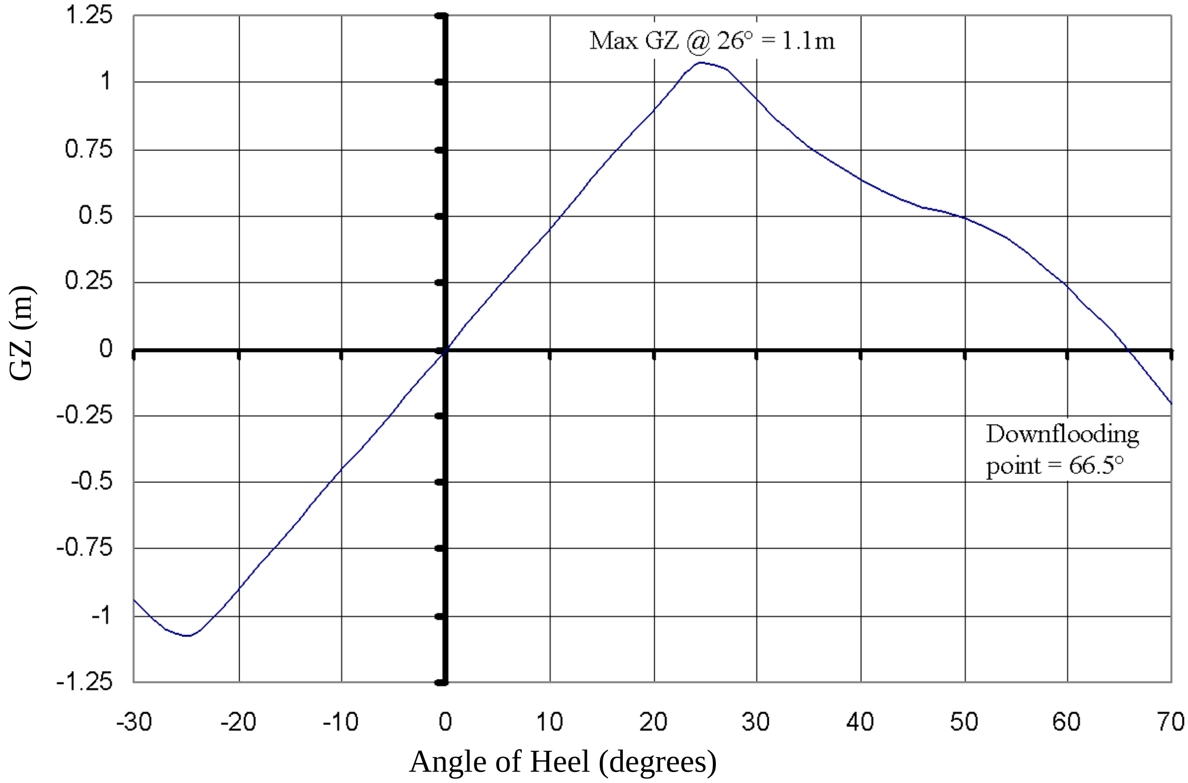


Figure 8 - GZ Curve for LSD (EFV) in Deep Condition

Analysis against USN stability criteria in each condition yielded the results shown in Table 10, shown alongside other useful stability characteristics.

Criteria		**Limits**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Wind Heeling	**Lever @100 kts**	0.6x $GZ_{MAX}/GZ_{EQ}>1$	5.26	4.93	3.54	5.17	3.83
	Areas @100 kts	A1/(A2 x 1.4)>1	1.63	1.67	1.28	2.16	2.21
Area under curve from 0-30° (m°)			20.05	20.26	19.36	25.30	26.20
Area under curve from 0-40° (m°)			28.24	28.55	28.67	39.81	40.06
Area under curve from 30-40° (m°)			8.19	8.30	9.31	13.81	13.86
GZ at 30° (m)			0.98	0.99	1.17	1.55	1.55
Angle of max GZ (°)			25.71	25.55	29.89	29.36	29.13
GM (m)			2.49	2.60	3.55	4.65	2.67

Table 10 - Stability Criteria and Characteristics for LSD (EFV)

3.7. LSD (EFV) Design Summary

A design has been developed to carry 48 EFVs and 1,000 troops to allow a large number of troops to be rapidly deployed to a position on land in a single amphibious assault wave.

The design has a large vehicle stowage deck in the cross-structure and a stern arrangement with a small floodable/pumpable well deck under the waterline. The vehicle stowage deck is relatively open, free of obstruction and flexible, allowing a significant flexibility in loading arrangements without compromising damage stability. From the well deck, EFVs can be rapidly launched. Although EFVs have no capability to carry large equipment, this ship also operates helicopters and can land an LCU's ramp (although not take the LCU on board) to transfer equipment and vehicles to shore. The stern arrangement around the well deck requires more detailed development to optimize the layout of this area.

The operational impact of having a ship carrying such a large number of one type of craft has not been fully investigated. It is assumed that a major amphibious assault will benefit from the ability to offload all 48 EFVs quickly and then have the LSD(EFV) retire from more exposed operational areas. However, it is envisioned that this concept could be reduced in scope to carry fewer EFVs if required.

Initial analysis has indicated that the design meets intact stability requirements although, as the design progresses, this would require reassessment. A comprehensive damage stability is also required.

The design is considered to have several significant benefits in that the impact of the well deck and vehicle stowage spaces on the vessel are less than usual on a traditional monohull landing ship. The vessel is also capable of allowing a single wave of up to 48 EFVs to be rapidly launched, limited only by the speed of the EFVs as they are driven into the well deck.

4. LANDING SHIP DOCK (LANDING CRAFT AIR CUSHION)

4.1. Concept Overview

The mission of this concept ship is to deploy 454 troops and Marine Expeditionary Unit Tier 1 associated vehicles and equipment to a base inland over an assault beach. A concept was identified carrying up to three LCACs while providing a vehicle deck with stowage accordance with the requirements outlined in Appendix A. This concept does not have the ability to operate displacement landing craft and, as a result, is more optimized to the requirements of an LCAC based mode of operations. This concept would also have the capability to operate two CH-53E Super Stallions.

LCACs require between 0 to 6" of water over the sill of the deck to launch. This design incorporates a large launch bay at the stern with the deck at the waterline to allow LCAC operations. This minimizes the ballast system required to allow LCAC operations in any ship condition (from lightship through to full load). The LCAC deck could also be used to land an LCU ramp to allow transfer of vehicles and equipment, although this concept has not been fully investigated. EFVs could potentially be operated from the LCAC launch bay via a ramp but this has not been considered in this design.

This design has the capability to deploy both troops and equipment similar to the LPD-17 class, when operating only LCACs. In addition to three LCACs, this design includes a 2,100m^2 vehicle deck, sized based on the requirements stated in Appendix A. Accommodation is provided for 454 troops including officers, again in accordance with the requirements given.

	Displacement (mt)	22,404
Enclosed Volume	**Hull and Box Section (m^3)**	63,049
	Superstructure (m^3)	37,411
	Total (m^3)	100,461
Length	**At Waterline (m)**	190
	Side Hull (m)	57
Beam	**Overall (m)**	45
	Main Hull (m)	18
	Side Hull (m)	4.5
	Draft (m)	8.87
	Depth (m)	19
Speed	**Sustained (knots)**	21.6
	Trial (knots)	23.7
Power	**Propulsive (MW)**	40
	Hotel (MW)	8
	Installed (MW)	48
Endurance	**Range @ 12 knots (NM)**	15,000
	Stores (days)	45
Accommodations	**Troops**	454
	Crew	360
Mission Loads	**LCACs**	3
	Cargo (m^3)	5,100
	Vehicle Stowage Space (m^2)	2,100

Table 11 - LSD (LCAC) Principal Characteristics

Vehicle stowage deck space is provided in the cross-structure surrounding the well deck. This provides a large open space with good access to the LCACs and the top deck. The cross-structure has a deck height of 5m to allow access to the tallest vehicles (Medium Tactical Replacement Vehicles, 3.53m high).

An embarkation point is located on the main deck alongside the hangar giving good access to the flight deck, medical facilities, stores and the vehicle deck (via a ramp). The ramp also allows vehicles stowed on the vehicle deck to be moved to the flight deck if required.

Hull form selection was driven by the need for a large LCAC launch bay at the stern. Given the lack of a floodable well deck, this ship would not be able to take other ship to shore connectors such as the LCU in the well deck.

4.2. Principal Characteristics and General Arrangement

Based on the requirements set and the method previously outlined the principal characteristics shown in Table 11 were determined for this design. A general arrangement for this concept design was developed. A schematic of the main hull inboard profile is shown in Figure 9. Appendix C contains a more detailed arrangement drawing.

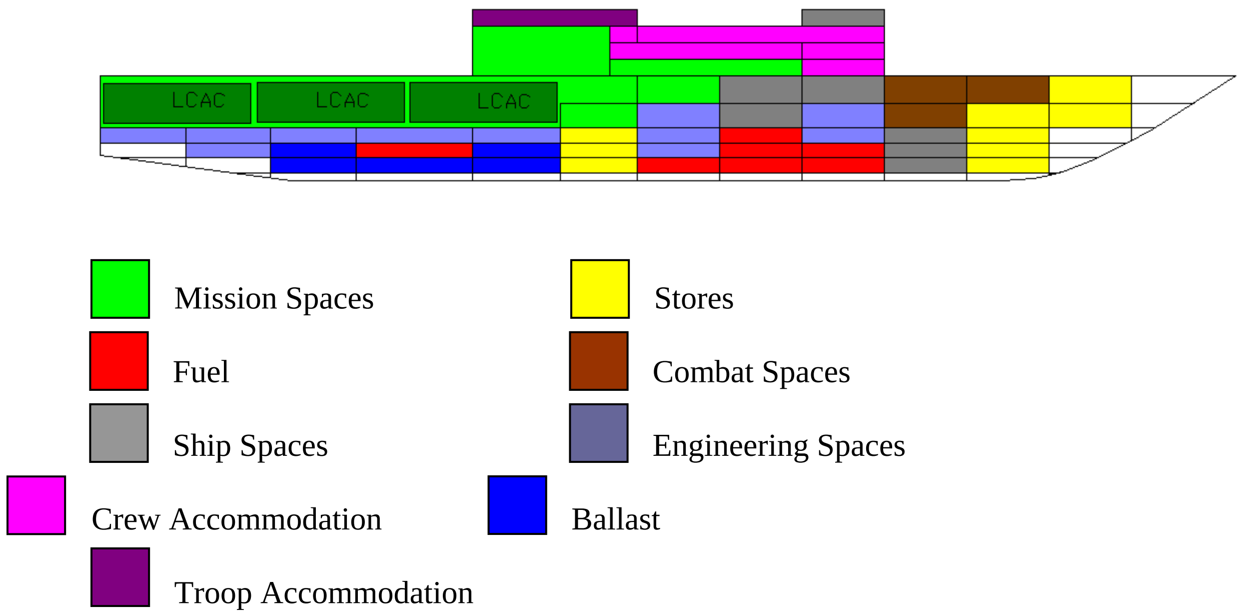


Figure 9 - LSD (LCAC) Main Hull Inboard Profile Schematic

As Figure 9 shows, all the mission-orientated spaces are located towards the aft end centered on the well deck. Given the necessary movement of equipment and personnel between the vehicle deck and flight deck, it is convenient to locate the flight deck and hangar at the aft end. Medical facilities are located just aft of the hangar to allow easy transportation of casualties from the flight deck, vehicle deck or embarkation point. Medical facilities are also located near accommodation for crew convenience.

All accommodation is located in the superstructure. Accommodation is divided by rank and troops have their own accommodation areas separated from the ships crew. Crew accommodation was located as near as possible to work spaces.

The main stores areas are located directly below the primary embarkation point with lifts connecting the stores and magazine to this area.

Ballast is required to maintain the required water depth for launch of LCACs. This is provided in the main hull towards the aft of the ship to control draft and trim with a minimum amount of ballast. Fuel tanks are distributed along the length of the ship to help maintain the trim as fuel is consumed and allow fuel to be transferred between tanks to adjust trim as necessary.

4.3. Weight and Volume

The weight summary for LSD (LCAC) is shown in Table 12. The volume summary for LSD (EFV) is shown in Table 13.

SWBS Group		Weight (mt)
100 – Hull Structure		8,540
200 – Propulsion		840
300 – Electric Plant		800
400 – Control		490
500 – Auxiliary Systems		1,750
600 – Outfitting + Furnishings		1,040
700 – Armament		230
Lightship		**13,690**
Lightship plus 10% Margin		**15,059**
800 – Loads	Personnel	90
	Fuel	3,780
	Vehicles	1,700
	Cargo	1,040
	Misc. - Liquids	480
	Misc. - Other	260
	Total	7,350
Full Load Displacement		**22,409**

Table 12 - Weight Summary for LSD (LCAC)

Group	Total Volume	Volume in Superstructure	Volume in Hull
Group 1 – Combat, Control, Aviation, Magazines, Stores	22,780	7,560	15,220
Group 2 – Accommodation, Medical	18,650	11,450	7,200
Group 3 – Well Deck and Vehicle Deck, Offices, Stores, Fuel	41,670	14,050	27,620
Group 4 – Engineering Spaces	8,230	960	7,270
Total without 10% margin	91,330	34,020	57,310
Total with 10% margin	**100,463**	**37,422**	**63,041**

Table 13 - Volume Summary for LSD (LCAC)

4.4. Hull Form

From the displacement and hull volume calculated above, parameters including beam, hull depth, side hull length and hull coefficients were adjusted to meet required criteria. These criteria included:

- Adequate but not excessive GM
- Well deck freeboard requirements to allow LCACs to be launched
- Layout constraints requiring a minimum main hull beam to accommodate LCACs on cushion
- Adequate side hull beam to accommodate machinery
- Main and side hulls proportioned to avoid adverse whipping

The coefficients in Table 14 were selected in conjunction with parameters in Table 11.

	Main Hull	Side Hull
C_B	0.65	0.45
C_P	0.68	0.55
C_M	0.96	0.82
C_W	0.81	0.71

Table 14 - LSD (LCAC) Hull Form Coefficients

4.5. Resistance and Powering

The estimated speed power curve for the LSD (LCAC) is shown in Figure 10.

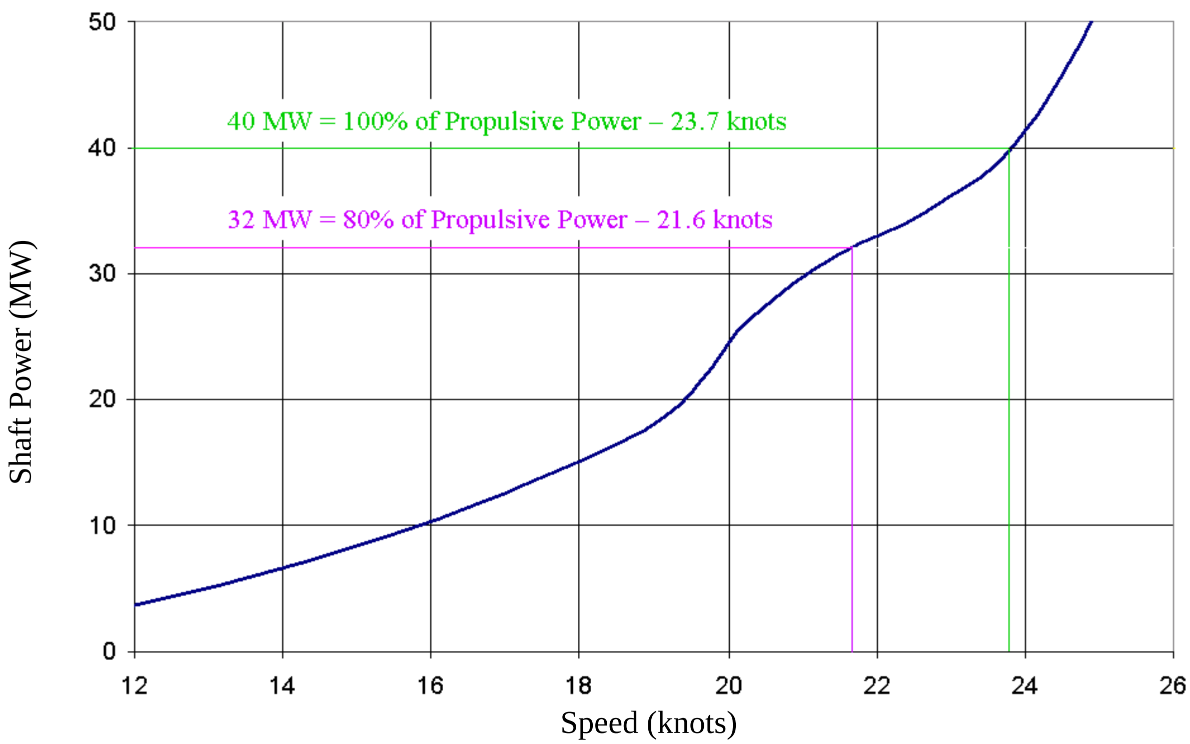


Figure 10 - Speed Power Curve for LSD (LCAC)

The LSD (LCAC) can maintain a sustained speed of 21.6 knots with 32 MW of propulsive load. An estimated trial speed of 23.7 knots would be achieved with 40 MW of propulsive power.

Hotel load was estimated based on data for other similar ships, scaled on enclosed volume. Hotel load for LSD (LCAC) was estimated to be 8 MW, giving a total maximum load of 48 MW. Six Wartsila 16V32 diesel generators were selected to provide this power. Each generator has an output of 8 MW, so the installed power for the LSD (LCAC) is 48 MW. These particular diesel generators were selected to fit into side hulls.

4.6. Stability and Hydrostatics

The ships stability was analyzed in several different conditions to find the GM of the ship and to assess if relevant stability criteria are met. The conditions assessed were:

1. Full load condition, fully laden with equipment, fuel and stores
2. Light ship condition, with no operational equipment and 20% of fuel and stores
3. Light ship condition, with no operational equipment and 20% of fuel and stores, ballasted to allow the LCACs to be launched

These conditions were used to provide an overview of the ships hydrostatics and stability. Further conditions will need to be analyzed to fully understand the different conditions experienced particularly during LCAC operations. Hydrostatic curves can be found in Appendix E.

The hydrostatic details of these conditions are outlined in Table 15. The draft at the aft perpendicular is quoted, as this must be kept as near constant as possible for LCAC operations to be undertaken.

	1	**2**	**3**
Displacement (mt)	22,404	20,564	22,376
Draft (Midships) (m)	8.87	8.33	8.86
Draft (Aft Perpendicular) (m)	10.30	9.20	10.36
LCG from Midships (m, + to bow)	-2.35	-1.56	-2.49
KG (m)	12.73	12.37	11.37
GM (m)	2.06	3.37	3.46
Trim (m, + by the bows)	-1.43	-0.87	-1.50
Moment to Change Trim by 1 cm (nm)	371	371	371

Table 15 - Hydrostatic Data for LSD (LCAC)

These results suggest that operations could be undertaken at a range of conditions between the full load and lightship conditions analyzed here, although analysis of each condition would be required to confirm this.

Righting arm curves were calculated for all cases. The GZ curve for the full load condition is shown in Figure 11.

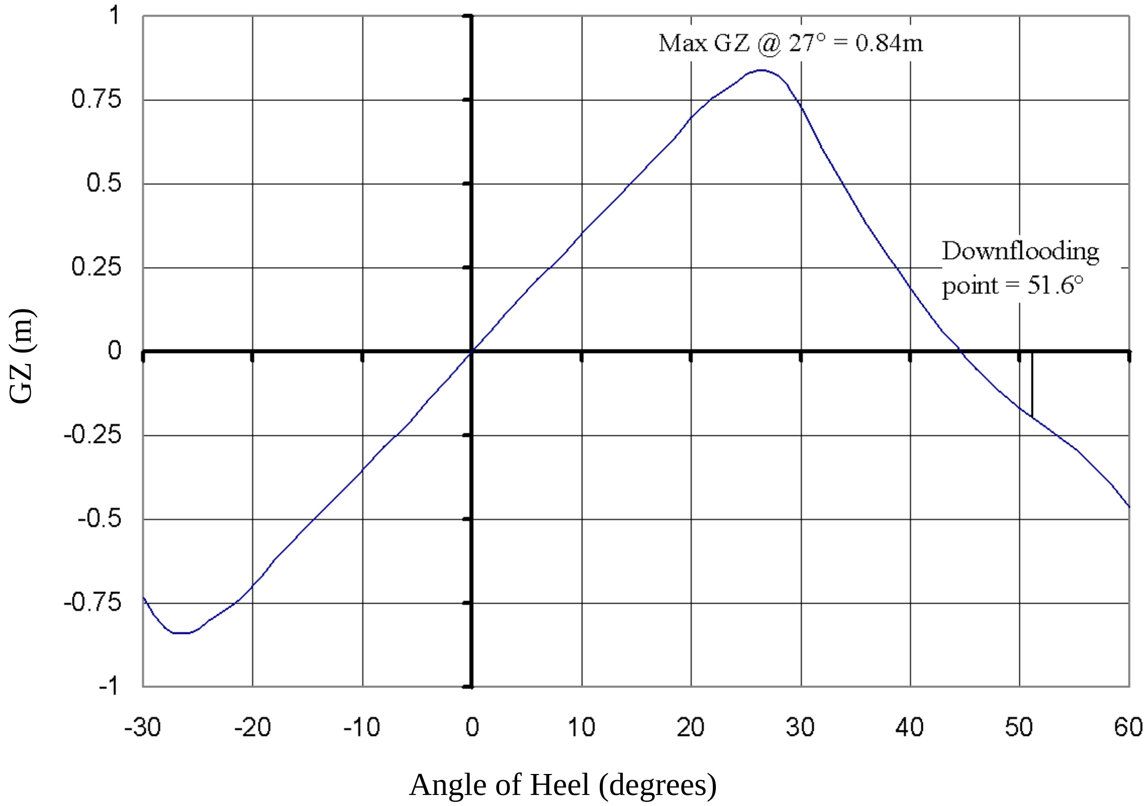


Figure 11 - GZ Curve for LSD (LCAC) in Deep Condition

Analysis against USN stability criteria in each condition, alongside calculation of IMO GZ curve shape characteristics yielded the results shown in Table 16.

Criteria		Limits	Case 1	Case 2	Case 3
Wind Heeling	**Lever @100 kts**	0.6 x GZ_{MAX}/GZ_{EQ}>1	3.41	3.57	5.51
	Areas @100 kts	A1/(A2 x 1.4)>1	1.01	1.28	2.17
Area under curve from 0-30° (m°)			15.78	19.31	25.32
Area under curve from 0-40° (m°)			20.90	27.87	37.64
Area under curve from 30-40° (m°)			5.12	8.56	12.31
GZ at 30° (m)			0.72	1.12	1.39
Angle of max GZ (°)			27.02	29.10	27.42
GM (m)			2.06	3.37	3.42

Table 16 - Stability Criteria for LSD (LCAC)

4.7. LSD (LCAC) Design Summary

This design provides the capability to deploy 454 Troops and vehicles with a combined stowed footprint of 2,100 m^2. This is achieved via three LCACs, although helicopters will also be operated.

This design is focused on a ‘dry’ well deck for LCAC operations, with between 0-6” of water over the sill of the deck. This is located in the main hull with the vehicles stowed in the cross-structure surrounding the well deck to provide optimum efficiency in loading and unloading and in use of space onboard the ship. A ballast and trim system is used to ensure that LCAC operations can be undertaken regardless of the loading condition of the ship.

The well deck occupies the full beam of the main hull. The procedure for loading vehicles onto LCACs is similar to current well deck practices. This involves driving vehicles through the forward LCACs to load the aft LCACs. As the well deck was sized to accommodate LCACs on cushion, when the LCACs are not on their cushions there will be sufficient clearance for longitudinal access in the well deck for personnel, cargo and equipment.

The LCAC only design has the ability to operate LCAC vessels with a high degree of efficiency as it does not need to vary it’s trim and draught to operate both air cushion and displacement craft. As a result the LCACs would be able to complete more sorties in a given amount of time. In addition the vessel would have a smaller, less intrusive, ballast system saving significant amounts of design and construction funding.

Initial analysis has indicated that the ship meets intact stability requirements although as the design is progressed, this would require continuous reassessment. A comprehensive damage stability assessment is also required.

5. SUMMARY

Two concept designs have been developed as potential LSD replacement ships. The designs attempt to move away from traditional large well deck centered ships capable of operating LCUs, LCACs and amphibians to reliance on a single craft type, either the LCAC or EFV surface connector. This allows designs to be optimized around operation of a specific surface connector. Although the ships will have less generic capability, the operation of each craft type will be more efficient.

The LSD(EFV) design has demonstrated the form of a vessel optimized to deliver a single wave consisting of all the amphibious vehicles in a Marine Expeditionary Unit. This allows high intensity amphibious operations to be undertaken with maximum speed. The vessel’s arrangements are designed to permit rapid departure of the amphibious vehicles, only limited by the speed of the vehicle as it enters the water.

The LSD(LCAC) has demonstrated a vessel dedicated to the use of air cushion landing craft. The shallow well deck is defined by the requirement to dock three LCACs. The upper decks are designed to provide access to the LCACs for the embarked vehicles.

Both vessels demonstrate the impact of removing the traditional requirement of Landing Ship Docks to provide a significant well dock and a ballast system to allow the operation of the dock with displacement landing craft.

Both designs share some common features in that they are both of Trimaran form, to allow the separation of ship's machinery from the stowage and operational areas for the landing craft or amphibious vehicles. In addition both designs are based on a common propulsion system based on six Wartsila and integrated electric propulsion with side hull located propulsion motors. In addition to the common system design features, the gross hull dimensions, form and properties are similar.

As a result of the high degree of commonality between the designs it is possible to postulate a common hull design series which with some modification in to two sub variants, could be produced to meet both the LSD(LCAC) and LSD(EFV) requirements. Provision of one of each vessel variant into an Expeditionary Strike Group would supply two vessels with flexibility to deploy LCACs and EFVs very efficiently.

Future work required on both these designs includes

- Assessment of maneuverability and the impact of placing control surfaces on the main hull or side hulls or using azimuthing pods
- Development of improved trimaran hull forms and appendages including improved powering estimates and optimization of side hull positioning
- Seakeeping analysis
- Structural design to improve the structural weight estimate
- Investigation of alternative machinery and propulsor concepts
- Comprehensive damage stability analyses
- Design and arrangement of engineering systems

It is recommended that a further study looks at specifically refining the LSD designs to develop a single design with two variants, with minimal change.

REFERENCES

1) 'Jane's Fighting Ships 2007-2008' (110th edition), editor Cmdr S. Saunders RN, Cambridge University Press (UK), ISBN – 13 978-0-7106-27995.

2) 'Amphibious Ships and Landing Craft Data Book', U.S. Marine Corps, 29 August 2001, MCRP 3-31B, PCN 144 000103 00.

3) Harris, Nancy, "Effective Horsepower and Seakeeping Tests on a Trimaran Model", March 1999, USNA Hydrodynamics Lab Report EW-01-99.

APPENDIX A – INDICATIVE LIFT REQUIREMENTS FOR 2015 MARINE EXPEDITIONARY UNIT

The following information was provided by Mr. Steve Wynn (NAVSEA 05D) relating to MEU requirements (Table A1 - 1) and LSD requirements (Table A1 - 2) based on the predicted 2015 MEU. Note the values quoted in these tables are estimates only, and were solely used for the initial design concept development.

TIER 1			
Lift Component	**Light**	**Medium**	**Heavy**
Vehicle Stowage (ft^2)	57,656	63,303	67,376
Cargo Capacity (ft^3)	216,000	216,000	216,000
Aircraft	28	35	41
Personnel	2807	2807	2807
LCAC spots	6	8	8
TIER 2			
Lift Component	**Light**	**Medium**	**Heavy**
Aviation Spaces (ft^2)	27,533	41,090	411,21
MEU Space (ft^2)	52,036	52,036	52,036
MEU Surge (PAX)	386	386	386
Aviation Fuel (Gallons)	979,000	1,672,000	1,850,000

Table A1 - 1 - 2015 MEU Estimated Composition

TIER 1			
Requirement	**Light**	**Medium**	**Heavy**
Troops	424	424	424
Vehicle (ft^2)	13,700	19,300	23,400
Cargo Capacity (ft^3)	5,100	5,100	5,100
LCAC (spots)	2	3	3
Aviation (spots)	2	2	2
TIER 2			
Requirement	**Light**	**Medium**	**Heavy**
MEU Offices (ft^2)	10,700	10,700	10,700
ACE Offices (ft^2)	0	0	0
MEU Surge (PAX)	101	101	101

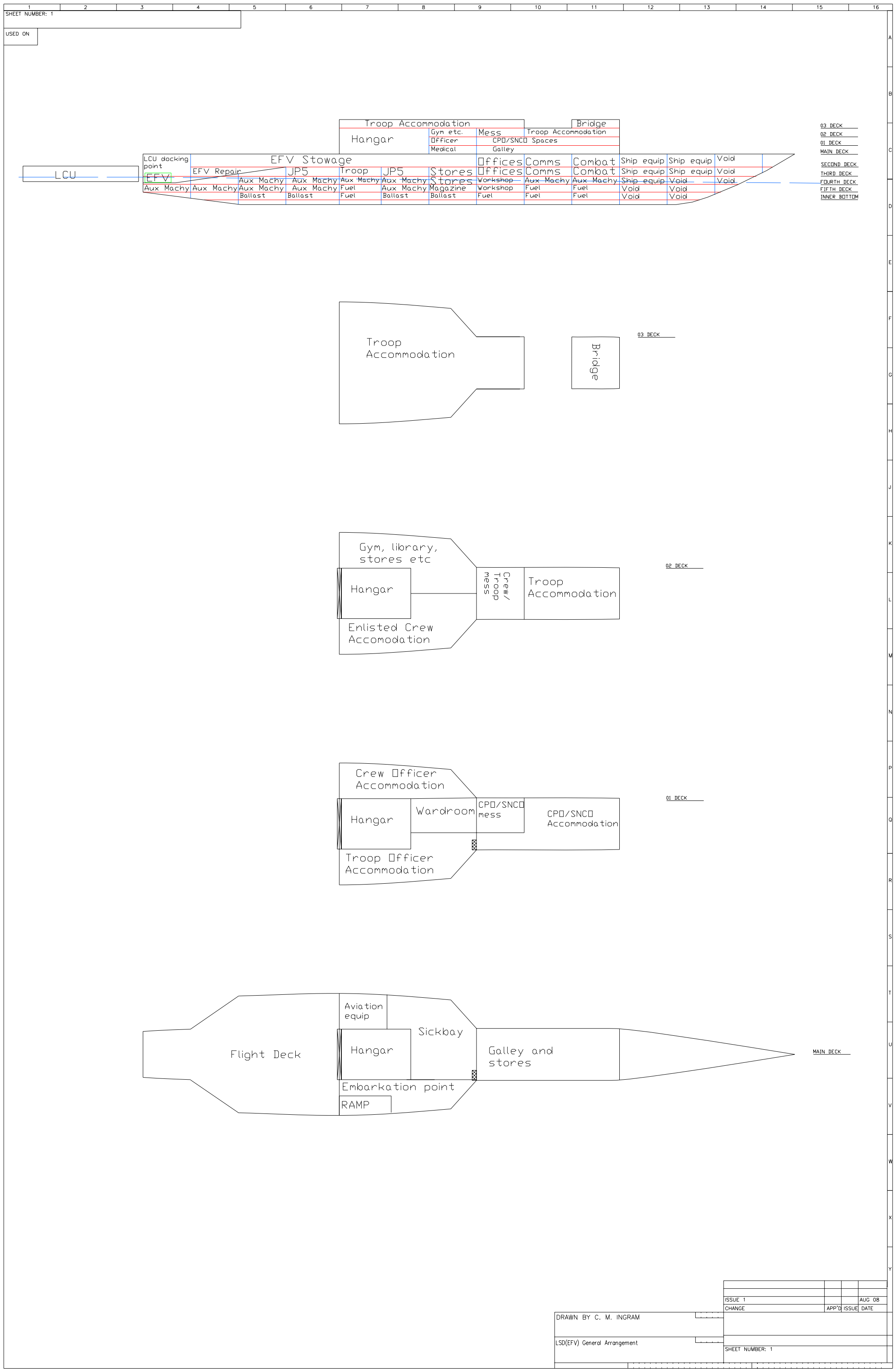
Table A1 - 2 - 2015 LSD Estimated Lift Requirements

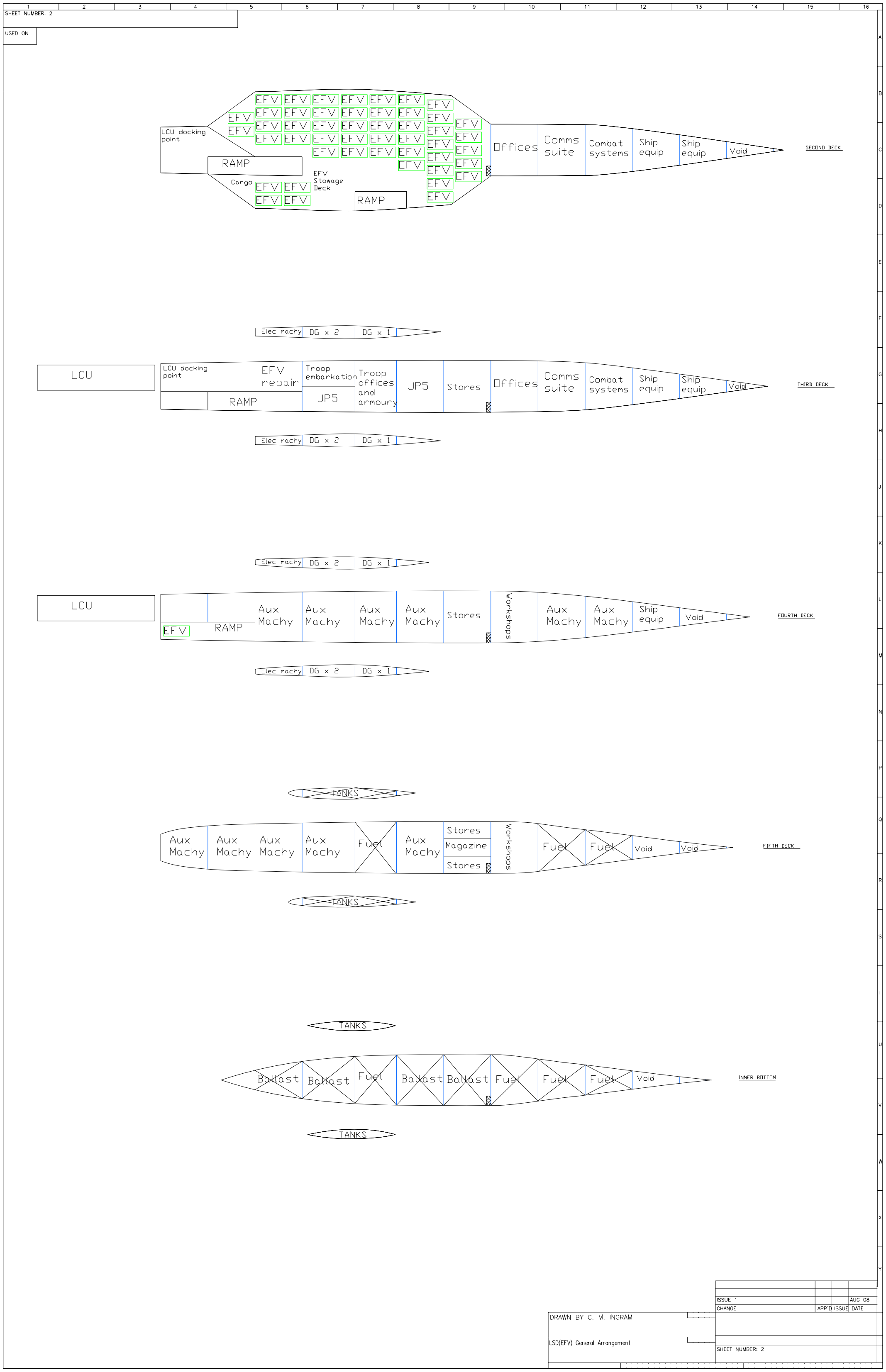
Additionally, the projected MEB used by the FY05 'Seabase to Treeline Connector Innovation Cell' (N.A. Good, N.P. Milbert, J.R. Chafin) is shown in Table A1 - 3, as this influenced the study requirements.

UNIT	PERSONNEL	HMMWV	MRC	TRLR	FORKLIFT	MTVR	M198	LVS	M1A1 TANK	M88	AVLB	MEWSS	AAV	Q46	CBV	LAV
1 INFBN (REIN)	1,018	55	13	-	-	-	-	-	-	-	-	-	48	-	2	-
3 D/S BTRY	330	15	12	24	3	42	18	-	-	-	-	-	-	-	-	-
1 ARTY Q46 DET	8	4	-	-	-	-	-	-	-	-	-	-	-	4	-	-
1 LAR CO	133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25
1 TANK CO	85	4	1	-	-	-	-	-	14	1	-	-	-	-	-	-
1 TANK CO H&S DET	35	-	-	4	-	6	-	1	-	-	1	-	-	-	-	-
1 AAV CO	200	-	1	1	-	3	-	-	-	-	-	-	-	-	-	-
1 AAV CO H&S DET	35	2	-	-	-	3	-	-	-	-	-	-	-	-	-	-
1 CSS DET	178	6	3	-	4	67	-	1	-	-	-	-	-	-	-	-
1 RADBN DET	98	7	-	6	-	6	-	-	-	-	-	3	-	-	-	-
1 CE SRI DET	76	6	-	6	-	6	-	-	-	-	-	-	-	-	-	-
1 CE COMM DET	30	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	2,226	99	33	41	7	133	18	2	14	1	1	3	48	4	2	25

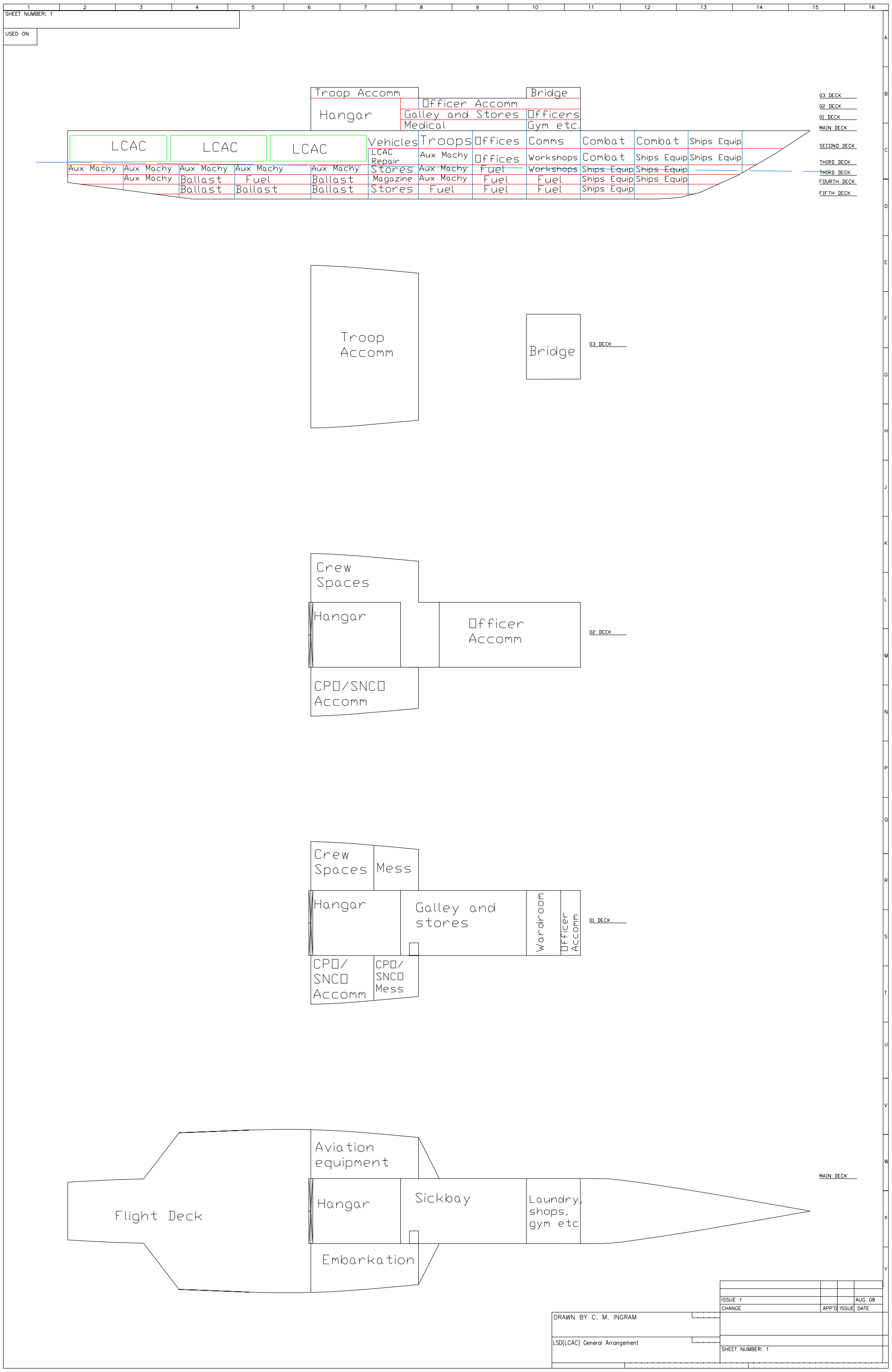
Table A1 - 3 - MEB Assault Element Table of Organization and Equipment

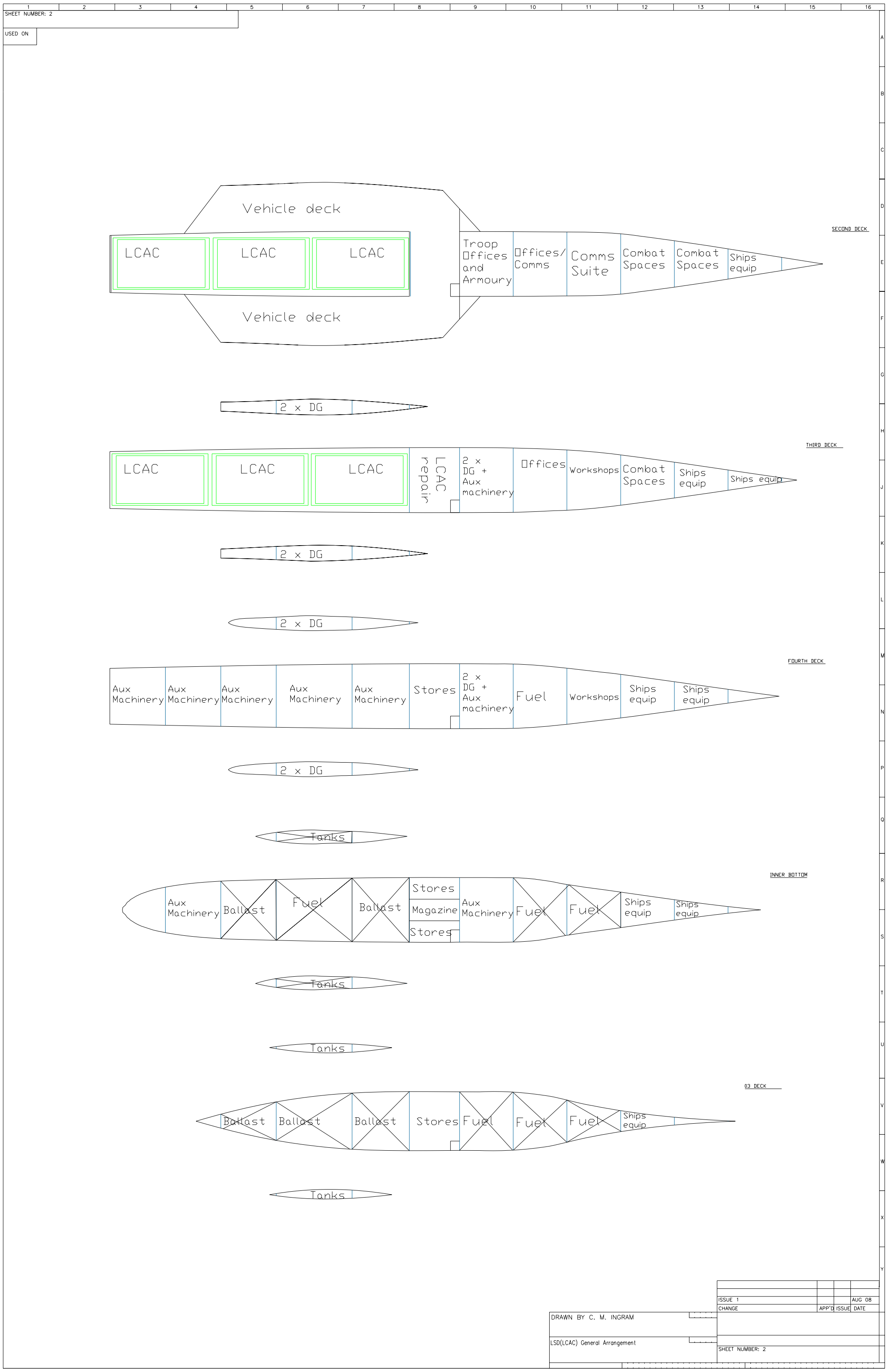
APPENDIX B – LSD (EFV) ARRANGEMENT




SHEET NUMBER: 2
USED ON
LCU docking point
RAMP
Cargo
EFV Stowage Deck
EFV
Offices
Comms suite
Combat systems
Ship equip
Void
SECOND DECK
Elec machy
DG x 2
DG x 1
LCU
EFV repair
Troop embarkation
JP5
Troop offices and armoury
Stores
THIRD DECK
Aux Machy
Workshops
FOURTH DECK
TANKS
Fuel
Magazine
FIFTH DECK
Ballast
INNER BOTTOM
ISSUE 1
AUG 08
CHANGE
APP'D
DATE
DRAWN BY C. M. INGRAM
LSD(EFV) General Arrangement

APPENDIX C – LSD (LCAC) ARRANGEMENT




SHEET NUMBER: 2
USED ON
Vehicle deck
LCAC
LCAC
LCAC
Vehicle deck
Troop Offices and Armoury
Offices/ Comms
Comms Suite
Combat Spaces
Combat Spaces
Ships equip
SECOND DECK
2 x DG
LCAC
LCAC
LCAC
LCAC repair
2 x DG + Aux machinery
Offices
Workshops
Combat Spaces
Ships equip
Ships equip
THIRD DECK
2 x DG
2 x DG
Aux Machinery
Aux Machinery
Aux Machinery
Aux Machinery
Aux Machinery
Stores
2 x DG + Aux machinery
Fuel
Workshops
Ships equip
Ships equip
FOURTH DECK
2 x DG
Tanks
Aux Machinery
Ballast
Fuel
Ballast
Stores
Magazine
Stores
Aux Machinery
Fuel
Fuel
Ships equip
Ships equip
INNER BOTTOM
Tanks
Tanks
Ballast
Ballast
Ballast
Stores
Fuel
Fuel
Fuel
Ships equip
03 DECK
Tanks
ISSUE 1
AUG 08
CHANGE
APP'D
ISSUE
DATE
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LSD(LCAC) General Arrangement
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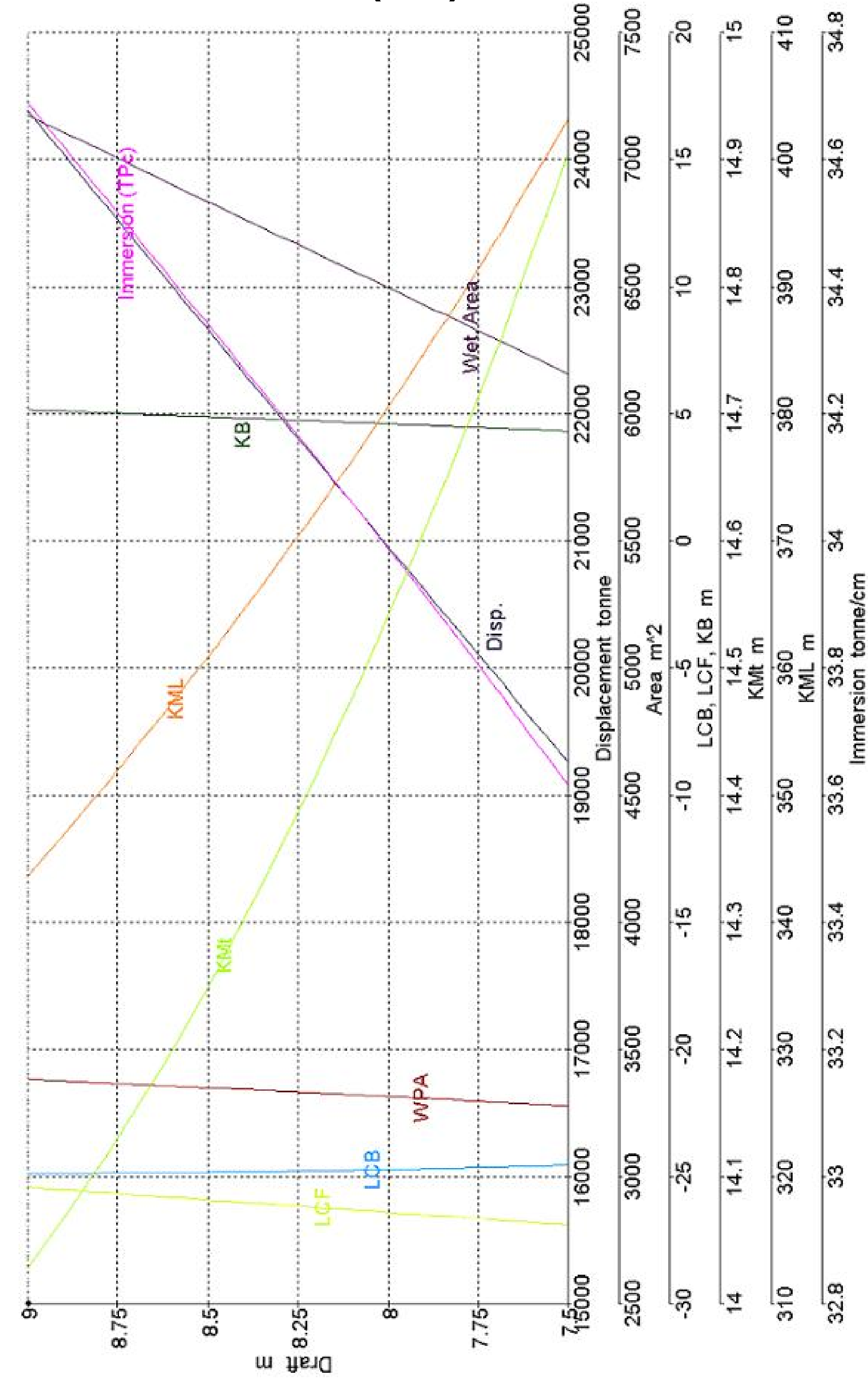
APPENDIX D – LSD (EFV) HYDROSTATIC CURVES



APPENDIX E – LSD (LCAC) HYDROSTATIC CURVES