NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

LOGISTICAL ANALYSIS OF THE LITTORAL COMBAT SHIP (LCS) OPERATING INDEPENDENTLY IN THE PACIFIC

by

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March 2008

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 2008	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE: Logistical Analysis of the Littoral Combat Ship (LCS) Operating Independently in the Pacific	5. FUNDING NUMBERS
6. AUTHOR(S) John P. Baggett	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

The LCS will be a small combatant designed to address many of the challenges facing the Navy in the 2002 Defense Planning Guidance (DPG). It will rely on newly developing mission modular technology that will allow the core component of LCS, the seaframe, to change out warfare mission packages to adapt it for different warfighting scenarios. Unlike the current combatants of the Navy, LCS will be a single-mission focused ship that will rely on still developing technology to conduct operations in one of three main areas: Anti-submarine Warfare (ASW), Mine Warfare (MIW) and Surface Warfare (SUW). Through models developed in Microsoft Excel this thesis evaluates how speed and different fuel reserve levels impact Littoral Combat Ship fuel consumption and endurance of the two approved versions of LCS, analyzes the implication of these findings and other possible mission limiting factors on Littoral Combat Ship logistics and analyzes how the current CLF force structure in the Pacific will affect overall mission capability of LCS.

14. SUBJECT TERMS Littoral Combat Ship, LCS, logistics, fuel consumption, fuel curve , Combat Logistics Force, PACFLT AOR , logistics planning factors, sustainment-at-sea, fuel capacity, fuel reserve levels, MIW, HA/DR, fuel prediction	15. NUMBER OF PAGES 118
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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**LOGISTICAL ANALYSIS OF THE LITTORAL COMBAT SHIP (LCS)
OPERATING INDEPENDENTLY IN THE PACIFIC**

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The LCS will be a small combatant designed to address many of the challenges facing the Navy in the 2002 Defense Planning Guidance (DPG). It will rely on newly developing mission modular technology that will allow the core component of LCS, the seaframe, to change out warfare mission packages to adapt it for different warfighting scenarios. Unlike the current combatants of the Navy, LCS will be a single-mission focused ship that will rely on still developing technology to conduct operations in one of three main areas: Anti-submarine Warfare (ASW), Mine Warfare (MIW) and Surface Warfare (SUW). Through models developed in Microsoft Excel this thesis evaluates how speed and different fuel reserve levels impact Littoral Combat Ship fuel consumption and endurance of the two approved versions of LCS, analyzes the implication of these findings and other possible mission limiting factors on Littoral Combat Ship logistics and analyzes how the current CLF force structure in the Pacific will affect overall mission capability of LCS.

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EXECUTIVE SUMMARY

The Defense Planning Guidance (DPG) of 2002 included the challenge that the Navy must be able to maintain an area devoid of mines for safe aircraft carrier operations, destroy or evade large numbers of submarines operating in littoral waters and have the capability to destroy numerous small anti-ship missile carrying combatants or weapons wielding merchant vessels without the support of carrier-based air power. In 2002, Admiral Vern Clark, Chief of Naval Operations, addressed these concerns when he introduced the vision for the future of the United States Navy titled "Sea Power 21". This concept was created to guide the Navy way of doing business and align it with the Joint Concept of Operations. In his vision, ADM Clark described how the new Littoral Combat Ship (LCS) would enable the Navy to control the littoral regions of the battlefield. The LCS will be a small combatant designed to address many of the challenges facing the Navy in the 2002 Defense Planning Guidance (DPG). It will rely on newly developing mission modular technology that will allow the core component of LCS, the seaframe, to change out warfare mission packages to adapt it for different warfighting scenarios. Unlike the current combatants of the Navy, LCS will be a single-mission focused ship that will rely on still developing technology to conduct operations in one of three main areas: Anti-submarine Warfare (ASW), Mine Warfare (MIW) and Surface Warfare (SUW).

Through models developed in Microsoft Excel, this thesis evaluates how speed and different fuel reserve levels impact Littoral Combat Ship fuel consumption and endurance of the two approved versions of LCS, analyzes the implication of these findings and other possible mission limiting factors on Littoral Combat Ship logistics and analyzes how the current Combat Logistics Force (CLF) force structure in the Pacific will affect overall mission capability of LCS.

The first analysis conducted on LCS involved using two sets of estimated fuel data to predict fuel consumption curves for LCS. Using these consumption curves an endurance analysis was then conducted to see how well LCS might perform compared to the parameters listed in the Capabilities and Development Document (N76, 2004). This

analysis showed that neither the Lockheed Martin (LM) nor General Dynamics (GD) LCS is able to meet the objective endurance range of 1,500nm at sprint speed. At the objective economical speed of 20kts only the GD version of LCS is able to meet an endurance range of 4,300nm. At the threshold sprint speed value of 40kts both versions of LCS meet the threshold endurance range of 1,000nm. Only the GD version of LCS meets the threshold requirement of a 3,500nm range at speed of greater than 18kts.

The endurance analysis for LCS also shows that the most economical speeds, the speed at which LCS has the longest range, for both the GD and LM versions are below the 18kt threshold value. Additionally, the endurance analysis noted a large disparity in range is created by the difference in the fuel capacity of the LM and GD versions of LCS, because GD has a much larger fuel capacity.

Once fuel consumption and endurance analysis is completed, a logistical analysis of LCS is done utilizing two distinct scenarios. The first scenario is an MIW scenario which places LCS on a 90 day patrol in the Western Pacific Ocean. During this scenario LCS is constrained by the Cardinal Rules described in Chapter I and the ROC/POE described in Chapter IV. Analysis concluded that compared to legacy MIW platforms LCS gives the logistics planner much more freedom in scheduling refueling events. LCS was found to utilize up to 66% less refueling assets than the legacy platforms when fuel reserve levels are lowered to an effective, but still mission capable level for LCS. The LCS, however, is shown to have a maximum operational availability (Ao) of 67% during this mission, compared to 70% of the legacy platforms. This only occurs when a crew rest constraint from the ROC/POE is relaxed to allow LCS to maintain an extra day on-station between necessary crew rest days. If this constraint is not relaxed LCS has a maximum Ao of 60%. Analysis of this mission also found that the large disparity in fuel capacity between the LM and GD versions of LCS gives the operational logistics planner more flexibility in scheduling fueling events for the GD LCS.

The second scenario created three generic HA/DR scenarios in which LCS deploys from a forward operating base or forward operating CSG/ESG in the western Pacific Ocean to render assistance to a disaster area. This scenario again showed how the large disparity in fuel capacity allows the logistics planner much more flexibility in

setting fuel reserve levels for the GD LCS than the LM LCS. This large disparity in fuel capacity also requires less CLF support to complete a mission for the GD LCS over the LM LCS. Additionally, analysis found, for these missions, slight reductions in the allowed fuel reserve levels allowed LCS to make the mission feasible in some cases, while in others, flexibility offered great improvements in the use of LCS sprint speed. One such example is found in the GD LCS Mission C scenario. In this scenario LCS is tasked with a 3,500nm transit. If fuel reserve levels are left at 50% and only one CLF ship is available, the mission is infeasible. A reduction in the fuel reserve level to 38% however, allows GD LCS to arrive on-station 19 hours ahead of the CSG/ESG. A further reduction in the fuel reserve level to 20% allows GD LCS to arrive almost 4 days ahead of the CSG/ESG.

This thesis cites multiple examples on how careful management of allowed fuel reserve levels for LCS, in concert with available CLF assets, can determine success of an LCS mission when utilizing the sprint speed capability it brings to the theater. Furthermore, this thesis emphasizes, through analysis, the need for logistics planners to be forward thinking in their ability to support LCS when tasking the ship to perform missions throughout the Pacific Fleet area of responsibility.

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ACKNOWLEDGMENTS

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I. INTRODUCTION

A. BACKGROUND

The ending of the Cold War in the early 1990's and the events of September 11, 2001 have ushered in a new era of warfare for the United States military. Like its sister services, the United States Navy has found a need to adapt to fight the wars of the 21st century. The Navy today is less likely to contend with other large blue water navies and more likely to need the capability to face smaller more agile and less technological foes. To engage these forces successfully the Navy will have to seek out and destroy them in more unfamiliar, unfriendly areas of the world where the U.S. may not hold the superior advantage it does on the open seas, the littorals.

The Defense Planning Guidance (DPG) of 2002 addressed some of these concerns and stated that the Navy must be able to maintain an area devoid of mines for safe Aircraft Carrier operations, destroy or evade submarines operating in littoral waters and have the capability to destroy numerous small anti-ship missile carrying combatants or weapons wielding merchant vessels without the support of carrier-based air power. In 2002 Admiral Vern Clark, Chief of Naval Operations, addressed these concerns when he introduced the vision for the future of the United States Navy titled "Sea Power 21". This concept was created to guide the Navy way of doing business and align it with the Joint Concept of Operations. This vision encompasses three fundamental pillars: Sea Strike, Sea Shield and Sea Basing.

> Sea Strike is the ability to project precise and persistent offensive power from the sea; Sea Shield extends defensive assurance throughout the world; and Sea Basing enhances operational independence and support for the joint force. These concepts build upon the solid foundation of the Navy-Marine Corps team, leverage U.S. asymmetric advantages, and strengthen joint combat effectiveness (Clark, 2002).

To answer the challenges of the DPG 2002 within the construct of "Sea Power 21", the Navy turned to a new class of combat ship, a member of the next generation of surface combatants, the Littoral Combat Ship (LCS). LCS promises to be an agile, fast and networked surface combatant centered on a mission module concept. This modular concept is designed to provide "Combatant Commanders with warfighting capabilities and operational flexibility that will contribute to maritime dominance and access for the joint force."(Fleet Forces Command, 2007) LCS along with current and future surface combatants, such as the *Zumwalt* class Destroyers and CG(X), promise to give Combatant Commanders "the full dimensional protection and precision engagement required to maintain freedom of the seas for the Joint forces, safeguard maritime trade and support the Maritime Security Operations (MSO)". (Fleet Forces Command, 2007)

B.   PROBLEM DEFINITION

The LCS will be a small combatant designed to address many of the Navy challenges in the 2002 DPG. It will rely on a newly developing mission modular technology that will allow the core component of LCS, the seaframe, to change out warfare mission packages to adapt it for different warfighting scenarios.   Unlike the current combatants of the Navy, LCS will be a single-mission focused ship that will rely on still developing technology to conduct operations in one of three main areas: Anti-submarine Warfare (ASW), Mine Warfare (MIW) and Surface Warfare (SUW). LCS will also be capable of conducting numerous secondary missions such as Intelligence Surveillance and Reconnaissance (ISR), Maritime Interdiction Operations (MIO) in support of the Global War on Terrorism (GWOT), humanitarian missions, support missions for special operations personnel as well as a host of other noncombatant missions.

In May 2004, the Navy awarded contracts to build two version of the LCS seaframe to two competing teams. The first team, led by Lockheed Martin (LM), was commissioned to build LCS-1 and LCS-3. The second team, led by General Dynamics

(GD) was commissioned to build LCS-2 and LCS-4. These two versions of LCS focus on two distinctly different hull types. The Lockheed Martin version is based on what it refers to as a semi-planning advanced steel monohull (Lockheed Martin, 2007) while General Dynamics has opted for a more untraditional trimaran hull. In April of 2007, the Navy announced that it could not reach an agreement with LM on the restructuring of the contract for LCS-1 and LCS-3. The Navy consequently terminated the contract for LCS-3. Commenting on the termination Secretary of the Navy Donald Winter stated that "LCS continues to be a critical warfighting requirement for our Navy to maintain dominance in the littorals and strategic choke points around the world" (OASD, 2007). In November of 2007, the Navy followed its cancellation of LCS-3 with the cancellation of LCS-4 because

> The Navy intended to begin construction of LCS 4 if the Navy and General Dynamics could agree on the terms for a fixed-price incentive agreement. The Navy worked closely with General Dynamics to try to restructure the agreement for LCS 4 to more equitably balance cost and risk, but could not come to terms and conditions that were acceptable to both parties (DoD, 2007).

Commenting on the newest cancellation of the next generation of naval combatants, Chief of Naval Operations ADM Gary Roughead was quoted as saying

> I am absolutely committed to the Littoral Combat Ship. We need this ship. It is very important that our acquisition efforts produce the right littoral combat ship capability to the fleet at the right cost (DoD, 2007).

Figure 1 shows an artists rendition of the General Dynamics version of LCS while Figure 2 shows a picture of the Lockheed Martin version of LCS just prior to launching in Marinette Wisconsin.

Figure 1. Artist conception of General Dynamics version of Littoral Combat Ship (From General Dynamics, 2008)

Figure 2. Lockheed Martin version of Littoral Combat Ship at christening ceremony in Marinette, Wisconsin (From Lockheed Martin, 2008)

With the future of LCS as a core component of both the Navy thirty year shipbuilding plan, in which 55 ships of the class have been proposed, and of future naval doctrine, many questions have arisen as to the value and impact LCS will have on the fleet. In 2003, David Rudko of the Naval Postgraduate School in Monterey California conducted a logistical analysis of LCS based on the conceptual nature of the ship. He concluded that a small, fast, agile ship conducting operations as outlined in the concept of operations (CONOPS) for LCS by Naval Warfare Development Command (NWDC) in 2003 the LCS would be very limited in its ability. "Just as the ASHEVILLE, PEGASUS and CYCLONE class ships were constrained in their operations due to low endurance and limited capability, the output from the Littoral Combat Ship model yields similar problems" (Rudko, 2003).

Now that LCS has taken shape this paper will revisit this question based on both types of hulls currently in production. With models developed in Microsoft Office Excel, this thesis evaluates how speed and different fuel reserve levels impact Littoral Combat Ship fuel consumption and endurance of the two approved versions of LCS, analyzes the implication of these findings and other possible mission limiting factors on Littoral Combat Ship logistics and analyzes how the current CLF force structure in the Pacific will affect overall mission capability of LCS.

C.   FOLLOWING THE CARDINAL RULES

Commander Naval Surface Forces created the Cardinal rules for LCS to help align implementation of the new combatant into the fleet. This thesis will adhere to these rules in all analysis. The rules are:

1. Do not deviate from the Capability Development Document. It provides operational performance attributes, including supportability, for the acquisition community to design the proposed system. It includes key performance parameters (KPP) and other parameters that guide the development,

demonstration, and testing of the current increment. It also outlines the overall strategy for developing full capability. Do not make policy decisions that don't match capability.

2. Do not covet Aegis or simultaneous multi-mission capability. LCS can do one focused mission at a time.

3. Do not try to compare LCS to legacy platforms. It cannot be manned, trained, equipped, maintained or tactically employed in the same way. No old think.

4. Manage expectations. The ship will perform as specified in the CDD. It can do no more and shouldn't be over-sold.

5. Risk is a given. Embrace it and manage it.

6. Do not add weight to LCS. For anything added, something else must be removed.

7. Manage Spirals. An effective spiral plan must balance capability to cost. Ensure spirals address critical needs and provide return on investment (ROI).

8. Manpower is a constraint. View the crew as you would an air crew. They operate the ship and keep it going when underway.

9. Shipboard logistics and maintenance efforts must be focused on achieving operational agility. Processes that are focused on sustainability should be accomplished either ashore or at the sea base.

10. Attack all LCS issues with the speed of heat. It will be here quickly. Be ready (Fleet Forces Command, 2007).

1.   Definitions

Seaframe is the ship platform and all of its inherent combat capabilities. Free standing with no mission module a seaframe will be able to perform all self-defense measures, navigation, C4I and air and small boat operations.

Mission Package is an interchangeable package that is used to configure LCS for its primary warfighting role. Mission Packages are currently being developed for ASW, MIW and SUW missions. Each package may consist of manned and unmanned vehicles, deployable sensors, specially trained mission module personnel and several cargo containers housing the command and control elements. These cargo containers will integrate with the seaframe creating a cohesive surface combatant specializing in any one warfare area. Specified elements of each of the three main mission packages are listed in Chapter II.

D.   METHODOLOGY

In Chapter II, the Littoral Combat Ship concept of operations is discussed and a model is designed to estimate the Littoral Combat Ship logistical efficiency. For the purpose of this thesis logistical efficiency will be defined for two separate LCS scenarios. For the first scenario LCS will deploy for a MIW mission. Efficiency, during this mission, will be measured in how long LCS can conduct continuous operations before a logistic or crew fatigue constraint forces it to leave the operating area. The efficiency measure will be called operational availability (Ao). The calculation method for Ao will be further defined in scenario development in Chapter III.

The second scenario will require LCS to perform humanitarian operations from a forward deployed naval base or by being detached from an underway forward deployed carrier strike group or expeditionary strike group (CSG/ESG). Speed is one of the key attributes LCS brings to a theater. Speed has been a critical factor in getting aid to disaster areas or to injured and/or sick persons on the high seas. The ability of the U.S. Navy to respond to tragedies quickly and provide life saving supplies and medical

technicians during relief operations could mean the difference between life and death for many. In December 2007 the USS Ronald Reagan was dispatched from the coast of Southern California to render medical assistance to an ailing cruise ship passenger off the coast of Baja, Mexico. The ships ability to close the cruise ship at a high rate of speed for a period of several hours allowed it to get close enough to launch a helicopter, air lift the passenger back to the ship, and render medical assistance which saved the passengers life. For this scenario, efficiency will be measured by how quickly LCS can get humanitarian aid to an affected region, without having to utilize CLF assets in the Western Pacific, for logistical needs. It will be measured through a combination of total fuel consumed, replenishment at sea evolutions required to maintain allowed fuel reserve levels and fuel on hand once the target destination is reached.

Using these two scenarios in Chapter III, the Littoral Combat Ship concept of operations is overviewed, scenarios are created and critical design parameters are discussed. These design parameters will reflect known usage rates on both version of LCS to show the difference in efficiency one might expect from the General Dynamics and Lockheed Martin versions. The scenarios created in this chapter will represent a portion of the missions that LCS will be expected to complete when fully integrated into the fleet. These scenarios will model possible MIW operations and Humanitarian Assistance/ Disaster Relief (HA/DR) Operations. The concept of operations (CONOPS) for the LCS is taken from the Littoral Combat Ship Wholeness Concept of Operations (Fleet Forces Command, 2007).

According to the LCS CONOPS, the Littoral Combat Ship will be capable of conducting missions over the full range of military operations, from combat missions to humanitarian assistance. The ship will be able to integrate into any naval combat group, including groups with coalition partners, or act as an independently deploying ship. The vessel will be capable of extended deployments in adverse weather environments, though these environments may inhibit LCS from conducting its primary mission.

Factors that are considered for computing LCS's operational availability while conducting a mission include fuel consumption, food consumption and ability to maintain

station based on assigned tasking. For the purposes of this thesis, LCS will deploy with a certain mission package and will not be expected to change out mission packages while on deployment.

In Chapter IV, the implications of mission planning for LCS when factoring in the current Combat Logistics Force is addressed. An analysis of Littoral Combat Ship off-station time due to required replenishments is compared with the current size and replenishment capabilities of the Combat Logistics Force in order to determine the overall impact on a mission capability for LCS.

In Chapter V, a conclusion of the Littoral Combat Ship logistical analysis is provided. This thesis is based on current unclassified LCS capabilities and limitations, to include sea keeping ability and fuel consumption. When known, true fuel data can replace the estimated figures in the mathematical models of this thesis to give a clear picture as to the impact the LCS may have on the Combat Logistics Force in the Pacific. In Chapter V, recommendations for further research into the logistical capabilities of the Littoral Combat Ship will also be presented.

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II.   LITTORAL COMBAT SHIP LOGISTICS MODEL DEVELOPMENT

LCS will incorporate single-mission focused ability and sprint speed to accomplish specific warfare missions. The ship will not be a typical U.S. combatant with multiple mission offensive and defensive capabilities. It will be, instead, specialized for a particular warfare mission during a deployment. The interchangeability of the LCS mission packages allows for the ship to alter its warfare specialty area during mid deployment.

In this chapter, the LCS concept of operations is overviewed, and critical design parameters are discussed. A model is then developed to estimate how well the LCS will perform based solely on logistical constraints. This thesis does not analyze the ability of LCS to conduct MIW operations nor does it analyze whether or not LCS is the best choice of ship to use to deliver humanitarian aid to a region. The concept of operations for the LCS in this thesis is taken from the Littoral Combat Ship Wholeness Concept of Operations (Fleet Forces Command, 2007)

A.   CONCEPT OF OPERATIONS

The Littoral Combat Ship will be unlike the modern day multi-mission ships of the U.S. Navy. LCS will be a reconfigurable single-mission focused ship. It will consist of a core seaframe that will give LCS its inherent self defense capabilities as well as the ability to plug in mission packages to allow it to specialize in specific littoral warfare areas. These mission packages are slated to include the warfare areas of MIW, ASW and SUW. Table 1 supplies the timelines mission packages are expected to enter the fleet in accordance with the Wholeness CONOPS.

MISSION PACKAGE	DELIVERY SCHEDULE
ASW	1 in FY07, 1 in FY09, 1 in FY10
MIW	2 in FY08
SUW	1 in FY08, 1 in FY09, 1 in FY10

Table 1.   Expected delivery of LCS Mission Modules to the fleet (After Fleet Forces Command, 2007)

Mission capabilities for the LCS will come aboard in different designed mission packages. Different logistics and manning will be associated with each mission package. These mission packages will allow LCS to be prepared to meet the needs of the Naval Component Commander in the region to which it will deploy. While deployed, LCS is not permanently attached to its deploying mission package. At the request of the Naval Component Commander, LCS can change out its mission package with another mission package forward deployed ashore, pre-positioned on other ships, or flown in. (Fleet Forces Command, 2007). This allows for commanders to adjust LCS for specialized missions based on the current situation in the area of operations in which LCS is deployed.

LCS will also have the ability to conduct other missions that are not are not part of its mission package outfitting. These missions will include Enhanced Maritime Interception Operations (EMIO), Special Operations Forces (SOF) support, Intelligence, Surveillance and Reconnaissance (ISR), Anti-Terrorism/Force Protection (AT/FP) and other missions and operations as deemed necessary by the Naval Component Commander.

1.   MIW Mission

According to the 2007 CONOPS, the MIW package for LCS will bring the Naval Combatant Commander a host of mine countermeasure capabilities. These capabilities will range from mine detection to neutralization, avoidance and sweeping, supporting

Joint operations conducted ahead of or concurrent with power projection forces (Fleet Forces Command, 2007).   These abilities along with the sprint capabilities of LCS are expected to allow it to gain access to an area and clear the way for amphibious landing operations as well as protect the amphibious forces prior to or in conjunction with their arrival. The ability of LCS to take full advantage of its speed and reach a contested area to clear it of mines prior to an amphibious group or CSG arriving is still under analysis. In 2003 Alidade Incorporated conducted a study relating how the proposed speed of LCS could impact the future tactical environment. The study found that for a squadron of 3 LCS to clear an area 160,000 nm sq. to a 90% probability of detection using a random search requires 10.4 days to complete the mission (Dickmann, 2003).

> This means that the only theater this type of operational scenario is effective is for a surge from CONUS to the Persian Gulf. In all other theaters the LCS squadron does not arrive in time for a random search to be completed (Dickmann, 2003).

In his study, Dickmann also suggests that for his findings to be true LCS will be required to maintain 50kts the entire search and transit.   This study entirely neglects all logistical and personnel needs of the ship.   Though this study relates to LCS finding a single surface target, the model can easily be adapted to assume this target is a floating mine or could be adapted further to portray other variants of mines found throughout the world. In any case, the study shows that for speed to greatly affect the battlespace it must be much greater than what the current LCS will have to offer, and furthermore higher speeds are unrealistic unless infinite refueling is assumed.

Figure 3 depicts how LCS will use its offboard sensor capabilities to conduct the MIW mission. Table 2 contains a list of the elements incorporated into the MIW mission package (Fleet Forces Command, 2007).
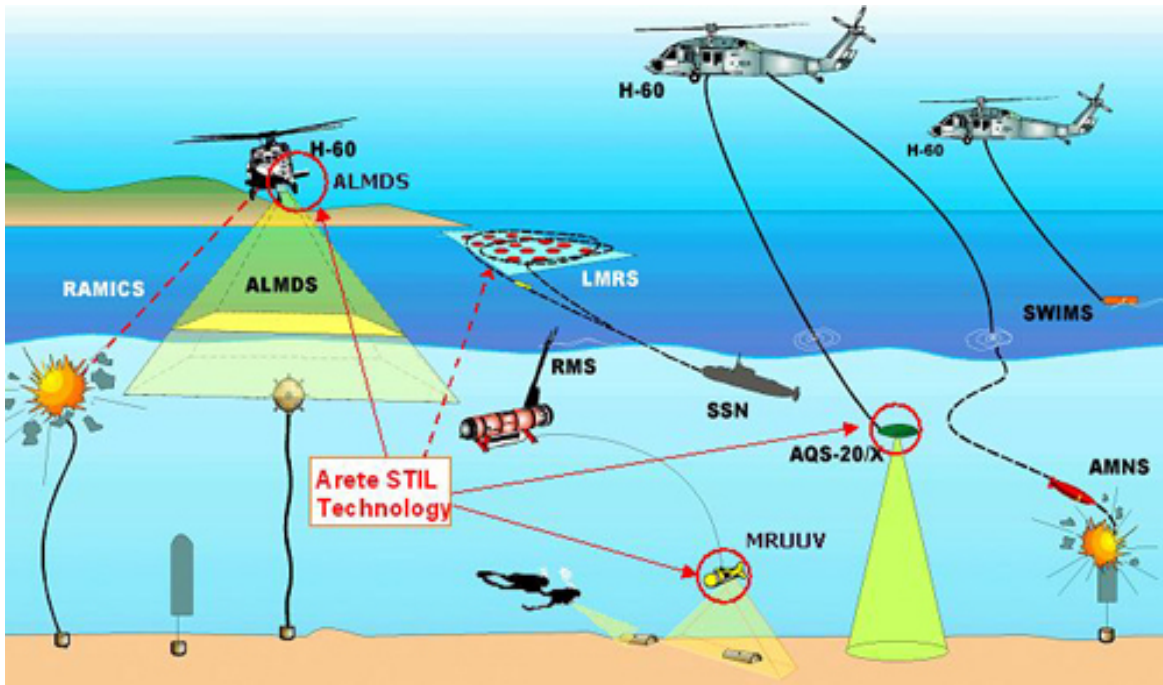
Figure 3. LCS MIW mission package capabilities (From Defense Industry Daily, 2007)

MIW Package Elements	QTY
Unmanned Surface Vehicle (USV)	1
Vertical Takeoff Unmanned Aerial Vehicle (VTUAV)	1
Coastal Battlefield Reconnaissance and Analysis (COBRA)	2
MH-60S	1
Organic Airborne and Surface Influence Sweep (OASIS)	1
AN/AQS-20A Minehunting Sonar Set (helicopter-configured)	1
Airborne Laser Mine Detection System (ALMDS)	1
Rapid Airborne Mine Clearance System (RAMICS)	1
Airborne Mine Neutralization System (AMNS)	1
Remote Minehunting Vehicle System (RMV/RMS)	2
AN/AQS-20A Minehunting Sonar Set (RMV-configured)	2

Table 2.   MIW Mission Package Elements (After Commander Third Fleet, 2005)

2.   SUW Mission

The second primary mission LCS will be configured for is SUW. During this mission, the Wholeness CONOPS states, commanders employing LCS will be able to use both its speed and ability to detect track and kill hostile small fast attack craft in an operating area. LCS is described in the CONOPS as bringing to the combatant commander's capabilities the ability to move joint forces through restricted waters with the security of successfully combating enemy small boat swarms. The SUW package, along with the inherent speed of the LCS is also claimed to provide the combatant commander a unique platform from which to conduct EMIO. According to the CONOPS, LCS will also be able to, through the use of speed and both manned and unmanned aerial assets attached to the SUW mission package, help extend the sensor range of a strike group and enable it to move more securely through restricted waters and littoral regions (Fleet Forces Command, 2007).

SUW Modular Elements	QTY
Vertical Take-Off Unmanned Aerial Vehicle (VTUAV)	2
EO/IR/LD sensor and datalink relay	1
MH-60R/S	1
GAU 16/19 machine gun	1 (60R) or 2 (60S)
Hellfire missiles	8
Non-Line-of-Sight Launch System (NLOS-LS) missile system	60 (4 launchers with 15 missiles each
Laser Designator for NLOS-LS missiles	1
Mk 46 Mod 1 30mm gun system	2
57 mm gun system	1

Table 3.   SUW Mission Package elements (After Commander Third Fleet, 2005)

3.   ASW Mission

LCS will enable the combatant commander, through the use of aerial, remote surface vehicles (RSV) and remote unmanned undersea vehicles (UUV) the ability to detect classify and destroy enemy submarines. LCS will be capable of performing this mission in both the littoral regions and in a deep water environment. LCS will also have

the capability to share sensor data with other elements of the joint task force enhancing the overall sub hunting capabilities of any naval task force.

ASW Modules	QTY
USV with ASW Systems	2
UDS	1
UTAS	1
MH-60R with	1
Mk 54 Torpedo	Set
ALFS	Set
Sonobouys	Set
RMV with ASW Systems	2
RTA (MFTA	1
RTAS	1

Table 4.   ASW Mission Package Elements (After Commander Third Fleet, 2005)

4.   Core Capabilities

According the LCS Wholeness CONOPS, LCS will have the ability to identify, track and protect itself from many, but not all, anti-ship cruise missiles and enemy aircraft. LCS was not designed to act in a high intensity air defense environment like multi-mission naval combatants, but rather was designed to act in those types of environments under the air defense umbrella of a Carrier Strike Group or Expeditionary Strike Group. The purpose of the ship, when acting in concert with other vessels during a high intensity conflict will be to operate as a node in the FORCEnet distributed network (Fleet Forces Command, 2007) adding to the Maritime Domain Awareness (MDA) picture.

In addition to the three focused missions and the self-defense capabilities, LCS will be capable of performing other missions which will take advantage of the inherent capabilities of the platform. The ability to maintain sprint speeds for a prolonged period of time, its inherent ability to traverse shallow areas and ports, the use of its maneuverability and its ability to carry cargo and personnel when properly outfitted, will allow LCS to handle secondary missions such as Humanitarian Assistance Operations/Disaster Relief (HA/DR) and Marine Security Operations (MSO). To help

further enhance LCS capabilities special mission packages and trained personnel may deploy with a ship to allow it to support an even wider range of missions. These inherent capabilities of LCS are part of the core seaframe and are able to be used by the combatant commander no matter what mission a particular LCS has been previously outfitted to carry out.

According to the Wholeness CONOPS, LCS will be able to inherently perform many of the secondary missions that today's legacy platforms are being used for. Such operations will include Maritime Interception Operations (MIO) and Enhanced MIO in support of Maritime Security Operations (MSO) or other operations (when equipped with an adequate Rigid Hull Inflatable Boat (RHIB)). The speed and maneuverability of LCS also make it a prime candidate to conduct Homeland Defense Missions and Joint Littoral Mobility Missions. LCS's payload capacity, proposed high endurance at high speeds, and shallow water draft should make it one of the best suited platforms in the Navy for Humanitarian Assistance Operations (HAO) (Mueser, 2007) and intra-theater lift operations for personnel and supplies when outfitted with a HA/DR mission module (Kime,2007) or when cargo room is maximized for carrying relief supplies. LCS will also be used as a sustainment and refueling base at-sea for H-60 sized non-organic helicopters. Due to its inherent speed LCS will have the ability to rapidly deploy Special Operations Forces (SOF) and their equipment into littoral regions to conduct Special Reconnaissance (SR) and Direct Action (DA) missions.

B.   LOGISTICS MODEL

The purpose of this model is to give logistics planners a better sense of how the Littoral Combat Ship will perform under certain mission parameters. It will give the planner an estimation of LCS endurance based on fuel consumption rates derived for different mission profiles. The model is developed using Microsoft EXCEL and JMP 7.0, and is divided up into two sections. The first section creates estimated fuel curves for LCS while the second section calculates the endurance factor of LCS based on the

fuel consumption calculations, applied to specific mission scenarios. As of January 2008, the LCS has still not conducted sea trials and no actual fuel consumption data is available. This model will use predicted fuel consumption values produced by Program Executive Office (PEO) Ships (Payor, 2007) and by Commander Logistics Group Western Pacific (COMLOGWESTPAC) (Darnell, 2007).

1.   LCS Critical Design Parameters

The conceptual idea of the Littoral Combat ship was to have a small, agile, low cost, shallow draft long range ship capable of high sprint speeds and high cruising speeds. This ship was to fill the capability gaps in the United States Navy revealed in the 2002 DPG. The gaps were identified in MIW, ASW and SUW warfare areas. In order to meet the challenges posed, critical design factors needed to be met by the engineers to enable LCS to fulfill its promised mission capabilities. The table below lists the critical parameters as listed by the final System Design Capabilities Development Document Requirements (N76, 2004). Located in the left hand column for each parameter is a descriptor identifying it as a key performance parameter (KPP) or an additional attribute (AA).

LCS Flight 0 Critical Design Parameters			
	Category	Threshold	Objective Level
	HULL		
KPP	Draft at Full load Displacement	20 feet	10 feet
KPP	Mission Module Payload (note 3)	180 MT (105 MT mission package / 75 MT mission package fuel)	210 MT (130 MT mission package / 80 MT mission package fuel)
AA	Hull Service Life	20 Years	30 Years
	PROPULSION AND ENGINEERING		
KPP	Sprint Speed at Full Load Displacement in Sea State #	40 Knots in Sea State 3 (note 1)	50 Knots in Sea State 3 (note 1)

KPP	Range at Sprint Speed	1,000 nautical miles (note 2)	1,500 nautical miles (note 2)
AA	Range at Economical Speed	3 500 nautical miles (>18 knots) with payload	4 300 nautical miles (20 knots) with payload
	OFFBOARD VEHICLE SUPPORT		
AA	Simultaneous OVC	4 indigenous Vehicles	All Off-board Vehicles
AA	Aviation Capabilities	Level I Class I	Level I Class I
AA	Aircraft Launch/Recover	Sea State 4 best heading (note 1)	Sea State 5 best heading (note 1)
AA	Mission Package Boat type	11 Meter RHIB	40 ft High Speed Boat
AA	Watercraft Launch/Recover	Sea State 3 best heading with in 45. mins. (note 1)	Sea State 4 best heading with in 15 ~ mins. (note 1)
AA	Mission Module Handling and Stowage	Handle and Stow w/ Organic systems	Handle and Stow w/ Organic systems
	LOGISTICS		
AA	Time for Mission Package Change-Out to full operational capability including system OPTEST	4 days	1 day
AA	Provisions 336 hours (14 days) 504 hours (21 days)	336 hours (14 days)	504 hour (21) days
AA	Underway Replenishment Modes (UNREP)	CONREP VERTREP and RAS	CONREP VERTREP and RAS
KPP	Core Crew Size	50	15
AA	Crew Accommodations (both core crew and mission package detachments)	75 personnel	75 personnel
AA	Operational Availability (Ao)	0.85	0.95
	INTEROPERABILITY		
KPP	Interoperability Exchange Requirements (IER)	1005 Critical Top-Level IER	100% Top-Level IER
	COMBAT SYSTEMS		
KPP	Focused Mission Execution	Conduct Successful MIW, SUW, ASW and Mission DTE	Conduct Successful MIW, SUW, ASW and Mission DTE
AA	Core Self Defense DTE	Conduct Successfully Using	Conduct Successfully Using

		Core Systems	Core Systems
AA	AAW Core Self Defense	Classified	Classified
AA	SUW Core Self Defense	Classified	Classified
	TOTAL COST		
AA	FY 05	Seaframe $220M, Mission Package $150M	Seaframe $150M, Mission Package $75M
Note 1: Sea State parameters are defined in Appendix A of PDIRD			
Note 2: Includes Payload - Taking into account the focused mission nature of the LCS, payload is defined as the heaviest possible Mission Package and core mission systems, excluding ship's fuel.			
Note 3: Mission package payload is defined as all non-core systems, vehicles, helos, ordnance, and associated personnel, equipment, and containers to perform a single mission. This includes fuels to operate the mission package.			
AA = Additional Attribute			
KPP=Key Performance Parameter			

Table 5.   Littoral Combat Ship Critical Design Parameters (After Czapiewski, 2005)

2.   Fuel Consumption Data

Fuel consumption data for either version of the Littoral Combat Ship has yet to be collected. To further add to the difficulties of providing a smooth fuel curve for LCS is the fact that it has a combined diesel and gas (CODAG) engineering plant. For the purposes of this model, two sources of data are used to help estimate a fuel consumption curve for both the General Dynamics and Lockheed Martin versions of LCS. Table 6 shows the conversion rates used to convert all data into gallons. Table 7 shows data used by COMLOGWESTPAC to predict fuel usage on the Lockheed Martin version of LCS and Table 8 shows the data used by COMLOGWESTPAC to predict fuel usage on the General Dynamics version of LCS. Table 9 shows data used by PEO Ships to predict fuel consumption rates for a generic Littoral Combat ship. This table takes into account the two different prime movers LCS will use to propel itself through the water. It shows the consumption rates for the diesel engines and then for the gas turbine motors (GTM) at higher speeds. A speed of approximately 18.5kts has been identified by PEO as the

speed at which the GTM's will take over and power LCS. For speeds below this threshold it is more economical for LCS to use its diesel capabilities

Fuel Conversion Factors:

1 kilogram (kg) = 2.2046 pounds
1 gallon (gal)   = 8 pounds
1 barrel (bbl)   = 42 gallons

Table 6.   Fuel Conversion Factors

LOCKHEED Version	
Speed (Kts)	Gal / Hr
7	83
18	443
30	2,072
40	3,135
45	3,800

Table 7.   COMLOGWESTPAC fuel usage data for LM LCS (After Darnell, 2007)

General Dynamics Version	
Speed (Kts)	Gal / Hr
7	69
18	246
30	2,052
40	3,713
46	4,855

Table 8.   COMLOGWESTPAC fuel usage data for GD LCS (After Darnell, 2007)

PEO LCS	
Speed (Kts)	Gal/ Hr
0	69
5	83
10	220
15	481
18.5	825
18.5	1,430
20	1,650
25	1,953
30	3,396
35	3,946
40	4,496
45	5,046
50	5,596

Table 9.   PEO fuel usage data for LCS (After Payor, 2007)

3.   Fuel Consumption Rate

In 1996 David Schrady, Gordon Smyth and Robert Vassian of the Naval Postgraduate School developed a way of calculating ship fuel consumption (Schrady, 1996) that better predicts consumption rates at low speeds.   Their analysis was undertaken to assist operational logistics planners in better estimating ship and strike group fueling-at-sea (FAS) requirements. At the conclusion of their analysis the authors recognized that an exponential model of fuel use as a function of ship speed is best used to create an overall fuel consumption curve. For the remainder of this thesis the model will be referred to as the Schrady model. The model took the form

$$F = p_0 + p_1 e^{p_2 V^3}$$

Figure 4. Exponential Model of Fuel use (From Schrady, 1996)

In the application of this model, the coefficients p_0, p_1 and p_2 are determined by regression performed using JMP 7.0 (JMP 1989-2007). As shown in the data in Table 9 LCS shows an exceptional increase in overall fuel consumption at a speed of approximately 18.5kts due to the change over in its prime mover at that speed. In order to more accurately capture how this will effect the fuel consumption of LCS, the Schrady model was applied to both diesel and GTM prime movers. This created two distinct curves as shown in Figure 5.
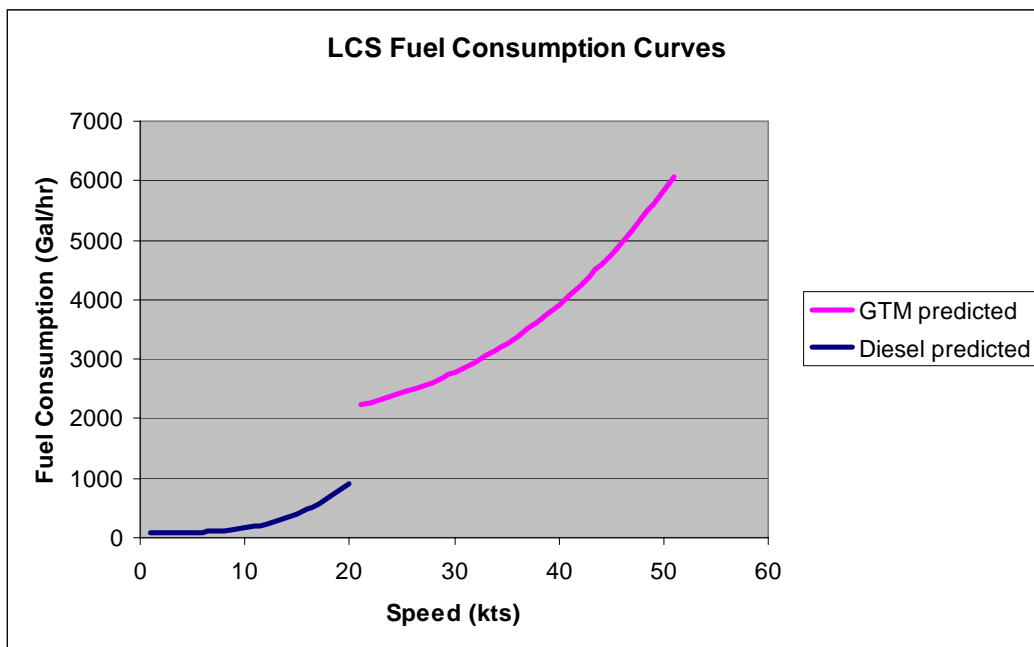
Figure 5. LCS Fuel Consumption Curve using Schrady model and data from PEO.

4.   Fuel Replenishment Calculations

The requirement for a ship to be refueled depends upon the amount of fuel it can carry, the amount of fuel it uses for a particular mission profile and the reserve level of fuel which the ship must maintain. The reserve level of fuel a ship must maintain is the minimum amount of fuel a ship must have onboard at any time during operations. A reserve level is calculated as a percentage of the overall fuel capacity of the ship. For the

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purpose of this thesis, fuel reserve levels will be calculated as a percentage of the fuel capacity of the Littoral Combat Ship. Fuel reserve levels of 50%, 35% and 20% of the 100% fuel carrying capacity of LCS will be used for analysis.

Once the Littoral Combat Ship has reached its minimum allotment of fuel, it must refuel. This can be done inport or while at-sea. If the Littoral Combat Ship needs to fuel-at-sea and is in transit from one destination to another, LCS will not have to deviate from track to complete a refueling evolution. This thesis will assume that if fuel is needed while in transit a Combat Logistics Force (CLF) ship will be able to meet the requirement and refuel LCS along its intended track. Further analysis is then done in Chapter IV to show how different levels of CLF availability will affect LCS mission planning. Upon completion of refueling, LCS will have 95% of fuel capacity. If LCS is conducting a mission in the littoral regions and reaches its minimum fuel allotment, it will be forced to break away from the mission to meet a CLF ship or conduct inport refueling. For the purpose of this thesis, it is estimated that a CLF ship rendezvousing with LCS will do so a safe distance from the littoral area of operation. Upon reaching its reserve level, LCS will detach from its mission and travel 200 nautical miles at a speed of 20kts to rendezvous with the CLF asset. Upon meeting up with the replenishment ship, LCS will spend on average 2 hours alongside and refuel to 95% of its capacity. Once refueled, LCS will travel back to its mission area and continue operating as directed.

To calculate the total amount of fuel consumed by LCS each day the average speed for the day is multiplied by the expected fuel consumption for that speed per hour and then multiplied by 24. To calculate the amount of fuel onboard the amount consumed for one day is subtracted by the current onboard amount. For the purpose of this thesis LCS will be at maximum fuel load when it is 95% of tank capacity. Once LCS has completed a mission the total number of required FAS's, over the duration of the mission, are divided by the total number of days in the mission to find the average number of days between refueling evolutions. A mission Operational Availability (Ao) is then calculated by subtracting the amount of days off station due to refueling events, crew rest and other reasons, from the total days of the mission, then dividing it by the total days in the mission.

The following formulas were used to derive the overall Ao of LCS during a specified mission profile:

$$Fuel\_Used = Avg\_daily\_speed * Fuel\_consumed\_at\_averag\_daily\_speed * 24$$
$$Fuel\_onboard\_end\_of\_day = Fuel\_used\_day - Fuel\_onboard\_$$
$$beginning\_day$$
$$Avg\_days\_between\_FAS =$$
$$Total\_number\_of\_requried\_refuelings / Mission\_Length$$
$$Total\_days\_off\_station = Total\_days\_off\_station\_FAS +$$
$$Total\_days\_off\_station\_crew\_rest + Total\_days\_off\_station\_other$$
$$Operational\_Availability = Total\_days\_off\_station / Mission\_Length$$

5.   Fuel Optimizer

In the summer of 2007 Brown, Kline, Rosenthal and Washburn of Naval Postgraduate School in Monterey, California published an article in Interfaces magazine titled "Steaming on Convex Hulls" (Brown, 2007). In this article, the authors discussed how U.S. Navy ships could better manage their fuel expenditures by steaming in mixed mode operation. This method entails using different engine configurations at different speeds for specified periods of time in order to reduce the amount of fuel used to transit from one point to another. Their method was proven to be a viable tool for one of the authors during a practical application in the fleet. This thesis will require LCS to use the same fuel usage optimization strategy while transiting between two points. A model was created using Microsoft EXCEL in which an operator can enter the distance to be traveled and the time in which it needs to be traveled, and returns to the user the speeds and amount of time needed to be spent at those speeds to ensure the most fuel conservative voyage is taken. The speed a ship needs to travel can easily be adjusted for wind and currents, but for simplicity this step is omitted in this model.

The objective of the formula is to minimize the amount of fuel used during a transit through a combination of different engine usage and speeds. The data required for computation using EXCEL Premium Solver V 5.0 are the distance to travel, the time required to travel that distance and the fuel consumption data for LCS. The decision

variables include the time spent transiting at a certain speed, the time it takes LCS to travel the specified distance and the amount of fuel used when minimizing fuel is the objective.   The information gathered is then used to determine how many FAS evolutions LCS would require during a transit of the proposed length. The given data, decision variables and formulation are the same or adaptations of those used by Brown et. al in their 2007 article (Brown, 2007).

Index use

$s \in S$ speed index [1…50]

Given Data (Units)

distance required distance LCS is to travel during a transit (nautical miles)

$speed_s$ the speed at which LCS travels during a particular time ((knots = nautical miles/hour).

$consumption_s$ fuel consumption rate for LCS operating with its most   efficient mode at speed *s* (gallons/hour).

hours required time LCS is to travel *distance* in (hours)

Decision variables (units)

$HOURS_s$ time spent underway at $speed_s$ (hours).

FUEL fuel consumed by *LCS* in transit, when minimizing fuel is the objective (gallons).

TIME time required by LCS for transit, when minimizing transit time is the objective (hours).

The formulation for minimizing fuel consumption for a given transit is then solved as a linear program

Formulation _MINFUEL_ for vessel LCS:

$$\underset{FUEL,\ HOURS}{\text{MIN}} \quad FUEL$$

s.t.

$$\sum_{s \in S} speed_S HOURS_S \geq \text{distance}$$

$$\sum_{s \in S} HOURS_s \leq hours$$

$$FUEL \geq \sum_{s \in S} consumption_s HOURS_s$$

$$TIME \leq hours$$

$$HOURS \geq 0 \quad \forall s \in S$$

Figure 6 is an EXCEL spreadsheet example of the LCS fuel optimizer. This figure is a derived from the Brown article (Brown, 2007). This spreadsheet shows that for LCS to travel 3,500nm in 78 hours it will require 385,151gal of fuel. This information is then used to determine the amount of FAS evolutions LCS will require to make the transit while maintaining its minimum allowed fuel capacity, or reserve level. This figure also shows that when data is unavailable, as in the COMLOGWESTPAC data, for low speeds of the GTMs or high speeds of the diesel a penalty consumption rate is assigned. This is done to ensure LCS maintains the assumption that diesel engines will be used for speeds below 18.5kts and GTMs will be used for speeds above 18.5kts.

	A	B	C	D	E	F	G	H	I	J	
1	LCS										
2	Data										
3	Transit Speed (KTS)	0	1	2	3	4	5	6	7	8	
4	Diesel (GL/HR)	76	76	77	79	84	91	102	118	138	
5	LM2500 (GL/HR)	99999	99999	99999	99999	99999	99999	99999	99999	99999	
6	Time at diesel speed (HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
7	Time at LM2500 Speed (HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
8											
9	Distance Traveled (NM)	3500.00									
10	Time Traveled (HR)	78.00			Output Information						
11	Fuel Used (GL)	385151.33									
12											
13	Desired Time to Travel (HR)	78									
14	Distance to Travel (NM)	3500									
15	Fuel on Board (GL)	11600			Planner Input Information						
16	Reserve Desired (GL)	2200									
17	Fuel For Transit (GL)	9400									
18											
19											
20											
21											
22											
23											
24											
25											
26											
27		Fuel Solver									
28											

Figure 6. LCS fuel optimizer (After Brown, 2007)

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III.   SCENARIO DEVELOPMENT

A sound logistics plan is the foundation upon which a war operation should be based. If the necessary minimum of logistics support cannot be given to the combatant forces involved, the operation may fail, or at best be only partially successful.

--ADM Raymond A. Spruance

A.   IMPORTANCE OF LOGISTICS PLANNING

The ability of the U.S. Navy to keep its fleet fueled, fed and armed around the world has been, and continues to be, the lynchpin for successful operations. The ability of logistics planners to thoroughly prepare for the needs of a fleet in action can be the difference between success and failure at sea. No matter how much firepower a ship can bring to the fight, it is worthless if it can not get there due to fuel constraints or missing parts. As LCS enters the fleet, logistics planners will be faced with a system that is untested and new to the Navy. Logistics planners must be able to adapt to this new system and the needs LCS will place on the Navy logistical system. LCS will have a supply and maintenance system that will rely heavily on shore support and automated sensors. LCS will be greatly limited in its capacity to perform maintenance, not have the ability to make major repairs at sea and be severely constrained in the amount of supplies it can carry. LCS will not have the space to increase its food and parts loadout, so LCS will require support from shore based assets to support any schedule deviations. A supply of 21 days of prepackaged meals will be allotted for each assigned sailor. Supplies, both consumables and repair, will be controlled by the shore based facility, currently located in San Diego, California with the Littoral Combat Ship Squadron (LCSRON) commander.   This arrangement for supply management will make it imperative for logistics planners to think ahead and meet the needs of the ship as it is deployed and operating.

The most critical logistics constraint that planners must prepare for is the ability to understand patterns for refueling LCS and how to get the fuel to the ship when it needs

it. If LCS is forced to slow down or drastically and continuously maneuver from its assigned operations to get fuel, the ship will ultimately negate its ability to use its speed the way it was intended to be used in accordance with the CDD. If LCS is forced to refuel at a higher rate than planners are used to seeing in other platforms, CLF may be forced to adapt and assign necessary assets to enable it to complete its missions. As Rudko alluded to in his thesis the history of the Navy has shown an inability to keep ships whose primary asset is speed, refueled in a manner so the ship could continue operating as a contributing force multiplier (Rudko, 2003). One of the best examples of this he gives relates to the PEGASUS class patrol boats of the 1980's.

The ability to predict when a ship needs to be refueled is crucial in any operational planning. If LCS is unable to overcome the stigma of short range and low on station availability time due to high fuel burn rates at high speeds, it may be relegated to the same fate as previous naval high speed craft as suggested by Rudko (Rudko,2003). The lack of attention focused on logistics planning can easily become a serious factor in victory or defeat in the world's oceans. In 1986 Hughes relates two stories on how placing insufficient importance on logistics can greatly alter a battle. One of his stories centers around fuel capacities and burn rates in battle planning and how lack of proper thought or planning in considering these two characteristics can lead to a disastrous outcome.

> It is important to assess fuel capabilities in battle planning. The Battle of the Eastern Solomons in 1942 gave us a memorable example of what happens when this area is neglected. Instead of three carriers, Fletcher only had two in the battle, because he had sent the WASP south to fuel. She missed all the fighting and was sunk soon thereafter by a submarine. Tactical endurance hardly ever enters into amateur force correlations, and, being a distraction, an aggravation, and a great source of friction, it is rarely given the place it deserves (Hughes, 1986).

In this chapter, two scenarios are created to analyze the logistics capabilities of LCS. The first scenario will focus on a LCS primary warfare mission, MIW. This

scenario will be used in conjunction with the models developed in Chapter II to better gain insight into how LCS may be expected to operate. The second scenario will focus on an inherent secondary mission of LCS. This thesis has chosen the HA/DR mission for LCS because according to the latest Maritime Strategy (Conway et al, 2007) the ability to conduct Humanitarian Assistance and Disaster Relief has been elevated to one of six core competencies of the U.S. maritime services. According to CDR Carl Mueser of Commander Naval Surface Forces LCS will be able to assist the Navy in this mission because the ships have lift capacity with the huge mission bays, they can go fast and get close to shore, they have a helicopter and they can make fresh water (Mueser,2007). In this scenario, models from Chapter II are again used to identify how LCS may perform during this particular mission. Both of these scenarios are set in the Western Pacific Ocean.

B.   MIW SCENARIO

LCS has been designed to handle one of three core warfare missions along with a host of secondary mission abilities.   MIW is one of the three core competent missions LCS must be able to perform. As legacy U.S. Navy MIW platforms are retired from the fleet, LCS will become the primary asset to fill this specialized role.   In this role, as described in Chapter II and in the Wholeness CONOPS

> The LCS will provide the JFMCC with a capable array of organic mine countermeasure (OMCM) capabilities ranging from mine detection to neutralization, avoidance and sweeping, supporting Joint operations conducted ahead of or concurrent with power projection forces. This capability will help open ingress lanes for Joint Forcible Entry Operations (JFEO) and contribute to protection of amphibious forces. Mine countermeasures (MCM) operations will commence earlier, potentially reducing the timeline for access to the contested littorals, providing more flexibility to the Joint Force Commander (Fleet Forces Command, 2007).

During fiscal year 2008, all remaining MHCs in the naval inventory are slated to be decommissioned leaving LCS as the ship that is to take over this vital role. During the decommissioning ceremony of USS OSPREY (MHC 51), Commanding Officer, CDR Knusten, was quoted as saying "LCS will continue where Osprey leaves off by carrying on and refining the Navy's critical mission of countering mine threats to this nation (Naval Station Ingleside Public Affairs, 2006)".

For this MIW scenario, a logistics baseline was created by using a generic 90 day patrol which is common to today's MCM platforms. During a 90 day patrol, based on a ship departing from a forward deployed operating base in the Western Pacific (WESTPAC), and operating in or around a potentially hostile area in the region, an expected Ao is calculated using the model described in Chapter II. For a legacy MCM, it is assumed that the ship will transit to the operating area at a speed of eight knots and will require two days to reach its destination. Once at the operating area, the vessel will commence mine countermeasure operations as long as it can logistically sustain them. Once the ship is required to refuel, repair a part or conduct necessary maintenance it will detach from operations and then return upon completion. For the purpose of refueling or repairing a part, the MCM will detach from its operations and conduct a brief stop for fuel (BSF) at a port in the region or conduct a FAS from an available CLF asset operating in area. For a legacy MCM leaving station to refuel it is estimated that it will take 24 hours for the vessel to transit from the operating area, refuel, get underway and then return and recommence operations.

While conducting operations, only daily requirements will be tallied. If a ship projects that during the next days operations it will require a refueling, it will refuel during that next day, and an operating vessel will not allow itself at any point to have less fuel on hand than prescribed by the required fuel reserve level. For an MCM, a requirement to conduct carbon burns is also instituted. On average it is assumed that every three days the ship must leave station for four hours to conduct a carbon burn prior to returning to operations. If an MCM is

required to conduct a BSF the day after a carbon burn, the carbon is not delayed. It is assumed that when requirements arise they are conducted that day.

LCS is then placed in the same baseline model, a 90 day MIW patrol in the operating area. For LCS fuel reserves of 50%, 35% and 20% will all be analyzed. When LCS is required to refuel it is assumed the ship can receive fuel during a BSF or through FAS if a CLF asset is available. During a refueling evolution it assumed LCS will require 22 hours to transit, refuel, transit back to the operating area and then recommence operations. Using the fuel curves and model created in Chapter II an Ao for LCS is then calculated.

C. HUMANITARIAN ASSISTANCE/DISASTER RELIEF SCENARIO

In order to gain a more thorough insight into the range and endurance capabilities of LCS in providing support for a HA/DR mission, three scenarios will be analyzed. Each scenario requires LCS to detach from a forward deployed CSG/ESG or depart form a forward deployed naval base and deliver aid to an effected region. It is assumed that each ship being detached to an area is outfitted with a proposed HA/DR mission if departing from a forward deployed naval base, or is loaded with HA/DR items from other ships in the deployed CSG/ESG prior to being detached to the affected area.. There currently is no approved HA/DR mission package but the contents of a likely package have been studied in an exercise for the CNO (Kime, 2007). Even without a specific package, LCS will still be expected to conduct life saving humanitarian operations when necessary.

In 2005, when the Abraham Lincoln Strike Group (ALCSG) provided humanitarian assistance to the tsunami stricken areas of Sumatra, no special HA/DR gear was provided. LCS is expected to add to the capability of a CSG because the ships are expected to be able to bring extra lift capacity through their mission bays, use their speed to get to an affected area faster than a normal CSG can travel and get closer

to shore because of their shallow draft. This combined with their ability to make fresh water and use their embarked helicopter assets appears to make the ship a well suited asset for this type of mission though this thesis does not conduct an analysis of the ability to conduct HA/DR missions.

For the purpose of this thesis, three generic intra-theater HA/DR missions will require LCS to travel 1,500, 2,500 and 3,500 nautical miles to get aid to affected regions. LCS will conduct each mission at speeds between 15 and 45 knots. Other ships operating in conjunction with LCS will depart from the same location at the same time and travel at a speed of 15 knots. The ships traveling at 15 knots will be accompanied by a CLF asset and will be able to refuel when necessary. It will be assumed that when LCS reaches its reserve capacity a CLF asset will be needed to refuel it along its intended track without forcing LCS to deviate from track. This assumption will be used in Chapter IV to further discuss the impact a high speed vessel will have on a logistics planner scheduling LCS and CLF assets if speed is to be used as an asset by LCS. Fuel reserves of 50%, 35% and 20% will all be analyzed for each LCS transit. A sensitivity analysis will then be conducted to help a logistics planner measure the tradeoff between lowering the fuel reserve and LCS time of arrival ahead of the CSG/ESG. Upon arriving at the final destination, LCS will commence HA/DR operations.

IV.   ANALYSIS

In this chapter, an analysis of LCS in both the HA/DR and MIW scenarios created in the previous chapter is conducted. In the MIW scenario, an analysis is conducted to show tradeoffs between different refueling schedules for both the LM and GD versions of LCS and how the missions are impacted by CLF availability and leveraging different fuel reserve levels. In the HA/DR scenario an analysis is conducted to gain insight for a decision maker as to how best to utilize the sprint speed capability of LCS based on fuel reserve levels and CLF asset availability. This analysis will give a decision maker the ability to make tradeoffs between the speed at which aid can reach an affected area and the cost incurred in overall fuel spent and CLF assets required for mission accomplishment.

A.   FUEL CONSUMPTION AND ENDURANCE ANALYSIS

As described in Chapter II, there is no data yet available for fuel consumption of either the LM or GD versions of LCS. For the purpose of this thesis, two estimated sources of data were used. The first source of data was received from Commander Logistics Group Western Pacific (COMLOGWESTPAC) (Darnell, 2007) and the second from Program Executive Office Ships (PEO) (Payor, 2007). The data received from COMLOGWESTPAC has subsequently been used for fleet analysis of LCS during a series of Logistics Rehearsal of Concept (LROC) drill sets. The purpose of these drill sets was to conduct a test of logistics processes in support of LCS and the Wholeness CONOPS and SOPs that govern that support (Amadio, 2007).   Both sets of data were applied to the model described in Chapter II and yielded fuel burn rates for LCS for the range of speed from 0 to 50 knots. Figure 7 shows the resultant fuel curves for both the LM and GD versions of LCS based on data from COMLOGWESTPAC.

LCS Fuel Consumption Curves Using COMLOGWESTPAC Data
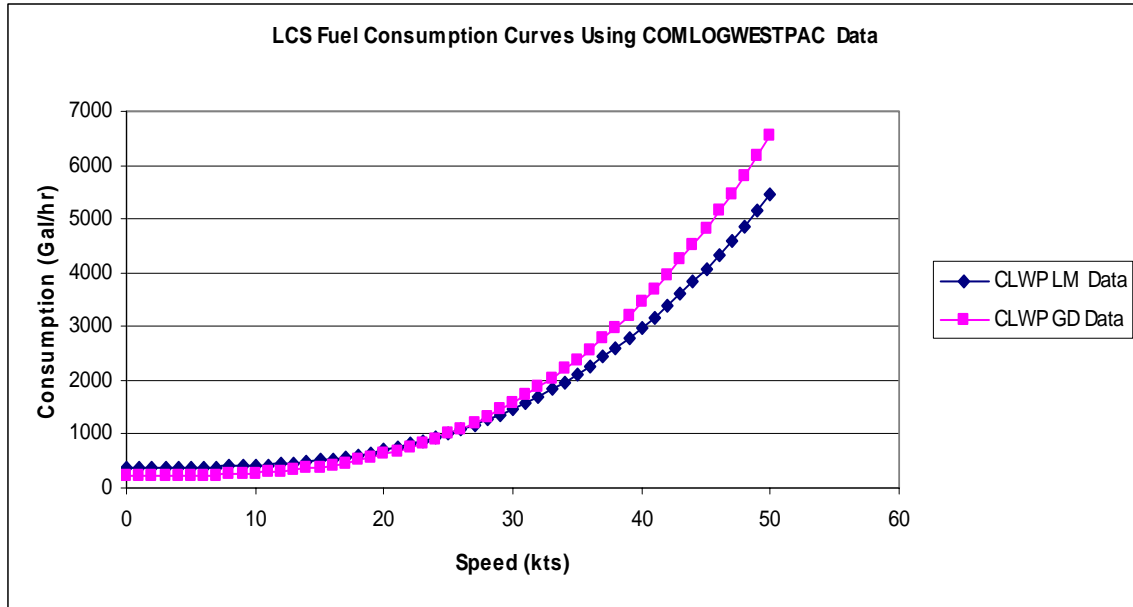
Figure 7.   Predicted fuel curves for both LM and GD versions of LCS using data from COMLOGWESTPAC.

Figure 8 shows the resultant fuel curves from the data provided by PEO. This data is given for a generic LCS and is not specific to either the LM or GD version. This fuel burn data also shows a distinct change over in the consumption rate at approximately the 18.5kt mark. This marks the point in the data in which the diesel engines are no longer sufficient to power LCS at the desired speed and the gas turbine engines must be used. Because this data shows a distinct difference in the consumption rates between the two prime movers a fuel curve was created for both the diesel and gas turbine engines. These two fuel curves were shown in Figure 5. To optimize the fuel usage of LCS a method created in Brown et al (Brown, 2007), is used to create a single smoothed fuel curve for LCS. This fuel curve requires LCS to operate in a mixed mode, using diesel engines and gas turbine engines at certain speeds in order to achieve the overall average speed required to reach a destination on time. This method of operation will be further referred to as PEO Optimal Mixed-mode Operations (PEO-OMO). This type of operating will be used in mainly transit type situations in this thesis. When PEO fuel curves are being applied to LCS in a non mixed-mode operating environment the ship will be described as using PEO Single Mode Operations (PEO-SMO).

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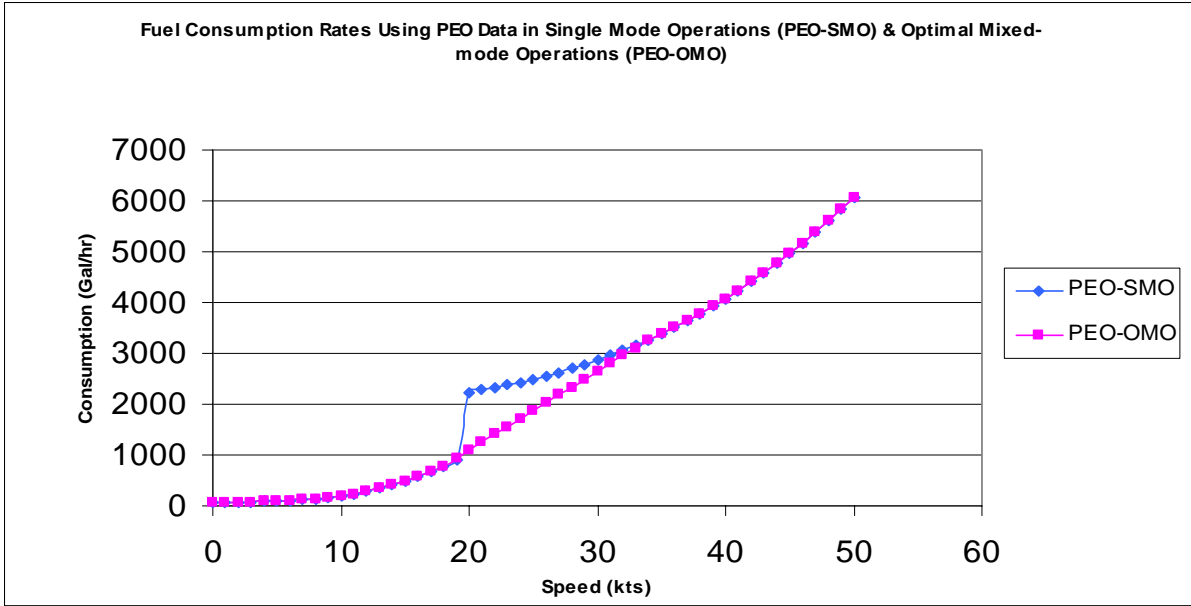
Figure 8. LCS Fuel consumption rates using PEO data in Single Mode Operations (PEO-SMO) and Optimal-mode Operations (PEO-OMO)
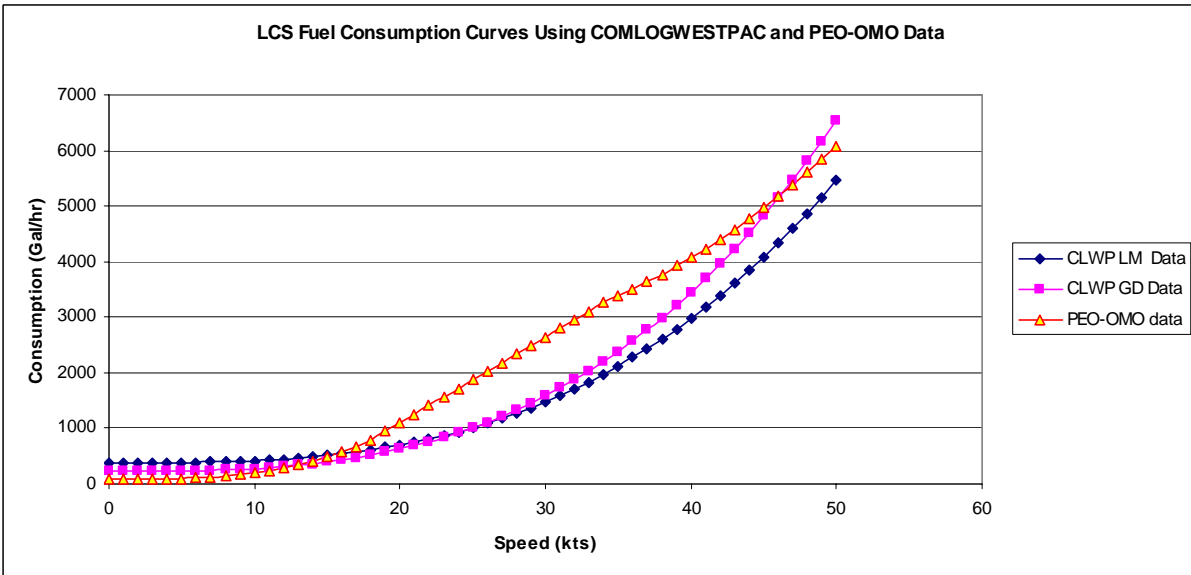
Figure 9. Comparison of LCS fuel consumption curves using COMLOGWESTPAC and PEO-OMO data.

Based on the fuel consumption data from Figure 9 an endurance analysis was conducted for LCS. According to the critical design parameters listed in Table 5 a key

performance parameter (KPP) objective for LCS endurance was created, which states that LCS should be able to travel 1,500nm at a sprint speed of 50kts. An AA also states that LCS should be able to transit 4,300nm at an economical speed of 20kts. For the purpose of range endurance calculations both the GD and LM versions of LCS have fuel capacities as described in NWP 4-01-2 Sustainment at Sea (DoN, Office of the CNO, 2007). The capacities are listed in Table 10.

LCS FUEL CAPCITY (gallons)	
LOCKHEED MARTIN LCS	111,846
GENERAL DYNAMICS LCS	179,592

Table 10.   LM and GD fuel capacities

Figure 10 shows endurance calculation predictions for LCS. For the purpose of this thesis, and because PEO fuel consumption data is not for a specific version of LCS, both LM and GD fuel capacities were applied to PEO-OMO fuel consumption data to create range calculations.
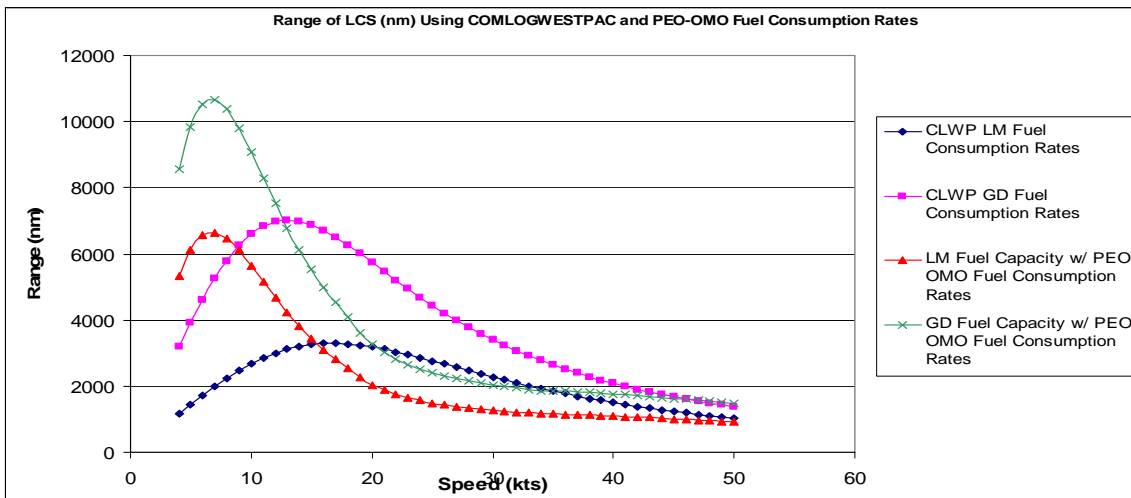
Figure 10. Range calculations for LCS using COMLOGWESTPAC and PEO-OMO fuel consumption rates.

The System Design Capabilities Development Document Requirements (N76, 2004) listed in Table 5 show both threshold and objective values for LCS endurance. Table 11 lists these endurance parameters. Sprint speed and range at sprint speed are KPPs while economical speed and range at economical speed are listed as AAs.

Endurance Parameters for LCS		
Parameter	Threshold	Objective
Sprint Speed	40kts	50kts
Range at Sprint Speed	1,000 nm	1,500 nm
Economical Speed	>18kts	20kts
Range at Economical Speed	3,500 nm	4,300 nm

Table 11.   Endurance parameters for LCS (After N76, 2004)

The endurance analysis shows that at 50kts none of the LCS models is able to meet the objective endurance of 1,500nm as described by the KPP. At the objective economical speed of 20kts only the GD version of LCS; using both the COMLOGWESTPAC and PEO-OMO data is able to meet an AA endurance range of 4,300nm. At the threshold sprint speed value of 40kts both versions of LCS applied to both COMLOGWESTPAC and PEO-OMO data are able to meet the KPP threshold endurance requirement of 1,000nm. Only the GD version of LCS meets the AA threshold requirement of a 3,500nm range at speed of greater than 18kts.

The endurance analysis for LCS also shows that the most economical speeds, the speed at which LCS has the longest range, for both the GD and LM versions are below the AA 18kt threshold value. For both the LM PEO-OMO and GD PEO-OMO versions of LCS the most economical speed is at 7kts. At this speed the LM PEO-OMO version of LCS has a range of approximately 6,650nm while the GD PEO-OMO has a range of approximately 10,675nm. The large disparity in range is created by the difference in the total fuel capacity the two versions of LCS.

Applied to the COMLOGWESTPAC data the LM version of LCS has a higher economical speed, 17kts vice 13kts for the GD version. The large disparity in overall

fuel capacity, a difference of 67,746 gallons, however, gives the GD dynamics version a much longer range at its economical speed. The GD COMLOGWESTPAC LCS is capable of traveling over twice the distance of the LM COMLOGWESTPAC LCS at their respective economical speeds. At sprint speeds of 40kts and 50kts the GD version of LCS is able to travel more than 25% further than the LM version of LCS when applied to both the COMLOGWESTPAC and PEO-OMO fuel burn rates.

B.   MIW MISSION ANALYSIS

As described in the previous chapter an MIW scenario was created in which LCS is deployed from a forward operating base in the western Pacific Ocean to a contested littoral region. LCS is deployed equipped with a MIW mission module and will be actively engaged in mine clearance operations in preparation for an approaching CSG/ESG. LCS will be sent on a 90 day patrol. In this situation, LCS is envisioned to be deployed with ships of other classes as well as other LCS combatants in a Task Force composition. For the purpose of this thesis, one LCS of the deployed Task Force will be analyzed to help operational logistic planners understand how different logistical planning factors will affect the deployment of LCS in a similar scenario.

1.   Current MIW Deployment Analysis

The U.S. Navy currently has one class of ship remaining to deal specifically with potential mine threats. In the 1980's and early 1990's during the Iraq-Iran War and the Gulf War the Navy was reminded of the importance of keeping potential operating areas and international chokepoints in the littoral regions of the world devoid of mines. It was during this timeframe that the U.S. Navy developed and employed the *Avenger* and *Osprey* class mine hunter-killer ships. These ships, along with new air mine warfighting assets became the backbone of the Navy MIW fleet. According to the Navy official website the *Avenger* class ships are

designed as mine hunter-killers capable of finding, classifying and destroying moored and bottom mines. The last three MCM ships were purchased in 1990, bringing the total to 14 fully deployable, oceangoing *Avenger* class ships.

These ships use sonar and video systems, cable cutters and a mine detonating device that can be released and detonated by remote control. They are also capable of conventional sweeping measures. The ships are of fiberglass sheathed, wooden hull construction (Department of the Navy, 2008).

The *Osprey* class ship was officially decommissioned from the Navy in 2007. The Navy currently has 14 *Avenger* class ships remaining whose MIW duties will be transferred to the LCS as the ship becomes integrated into the fleet.

The *Avenger* class ship currently conducts regular patrols and training throughout the world. Training exercises are conducted on both unilateral and multilateral dimensions. *Avenger* class ships are an integral part of both the operating Navy abroad and Homeland Security Department operations at home. During a routine patrol in the Western Pacific Ocean, an *Avenger* class ship can routinely conduct a 90 day patrol in which it can conduct MIW operations in support of an exercise or combat operations if necessary. This thesis will assume that an *Avenger* class ship will conduct a routine patrol in which MIW operations are conducted for a period of 90 days.

During this 90 day patrol, an *Avenger* class ship on station availability (Ao) is constrained by several logistics factors. On average an *Avenger* class ship must leave station once every 5 days to conduct refueling operations. On days when a refueling is scheduled the ship will conduct no MIW operations. During these days it is also assumed that all other necessary supplies such as food and parts will be supplied. Average days between refueling are calculated based on MIW operations being conducted at an average speed of 4-6kts a day. For the purpose of this thesis, an *Avenger* class ship will travel from a forward deployed home port to an operating area at a speed of 8kts and arrive on station after two days of transiting. The final constraining factor that will cause a decrease in Ao for an avenger class ship is the need to conduct a carbon burn on its diesel engines. This will occur on average for four hours after every 36 hours of operation.

Using this information, the Ao is calculated by subtracting the total number of days the ship was required to be off station from the total number of days in the patrol then divided by the total number of days in the patrol. Table 12 shows the average Ao for an *Avenger* class ship based on the constraining factors assumed in this thesis an average Ao of 70% and a requirement for a CLF asset or BSF every 5 days. This requirement assumes a fuel reserve level of 50% is required during operations.

Avenger Class Analysis		
Patrol length	90	days
Avg. time b/w refueling evolutions	5	days
Total time off station for refueling	17	days
Carbon burn requirements	4	hours every 36 hours of operations
Total time off station for carbon burn	6	days
Total time traveling	4	days
Total days off station	27	days
Ao	70%	

Table 12.　　Calculated average Ao for an *Avenger* class ship conducting a 90 MIW mission (After Shu, 2007)

2.　　LCS MIW Deployment Analysis

To conduct an analysis of LCS, how LCS is intended to be employed during a mission must be considered.   For the purpose of this thesis it is assumed that LCS will operate per the Required Operational Capabilities (ROC) and Projected Operational Environment (POE) For LCS 1 (FREEDOM) Class Littoral Combat Ships rough draft dated August of 2006 (N86E, 2006). This rough draft classifies different environments into which LCS will deploy, and how it will operate in them. This section of the thesis will focus on Condition IIM: Battle Readiness – Mine Countermeasures (N86E, 2006). The draft ROC/POE defines this condition as a

> Special readiness condition applicable only to mine countermeasures vessels. The LCS Class will operate in Condition IIM only when conducting its focused MIW mission with the MIW Focused Mission Package embarked. This is the highest state of mine countermeasures

readiness in which mines are present or a probable threat. The LCS conducts all mine prosecution and neutralization using stand-off operations. Condition IIM is set:

‑ For mine hunting operations;

‑ For mine-like contact prosecution or mine neutralization operations using the Airborne Mine Neutralization System (AMNS) or Rapid Airborne Mine Clearance System (RAMICS), remotely operated vehicles (ROV), or embarked helicopters;

‑ When conducting route survey operations (OPNAV N86E, 2006).

During Condition IIM restrictions are placed on how long LCS will be able to operate due to crew endurance. According to the draft ROC/POE LCS will only be able to conduct operations in a Condition IIM state for 72 hours. After LCS has been at condition IIM for 72 hours the schedule must allow for 48 hours of Condition III operations. Condition III, as defined by in the draft ROC/POE (OPNAV N86E, 2006) still places LCS in a heightened warfare posture but allows for other routine activities to take place.

> The crew is in two-section watches with an opportunity for 4-6 hours of rest per day. The ship is limited by crew endurance to 72 consecutive hours of mine sweeping operations followed by 48 hours of Condition III operations to refuel, and to perform routine PMS and urgent repairs. Only the minimum required maintenance and mission critical repairs are expected during Condition IIM (N86E, 2006).

To accommodate for the imposed scheduling restrictions two scheduling options are proposed in this thesis for LCS. The first option places LCS in a 3-2 schedule during a 90 day patrol. During this schedule, LCS will adhere strictly to the ROC/POE draft by conducting focused MIW operations for 72 hours followed by 48 hours of Condition III steaming. The second schedule allows for a relaxation of the Condition IIM constraint and allows LCS to conduct operations for 96 hours followed by 48 hours of Condition III steaming. As is stated in the ROC/POE draft all fueling and supplying evolutions, as

well as maintenance and drills will take place on non-MIW days. For analytical purposes, supplying evolutions will take place on the first non-MIW operating day. This constrains a logistics planner to ensure assets are available for a FAS/RAS or brief stop for fuel (BFS) during an LCS downtime.

Based on the two proposed schedules it is assumed LCS will be able to maintain Condition IIM and conduct operations without problems during scheduled MIW time periods. LCS will begin MIW operations on day 2 of both schedules, following 1 day of transit, and complete operations on day 89, followed by 1 day of transit to home port. Based on these assumptions an average Ao for LCS is calculated for both the 3-2 schedule and the 4-2 schedule using the same calculations as for the *Avenger* class ship. Tables 13 and 14 show the average Ao for a 3-2 schedule and 4-2 schedule respectively.

LCS Class Analysis for 3-2 Schedule		
Patrol length	90	days
Total scheduled condition IIM time	54	days
Total scheduled Condition III time	34	days
Total time traveling	2	days
Total days off station	36	days
Ao	60%	

Table 13.   Calculated Ao for LCS on a 90 MIW mission using a 3-2 schedule

LCS Class Analysis for 4-2 Schedule		
Patrol length	90	days
Total scheduled condition IIM time	60	days
Total scheduled Condition III time	28	days
Total time traveling	2	days
Total days off station	30	days
Ao	67%	

Table 14.   Calculated Ao for LCS on a 90 MIW mission using a 4-2 schedule

Using a 3-2 schedule LCS has an average mission Ao of 60% while using a 4-2 schedule allows LCS to have an average Ao of 67%. Even using a 4-2 schedule LCS is on station an average of 03% less time than the current *Avenger* class ships. Further

analysis will show, however, that LCS, although spending less time on station conducting MIW operations, has the opportunity to lessen the strain on CLF assets and create more flexibility for a logistics planner.

3.   COMLOGWESTPAC LM LCS Replenishment Requirements

Throughout this section when LCS is mentioned, it will refer to the LM version applied to COMLOGWESTPAC fuel consumption rates unless otherwise specifically noted. LCS, although giving the combatant commander less time for mission availability due to crew constraints, does offer the combatant commander more flexibility with logistics than the current *Avenger* class. Operations occur in a cyclical fashion, a 3-2 or 4-2 schedule, allowing the resupplying of LCS for food, parts and fuel to take place at intervals greater than five days. Assuming that fuel reserve levels for LCS will be adjusted to gain the greatest benefit, a scheduler can greatly extend the amount of days between supply events. As stated in Chapter III, each refueling event will bring LCS back to 95% fuel capacity.

As shown in Figure 11, if LCS is to be scheduled on every off-cycle for a fueling event, it will retain a fuel reserve level of 58% during cyclic operations. This level will dip to 48% during the first cycle due to travel to get on station and begin operations. The fuel reserve level can be kept above 50% if a CLF asset was able to meet LCS upon arrival to the area prior to beginning operations. This schedule will also cause LCS fuel reserve levels to dip to 37% upon return to homeport. This can also be avoided if a CLF asset is available to refuel LCS upon completion of MIW operations during the transit day.

LCS has the flexibility to refuel every other cycle, reducing the necessary CLF assets by half. This flexibility may, however, come at an unrealistic cost to mission planners for the LM version. This option will only be available to planners if LCS is allowed to maintain a fuel reserve level of 10%. LCS must also refuel after the first cycle of operations, day 5 of deployment, due to the fuel consumed during the transit.

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Remaining on-hand daily fuel percentages for a 90 day patrol replenishing every other cycle are shown in Figure 12.

Figure 11.   Daily Fuel Remaining (%) for COMLOGWESTPAC LM LCS on 90 day MIW mission (3-2 Mission schedule refueling every cycle)

Figure 12.   Daily Fuel Remaining (%) for COMLOGWESTPAC LM LCS on 90 day MIW mission (3-2 Mission schedule refueling every other cycle)

If allowed a fuel reserve of 10% other considerations, such as stability and range of LCS must be taken into consideration by the logistics planner.

If employed on a 4-2 cycle schedule, COMLOGWESTPAC LM LCS becomes more restrictive for a logistics planner. If this schedule is employed, a logistics planner would gain little scheduling flexibility over an *Avenger* class ship. In order for LCS to maintain single cycle replenishment cycle, a fuel reserve of 49% must be established. During the first cycle, due to transiting speeds LCS must be allowed dip to 39% of its fuel capacity. By allowing this deviation, LCS will still be capable of transiting over 1,200nm at 13kts. Figure 13 shows daily fuel remaining (%) for COMLOGWESTPAC LM MIW on 90 day Patrol using a 4-2 mission profile and refueling each cycle. Without a refueling on the transit to home port LCS will arrive with a fuel level of 28%

Figure 13.   Daily Fuel Remaining (%) for COMLOGWESTPAC LM LCS on 90 day MIW mission (4-2 Mission schedule refueling every cycle)

4.   COMLOGWESTPAC GD LCS Replenishment Requirements

Throughout this section when LCS is mentioned, it will refer to the GD version applied to COMLOGWESTPAC fuel consumption rates unless otherwise specifically

noted. This version of LCS has a greater fuel capacity, as noted in Table 11, and is also more fuel efficient at slower speeds than the LM version described in the previous section. This combination of greater fuel capacity and greater fuel efficiency allows a logistics planner much greater planning flexibility over the COMLOGWESTPAC LM LCS.

As shown in Figure 14 if LCS is scheduled for single cycle refulings during a 3-2 mission profile it will maintain a fuel reserve level of 79%. This level will drop to 72% during the first cycle and 66% upon arrival to home port. This analysis suggests that it would not be necessary to schedule a CLF asset or BSF for LCS during every off cycle.

Figure 14. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (3-2 Mission schedule refueling every cycle)

To schedule LCS for refuelings on an every other cycle basis, would require 50% of the CLF usage of an every cycle schedule. Figure 15 shows, that if employed, LCS will still maintain a 59% reserve during operations. This mission shows LCS at its lowest estimated fuel levels of 51% and 46% during transit periods. This analysis also shows LCS will receive its first fueling evolution on day 10 and a final refueling on day 80.
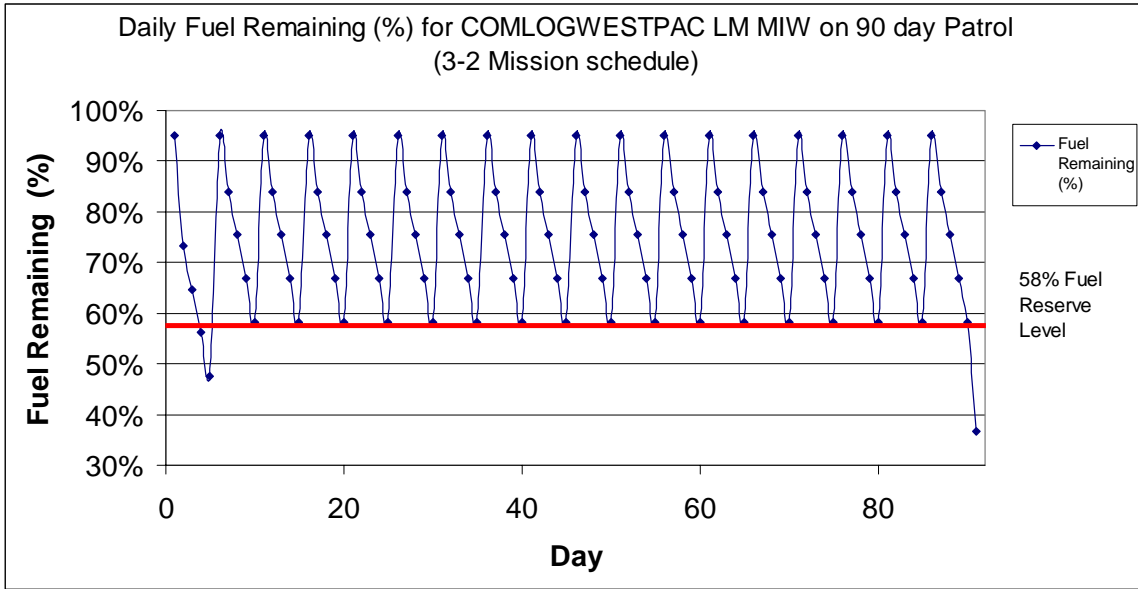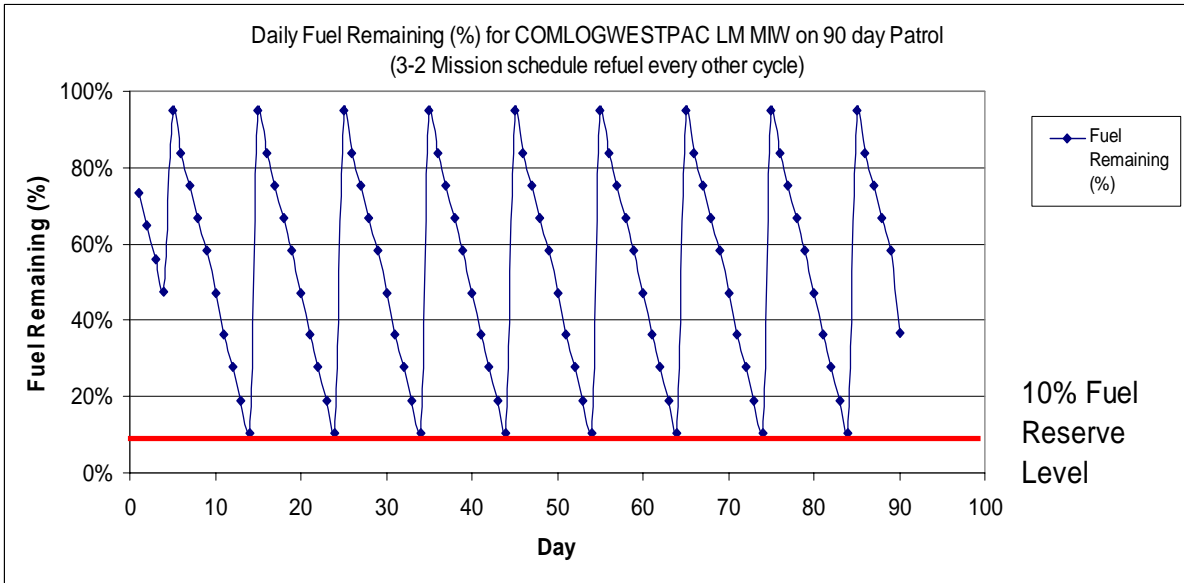
Figure 15. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (3-2 Mission schedule refueling every other cycle)

The larger fuel capacity and more efficient burn rates of the GD LCS allow a logistics planner to consider scheduling a refueling event for LCS every third cycle. As Figure 16 shows this would require allowing LCS to establish a fuel reserve level of 39% during cyclic operations. At a fuel level of 39% LCS would still have a range of over 2,700nm at 13kts. At this fuel reserve level, LCS would still have the capability to return to homeport and conduct possible storm avoidance. This refueling schedule would use one third of the assets required to maintain refueling LCS every cycle. This would give a planner more flexibility in scheduling refueling events and the ship more flexibility in being able to schedule maintenance, conduct training and ensure adequate crew rest is achieved during non-MIW time. This schedule assumes the first refueling event will take place on day 15 of the mission, causing LCS to drop to a 31% fuel level prior to the first refueling. A first refueling event can be scheduled earlier in the patrol to negate this low of a fuel level and then the logistics planner may establish an every third cycle fueling evolution to maintain a reserve level of 39% throughout Condition IIM operations. The final fueling event happens on day 75 in this model but may change depending on when the first fueling event is actually scheduled.
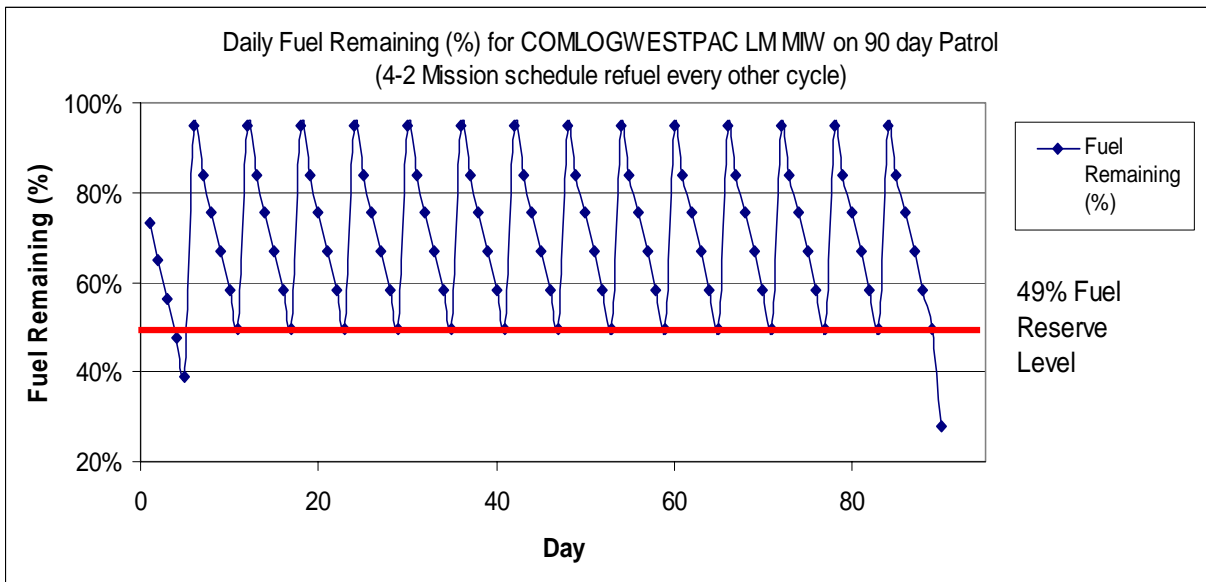
Figure 16. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (3-2 Mission schedule refueling every third cycle)

As an example, to ensure LCS remains above a 39% fuel level, a planner can schedule the first fueling evolution on day 10 of the patrol. This would cause the last fueling evolution to occur on day 85. Figure 17 shows this example employment of LCS.
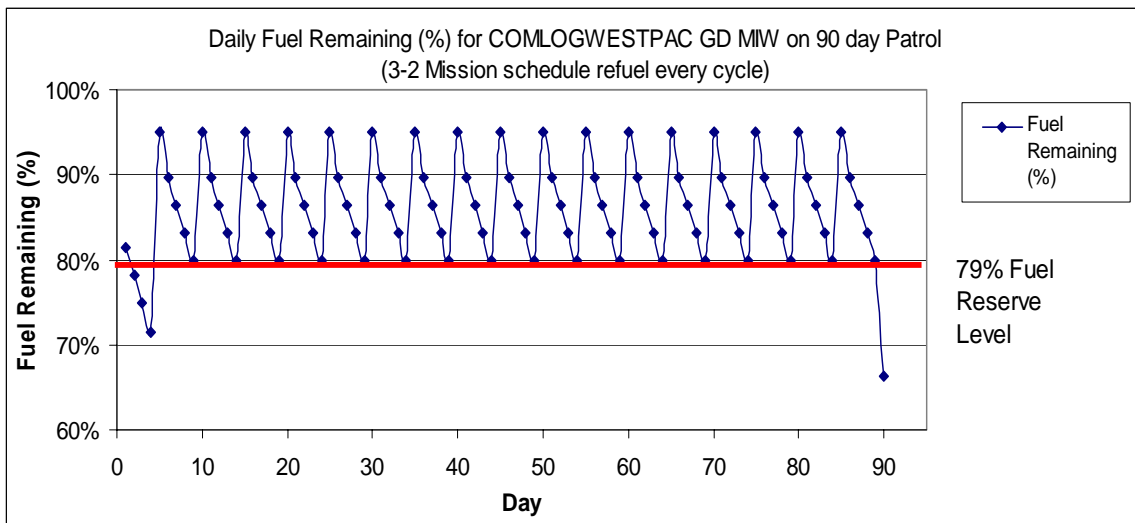

Figure 17. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (3-2 Mission schedule refueling every third cycle w/ first event occurring on day 10)

The GD LCS also enables logistics planners the ability to schedule a refueling event every fourth cycle. This would require allowing LCS to observe a fuel reserve level of 20%. At 20% GD LCS still has the capability of transiting up to almost 1,300nm at 13kts. When allowing LCS to refuel every twenty days planners must be aware that no reserves will be left for food. When deployed LCS will carry prepackaged meals for each sailor aboard that will last for 21 days. If a refueling is scheduled every 20 days LCS must still complete a replenishment event for food and stores at a shorter interval. This will enable logistics planners the ability to use a CLF asset that does not need to be refueling capable and allows the fleets oilers the flexibility to service other customers if necessary. An asset needs only to be able of conducting a vertical replenishment and have the storage capacity to hold LCS food and parts to assist LCS. This allows a planner to use CLF assets, aircraft carriers, and amphibious assault ships. Using this schedule the GD LCS will use only 25% of the oiler assets necessary to refuel the same ship on an every cycle refueling schedule.

Employed in a 4-2 MIW schedule GD LCS becomes more restrictive during longer refueling periods but less restrictive during an every cycle refueling period. During an every cycle refueling schedule, because there is a longer duration between refuelings than when a 3-2 schedule is used, there are less overall fueling events necessary. When conducting a 4-2 mission profile, the first refueling event occurs on day 6 and the final event on day 84 of the patrol. This leaves a requirement for 14 total fueling events vice 17 for a 3-2 schedule. This creates an 18% less need for a CLF asset or port call. This finding also holds true for the LM LCS.

Employed in a 4-2 mission profile LCS will maintain a fuel reserve level of 76%. If the first scheduled refueling occurs at the end of the first four days of operation, day 6, LCS will drop to a 68% fuel level. LCS will arrive back at homeport at a 63% fuel level. Figure 18 shows how this fueling schedule affects fuel levels for MIW operations.
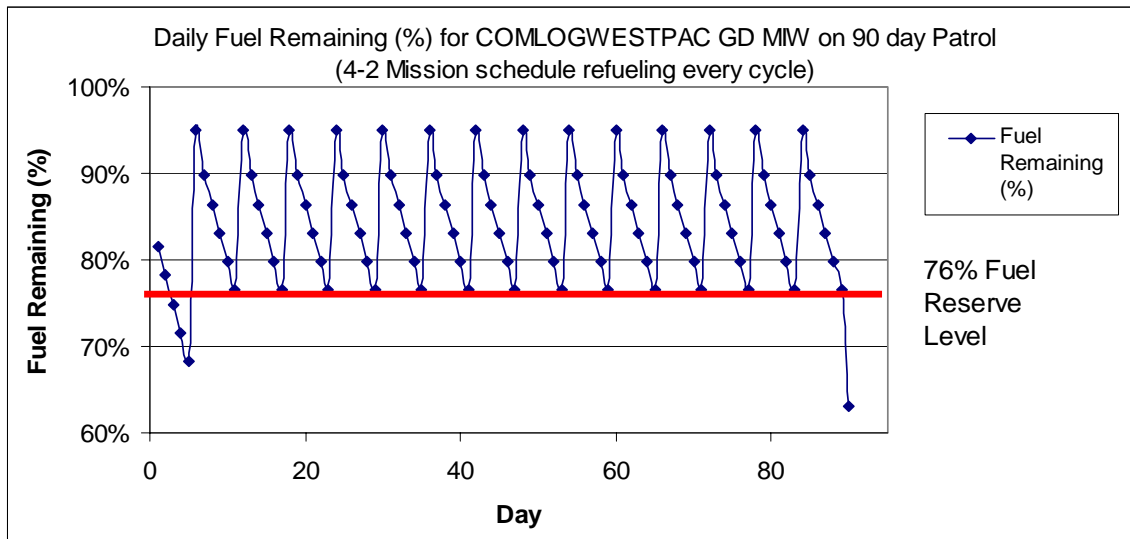
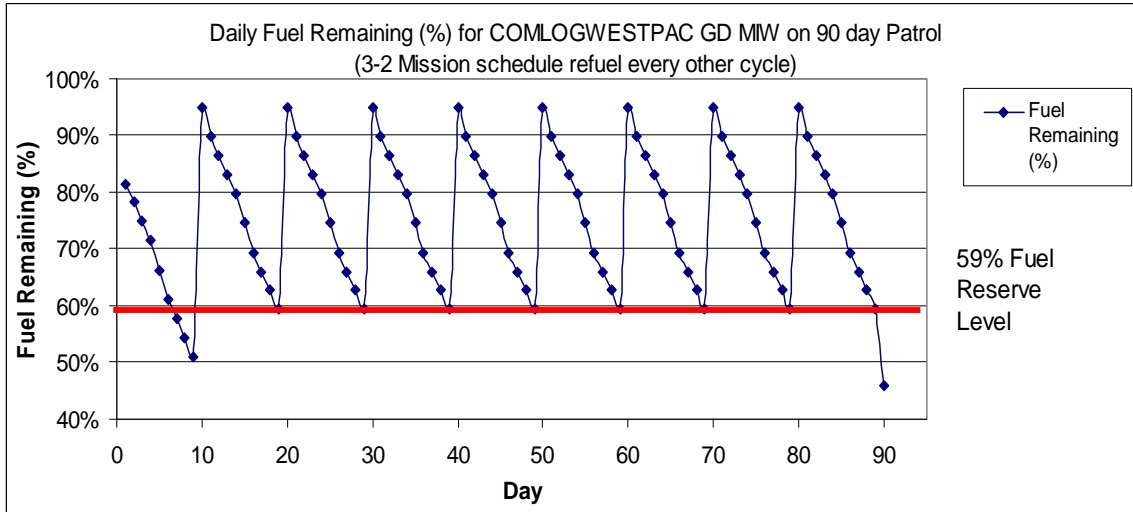Figure 18. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (4-2 Mission schedule refueling every cycle)

Figures 19 and 20 display the effects of refueling every second and third cycles, respectively, on fuel levels during a 90 day mission profile. When refueling every other cycle, LCS maintains fuel levels above 53% during cyclic operations and drops to 44% prior to the first scheduled refueling. When refueling is scheduled after every third full cycle of operations a minimum fuel level of 21% is reached. LCS will drop to a fuel level of 21% during prior to the initial fueling if the scheduled first refueling event does not take place until day 17 of the deployment.
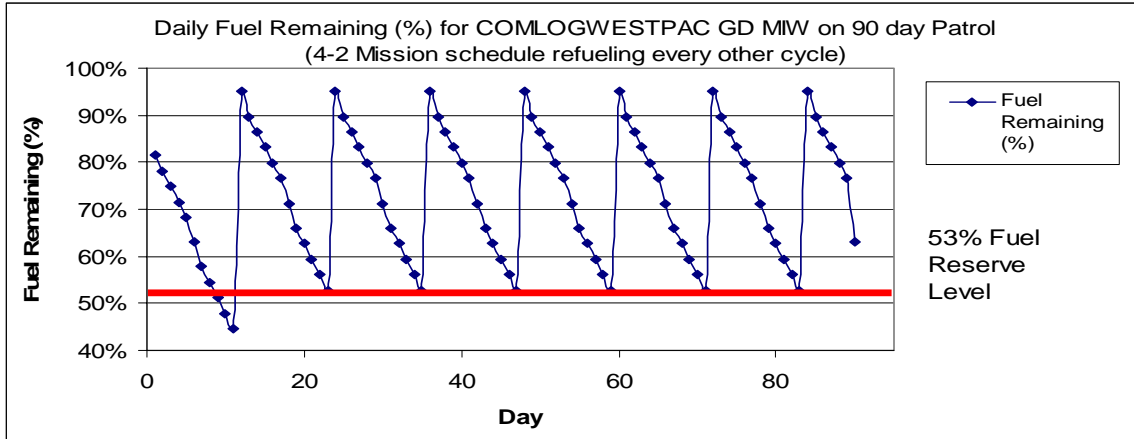
Figure 19. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (4-2 Mission schedule refueling every other cycle)
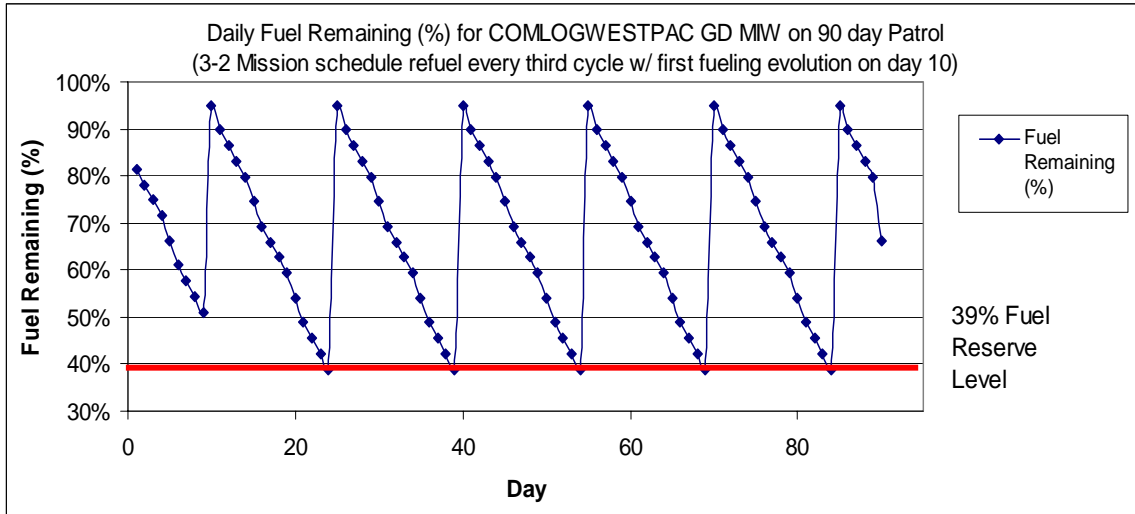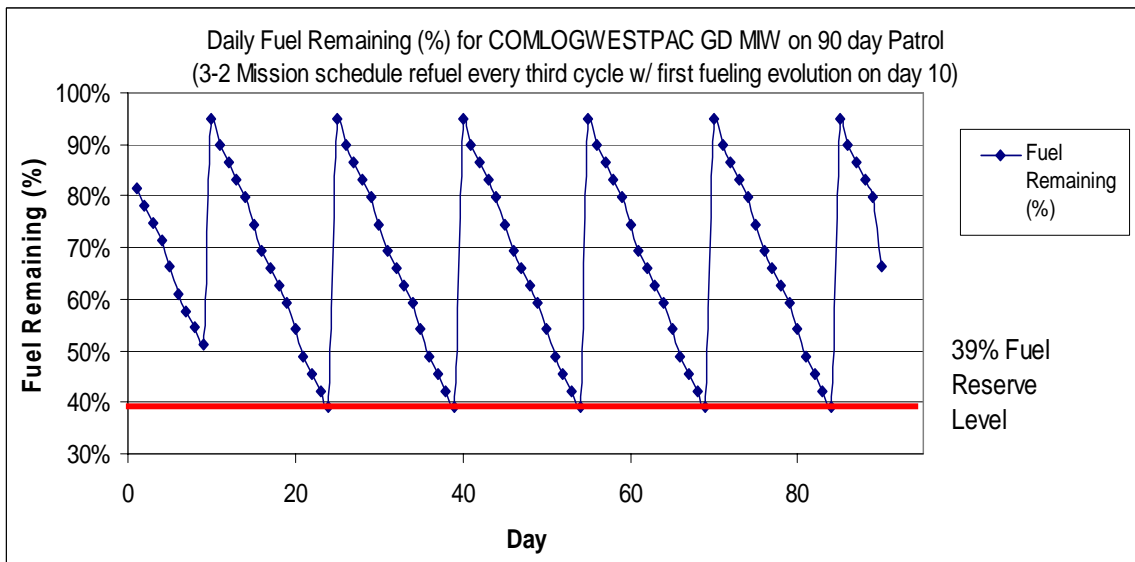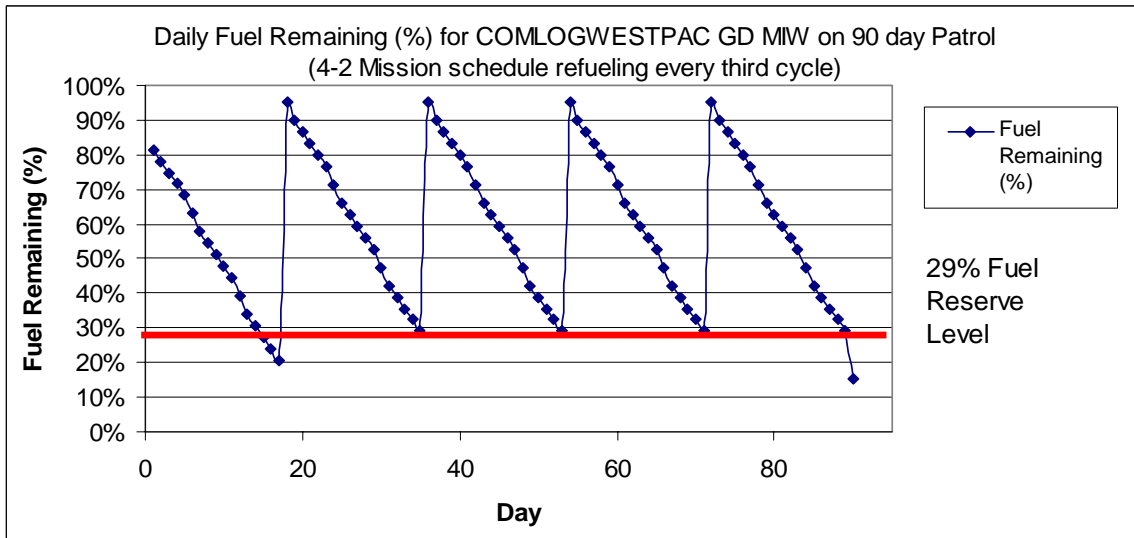

Figure 20. Daily Fuel Remaining (%) for COMLOGWESTPAC GD LCS on 90 day mission (4-2 Mission schedule refueling every third cycle)

If a 4-2 mission schedule is employed for LCS, the ship will not be able to extend the time between refueling events to more than every third cycle.

5. Comparative Analysis between COMLOGWESTPAC GD and LM Versions of LCS

Throughout this section when GD LCS and LM LCS are mentioned, they will refer to the GD or LM approved versions of LCS applied to COMLOGWESTPAC fuel consumption rates.

As noted in the previous section the larger fuel capacity and greater fuel efficiency at lower speeds allow for the GD LCS to have more flexibility when scheduling its logistical needs. Figure 21 shows the effects of different cyclic refueling schedules for both the LM LCS and GD LCS during a 3-2 mission profile on a 90 day patrol. During this mission profile, GD LCS is capable of using 50% of the CLF and port visit assets needed to maintain enough fuel to complete the MIW mission between refuelings. Even when using only half the fueling assets necessary to maintain the LM LCS during a 90 day MIW mission, GD LCS is able to maintain a fuel reserve of almost twice that of its counterpart.
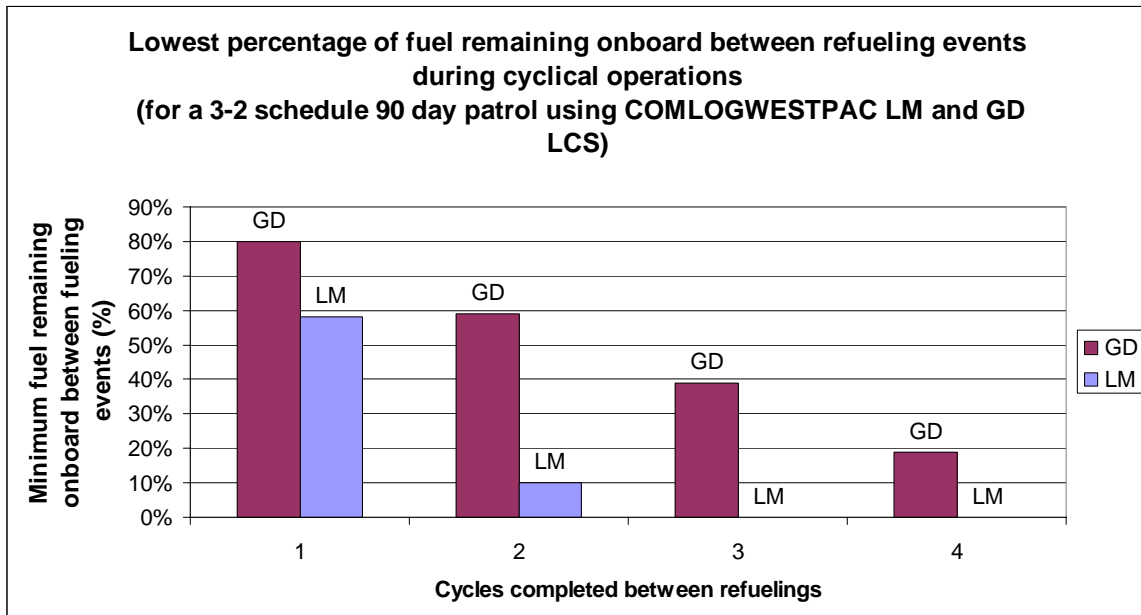
Figure 21. Minimum percentage of fuel remaining onboard between fueling events for cyclical operations during a 3-2 schedule for GD and LM LCS

In section 3 of Chapter IV it was stated that LM LCS is only able to complete its mission if a CLF asset or inport refueling is available at the end of each cycle of operations during a 4-2 mission profile. This gives the LM LCS the same flexibility and less Ao then the *Avenger* class ship. The GD LCS is able to offer the option of scheduled refuelings up to and including after every third cycle of completed operations. Upon completion of the third cycle of operations, GD LCS will still have the ability to transit almost 2000nm. In comparison, when refueling at the end of every cycle and maintaining a minimum fuel level of 49% during cyclical operations the LM LCS will be able to transit 1524nm. The GD LCS provides more flexibility for scheduling while using only one third of the refueling assets necessary to maintain the LM LCS. GD LCS is also capable at transiting nearly 480nm more at its lowest fuel reserve between refuelings. This allows the scheduler the flexibility to allow a CLF asset to stand off further from a dangerous littoral region, or to schedule GD LCS to use a further secondary port for refueling operations if a primary port is unavailable. Figure 22 shows the effects of different cyclic refueling schedules for both the LM LCS and GD LCS during a 4-2 mission profile on a 90 day patrol.
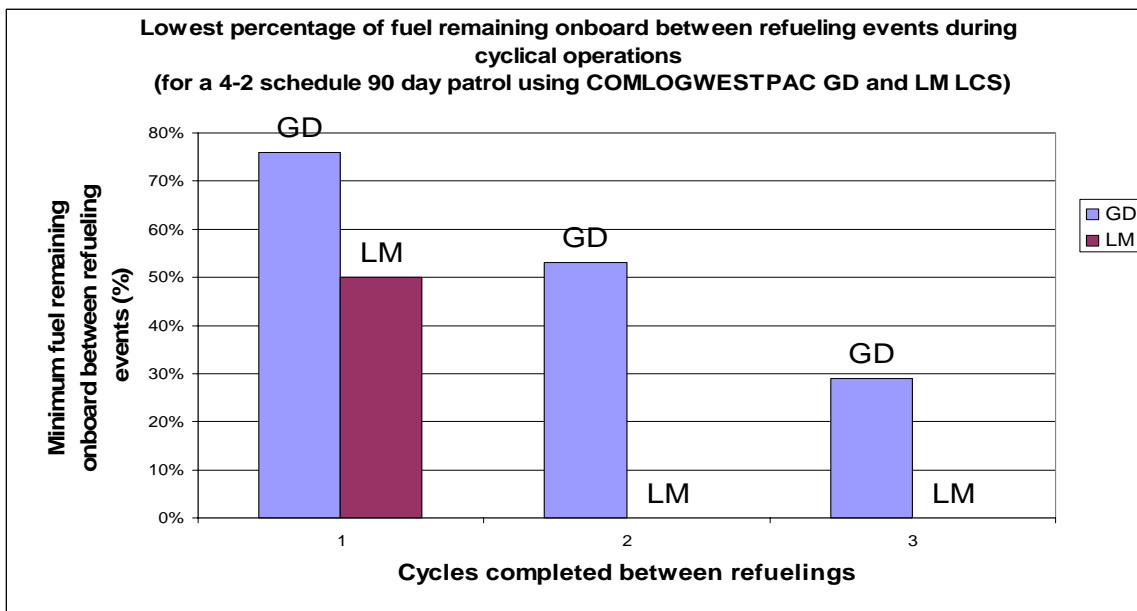
Figure 22. Minimum percentage of fuel remaining onboard between fueling events during cyclical operations for a 4-2 schedule for GD and LM LCS

6. PEO LM LCS Replenishment Requirements

Throughout this section when LCS is mentioned it will refer to the LM version applied to PEO-OMO fuel consumption rates unless otherwise specifically noted. As shown in Figure 8, PEO-OMO fuel consumption rates and PEO-SMO fuel consumption rates are the same for speeds below 19kts. Although PEO-OMO fuel consumption rates are better suited for transit analysis than MIW operations analysis the maximum speed used in this scenario of 15kts allows this fuel curve to be used for analysis.

Figure 9 showed that the PEO-OMO consumption rate is more efficient than the COMLOGWESTPAC LM LCS consumption rate at speeds below 16kts. This added efficiency gives logistics planners the ability prolong refueling during cyclical operations. The high burn rate of LCS above 16kts, combined with a relatively small overall fuel capacity, requires logistics planners to be much more vigilant of LCS fuel levels during high speed transits.

In a 3-2 mission profile, due to the high speed of the transit to the operating area, LCS requires a refueling after the first cycle of MIW operations. Refuelings after the first cycle can then be altered to allow for refueling events to be scheduled after every other cycle or after every third cycle. Figure 23 display the effects of refueling every cycle on fuel levels during a 90 day mission profile. During this mission profile, LCS will maintain a minimum fuel level of 76% during cyclical operations and minimum fuel level of 33% after the first cycle and of 22% upon arrival at homeport. This scenario assumes the first fueling event will take place on day 5 and the final event will take place on day 85. If a CLF asset is available to meet LCS during the transit to homeport LCS can be kept above a 50% minimum fuel level for the entire mission.

This scheduling maximizes the Ao of LCS but increases its dependence on CLF assets and/or BSF evolutions.
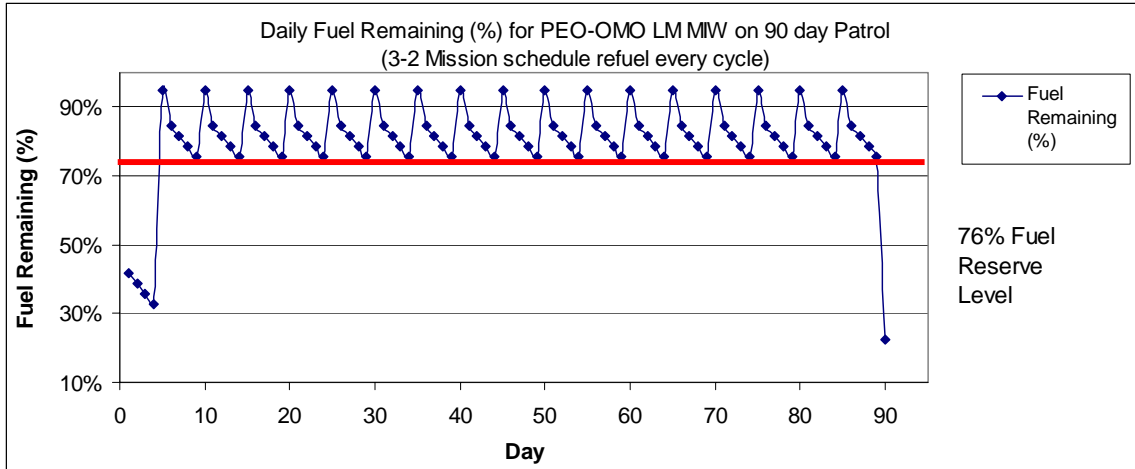
Figure 23. Daily Fuel Remaining (%) for PEO-OMO LM LCS on 90 day mission (3-2 Mission schedule refueling every cycle)

A more efficient use of CLF assets can be made by allowing LCS to refuel every other cycle. This will allow ten days between fueling cycles and use 50% of the CLF and inport assets needed to achieve mission completion using a single cycle refueling schedule. Using an every other refueling cycle would give LCS a minimum fuel reserve of 46% during cyclic operations and a 33% fuel level upon completion of the first cycle. LCS must refuel upon the completion of the first cycle of operations in order to continue the MIW mission. Upon completion of this fueling event, the schedule may change to allow refueling every other or every third cycle of operations. If every third cycle is chosen as the refueling schedule, LCS will maintain a fuel reserve level of only 16% during cyclic operations. This schedule proposes the final refueling event take place on day 80 of the patrol. This would not allow LCS to make it back to homeport thus another RAS would need to be added. This means that if a fueling event was scheduled every third cycle LCS would still require a total of 7 FAS/BFSs. This is a reduction of only 22% or 2 total events. Though this is a feasible solution, if the benefit gained by reducing the need for CLF assets by 22% is outweighed by the minimum amount of fuel that LCS will routinely have onboard during cyclic operations this schedule should not be chosen. Figure 24 displays the effects of refueling every other cycle on fuel levels during a 90 day mission profile.
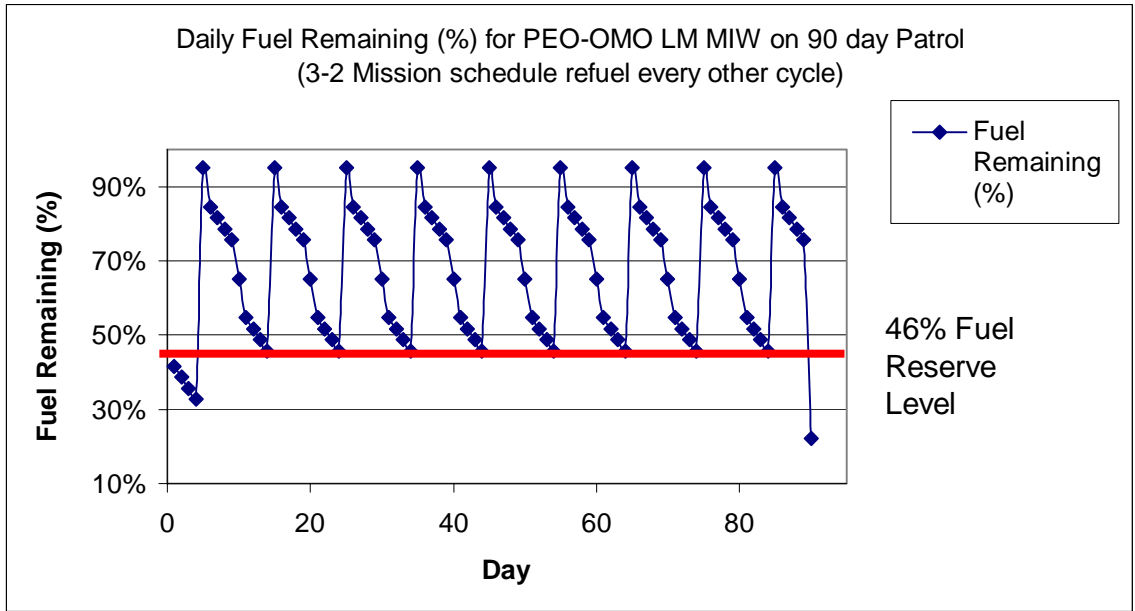
Figure 24. Daily Fuel Remaining (%) for PEO-OMO LM LCS on 90 day mission (3-2 Mission schedule refueling every other cycle)

Employed in a 4-2 mission profile LCS is subject to many of the same constraints. This schedule reduces the overall necessity for a CLF asset or BSF from 17 to 14 total events, but may come at an overall cost to crew rest. If a refueling is scheduled every off cycle LCS will maintain a minimum fuel level of 73% during cyclic operations. This scheduling also causes LCS to enter into its first refueling event with a 30% fuel level. This level can be substantially increased by the operational planner if LCS is able to refuel upon arrival at the operating area and prior to commencing operations, thereby placing LCS at a fuel level of 83% upon its first refueling.

A more effective approach to servicing LCS during a 4-2 mission profile would be to schedule a refueling event every other cycle during cyclical operations. This would also require LCS to be refueled at the end of the first complete cycle of MIW operations. A second non-cyclic scheduled refueling would be required for LCS prior to arrival at homeport to maintain a fuel reserve level above 46% as well. This would overall reduce the need for a CLF asset or BSF by 43% over a single cycle refueling schedule. This schedule would cause LCS to attain a minimum fuel level of 40% during cyclical

operations. Figure 25 shows the effects of refueling every other cycle on fuel levels during a 90 day mission profile.

Figure 25. Daily Fuel Remaining (%) for PEO-OMO LM LCS on 90 day mission (4-2 Mission schedule refueling every other cycle)

This scenario schedules the first fueling event on day 10 and the final cyclical refueling on day 80. An extra refueling is scheduled on day 85 to allow LCS to transit back to homeport at a high rate of speed to ensure travel time remains 1 day.

7. PEO GD LCS Replenishment Requirements

Throughout this section when LCS is mentioned it will refer to the GD version applied to PEO-OMO fuel consumption rates unless otherwise specifically noted. The overall larger fuel capacity of GD LCS over LM LCS allows a logistics planner much more flexibility when scheduling refueling events during this tailored scenario. If LCS is scheduled for a 3-2 mission profile a mission planner has the opportunity to schedule refuelings up to every forth cycle during MIW operations. If a scheduler chooses to refuel LCS after each cycle it will take 17 RAS/BFS events to complete the mission and

the ship will maintain a minimum fuel level of 83% during 3-2 cyclical MIW operations. If the first refueling is scheduled on day 5 of the patrol and the final scheduled on day 85, the minimum fuel level LCS will attain is 50%. This level will not be reached until arrival at homeport.

If a planner chooses to refuel LCS every ten days the lowest expected fuel level during cyclic operations that will be reached is 64%. This schedule requires only half of the CLF and inport assets necessary to refuel LCS, and allows the ship to remain fully mission capable. At 15 days between scheduled refuelings LCS will maintain a minimum fuel level of 46% while conducting operations. If this schedule is chosen and the first fueling event takes place on day 15 LCS will see a minimum fuel level of 19% while on patrol. At this fuel level LCS is capable of transiting over 1300nm at 13kts. Assuming the last fueling event takes place on day 75 of the patrol LCS will complete operations at a 46% fuel level and arrive at homeport after a full day transit at 25kts with a 13% fuel level. This schedule will require LCS to receive a total of 5 fueling events, less than one third the events required if refueling every cycle and almost one half less the events required if refueling every other cycle.

GD LCS is also capable of refueling every fourth cycle between cyclical operations. If this schedule is used and no separate RAS evolutions are scheduled at shorter intervals LCS will be left with a food reserve level of 1 day. To optimize the schedule and use the least amount of CLF and inport assets to refuel LCS, while maintaining a fuel reserve level that will assure full mission capability, the first scheduled event will occur on day 10 and the final event will occur on day 85. This schedule will require a total of 5 refueling events and will assure LCS will maintain a fuel reserve level above 29% during cyclic operations. Not included in the member of refueling events required is the number of off station events needed to ensure LCS maintains a desired reserve level of rations per person. This schedule does not lessen the need for CLF or inport refueling assets but it does allow the scheduler the flexibility to schedule a fleet oiler asset or non-oiler replenishment asset at different times as opposed to a ship with combined capabilities each time a refueling event is schedule. Figure 26 shows the effects of refueling every third cycle on fuel levels during a 90 day mission profile.

Figure 27 shows the effects of refueling every fourth cycle on fuel levels during a 90 day mission profile while Figure 28 shows the effect on food reserve levels if not resupplied at a shorter interval. These levels are based on the 21 day pre-packaged meal plan for LCS sailors.

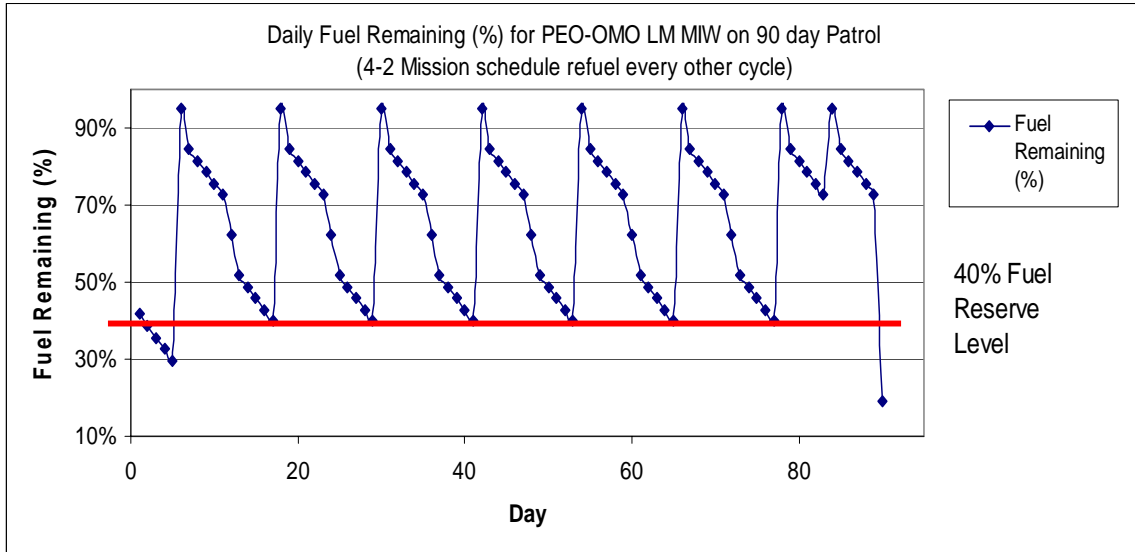Figure 26. Daily Fuel Remaining (%) for PEO-OMO GD LCS on 90 day mission (3-2 Mission schedule refueling every 15 days during cyclic MIW ops)

Figure 27. Daily Fuel Remaining (%) for PEO-OMO GD LCS on 90 day mission (3-2 Mission schedule refueling every fourth cycle during cyclic ops)

Daily amount of food remaining per sailor in 21 day pre-packaged meal plan
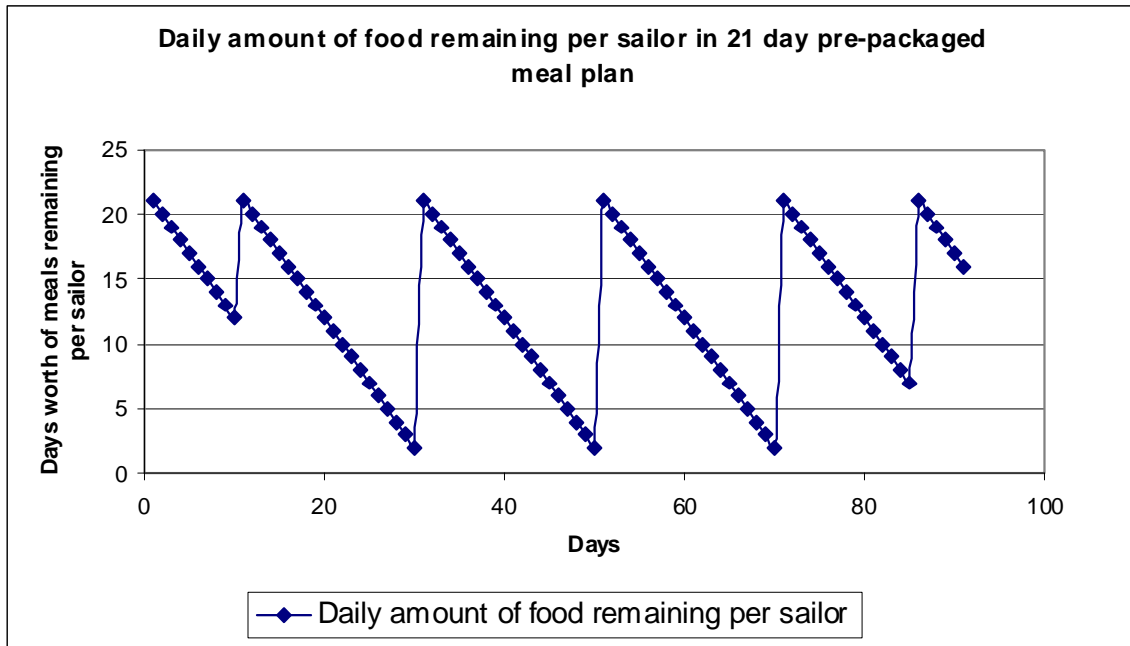
Figure 28. Daily food remaining (amount in days worth per sailor) for PEO-OMO GD LCS on 90 day MIW patrol when resupplying every fourth cycle of a 3-2 mission profile

As shown in Figure 28 on resupply days LCS will have 1 day of prepackaged food remaining out of a 21 day meal plan for each crew member. This implies that if LCS is unable to conduct a RAS on a scheduled day due to weather or lack of assets the ship would simply run out of food. The overall analysis of GD LCS conducting a 3-2 mission profile suggests refueling every third cycle is the most effective scheduling for operational planners to choose.

If LCS is able to conduct a 4-2 mission profile vice a 3-2 profile, as discussed earlier it will be able to increase Ao by 7%. This change in mission profile shows a slight overall improvement in reducing the necessary amount of CLF and inport assets necessary to keep LCS refueled but at a cost in mission reliability. When LCS is enabled to conduct a refueling event every third cycle a minimum fuel level of 7% is reached upon return to homeport. During cyclic MIW operations a fuel reserve level of 40% is maintained when this scheduling preference is used. Compared with a 3-2 mission profile, which requires 5 refueling evolutions, if allowed to drop below a 10% fueling

level LCS will require 4 FAS/BFS evolutions. A fuel level of 7% can easily be overcome by scheduling a FAS or BSF after the final cycle of mine hunting/sweeping operations is conducted. The analysis in Figure 29 does not show this and leaves it to the planner to address this issue.   Overall the 4-2 mission profile offers a slight improvement logistically over the 3-2 schedule because it involves overall less fueling events. This still, however, is the preferable schedule if crew fatigue levels allow it because of the added increase it offers in Ao. Conducting resupplying evolutions every 4 cycles for LCS with a 4-2 mission profile is infeasible due to the 21 day meal plan constraint. It is assumed for the purpose of this thesis that this constraint is not flexible based on food storage capacity in LCS.
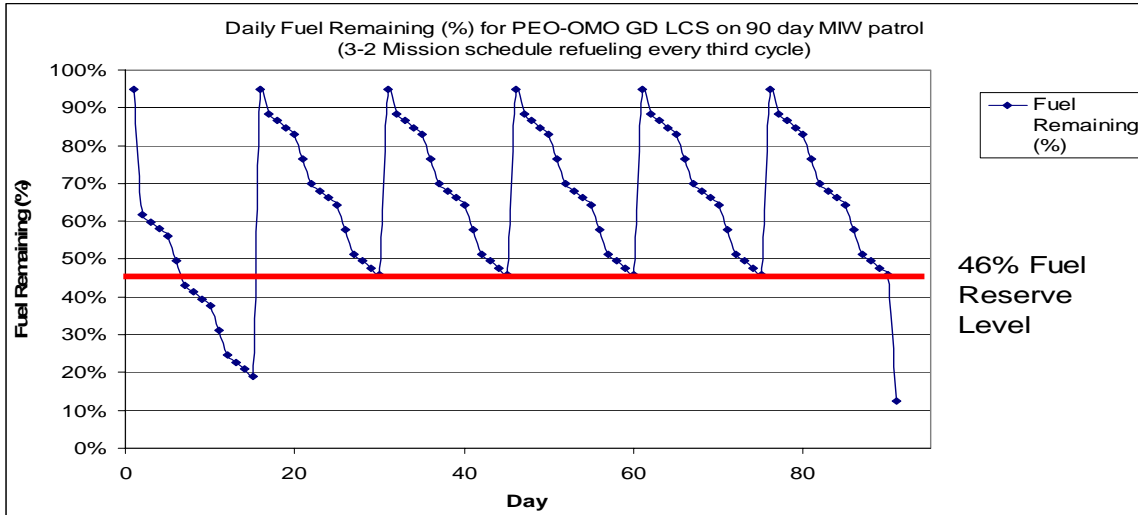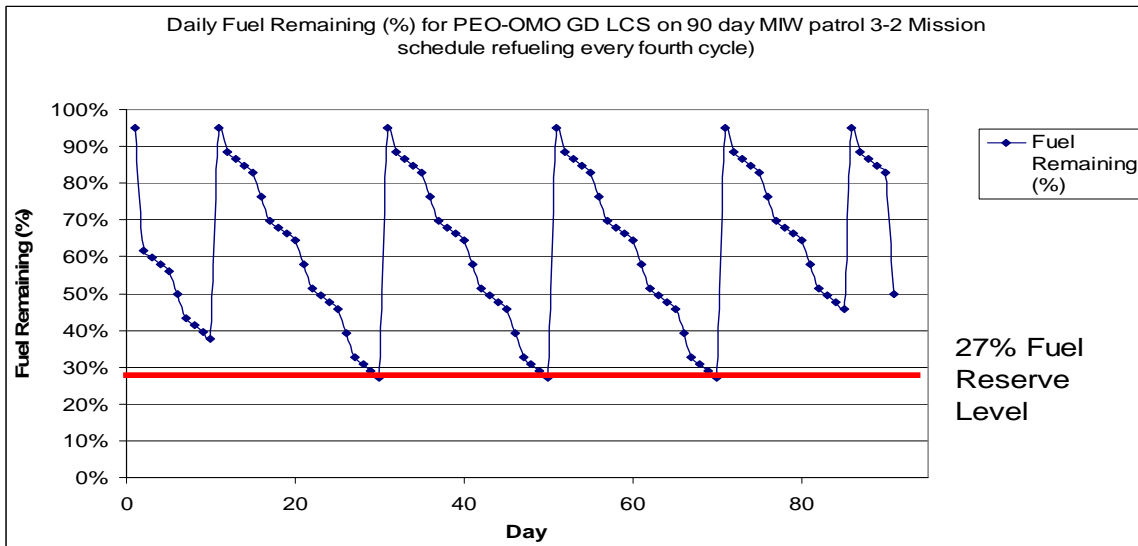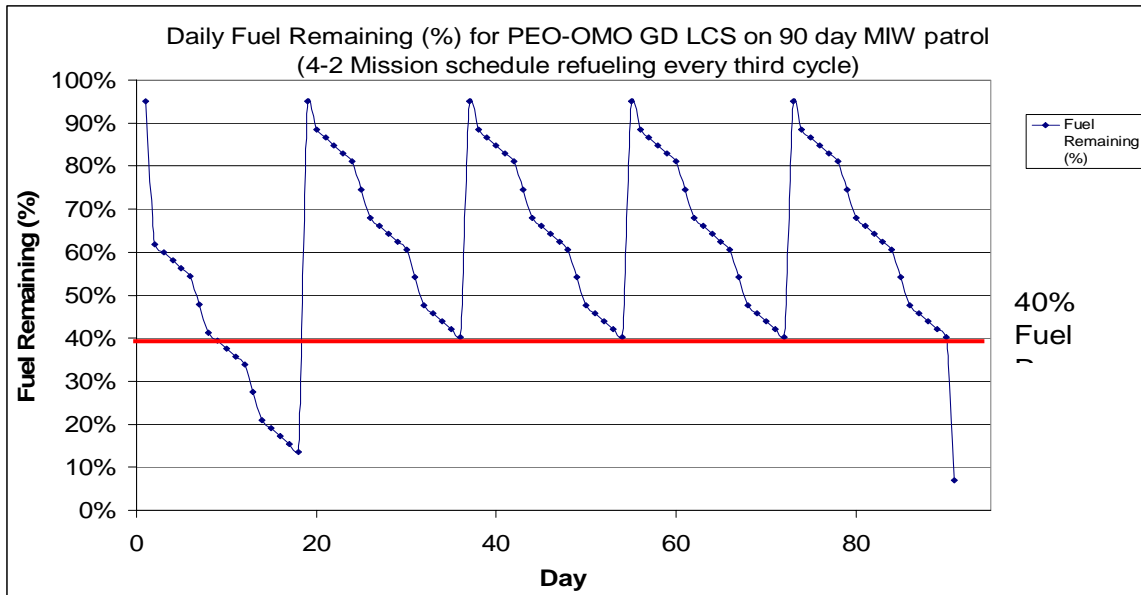

Figure 29. Daily Fuel Remaining (%) for PEO-OMO GD LCS on 90 day mission (4-2 Mission schedule refueling every third cycle during cyclic MIW ops)

8.   Comparative Analysis between PEO-OMO GD and LM Versions of LCS

A comparison of both the PEO-OMO GD an LM version of LCS during a 3-2 mission profile is shown in Figure 30.   This chart shows the operational planner what

expected minimum fuel levels will be reached for a chosen refueling policy during a 3-2 mission profile. Figure 30 also shows that when refueling every cycle both the GD and LM PEO-OMO versions of LCS record similar minimum fuel levels during a 3-2 mission profile.
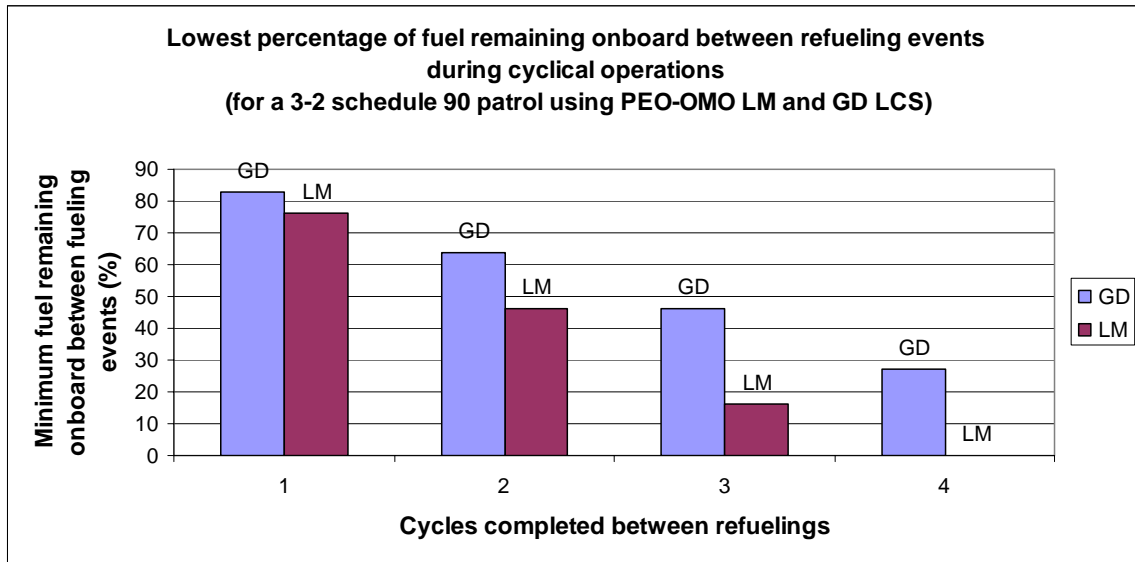
Figure 30. Minimum percentage of fuel remaining onboard between fueling events during cyclical operations for a 3-2 schedule for GD and LM PEO-OMO LCS

When LCS refuels every cycle although each version records similar minimum fuel levels during cyclic operations GD LCS is able to transit almost 2,400nm further at 13kts as the LM LCS. This, again, is due to the large disparity in fuel capacity between the two models. The difference in the endurance of both the LM and GD LCS at minimum fuel levels during a 3-2 mission profile is explored at a transit speed of 13kts and a sprint speed of 45kts in Figure 31 and Figure 32 respectively. These figures are shown to further assist a decision maker as to which refueling schedule will yield the largest benefit by reducing the need for CLF and inport assets, while still maintaining the ability to remain a fully mission capable asset to a combatant commander for other tasking if necessary.
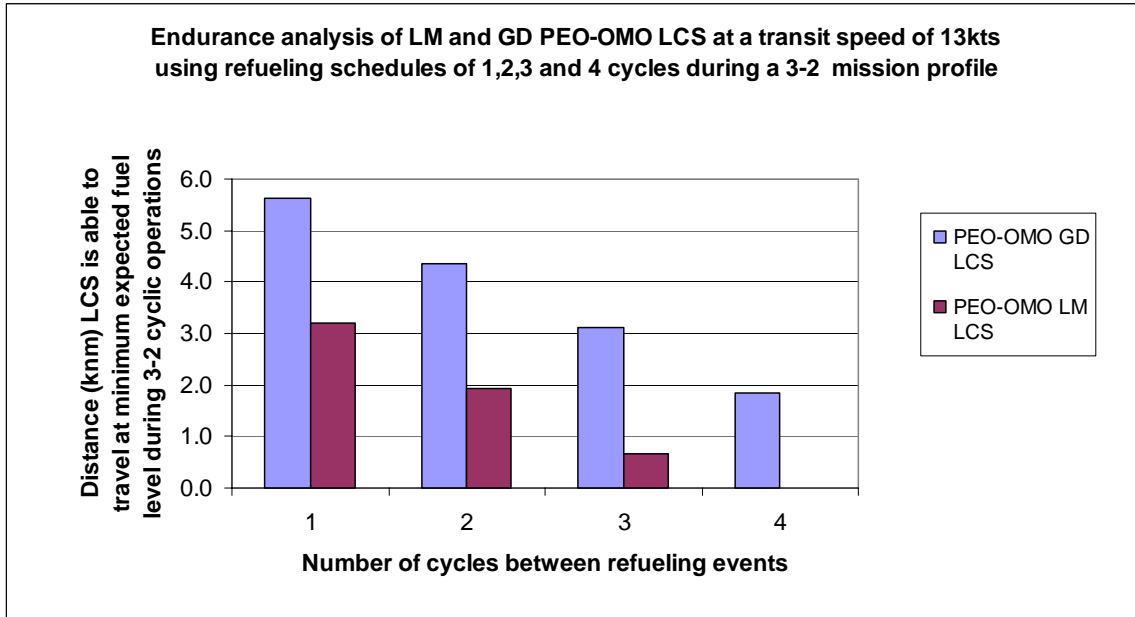
Figure 31. Endurance analysis of LM and GD PEO-OMO LCS at a transit speed of 13kts using refueling schedules of 1, 2, 3 and 4 cycles during a 3-2 mission profile
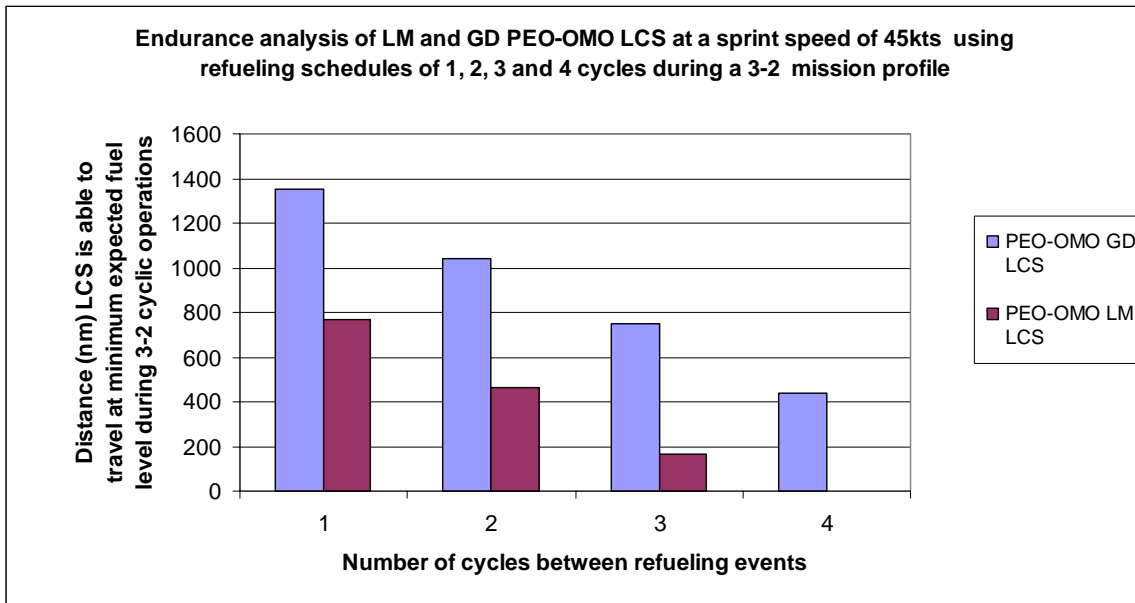
Figure 32. Endurance analysis of LM and GD PEO-OMO LCS at a sprint speed of 45kts using refueling schedules of 1, 2, 3 and 4 cycles during a 3-2 mission profile

In a 4-2 mission profile GD and LM assets retain many of the same differences as in a 3-2 mission profile. GD offers more flexibility to a scheduler because of its ability to go up to 18 days without needing to refuel. Assuming fueling and resupplying events take place at the same intervals this would, however, allow meals per person on board to dip to 3 while still maintaining a fuel reserve level of 40%. Figure 33 shows a comparison of necessary minimum fuel reserve levels to allow LCS to conduct refueling events every, every other, every third and every fourth cycles.
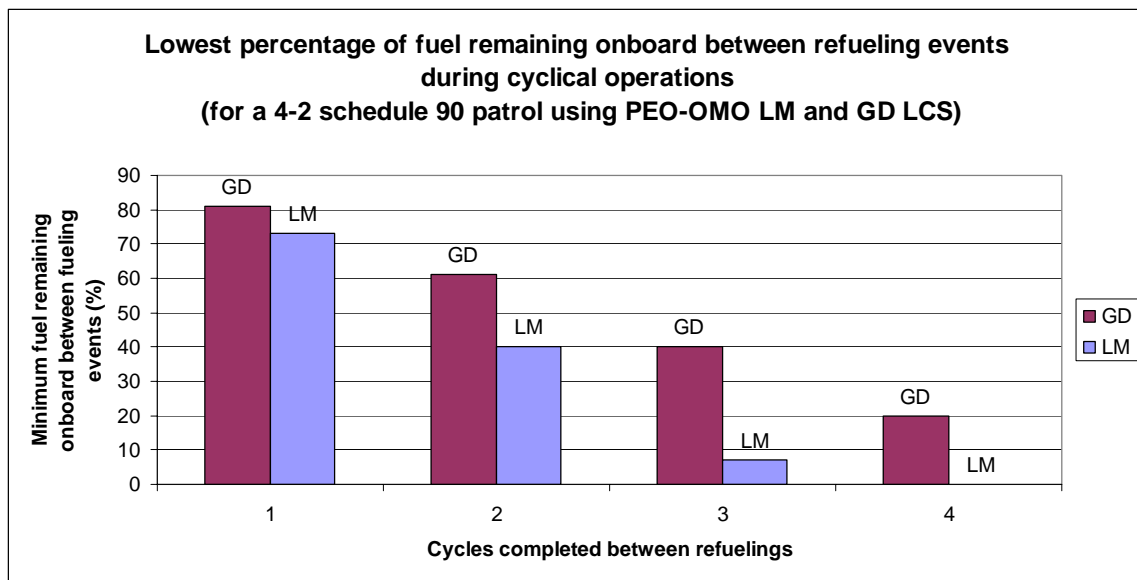
Figure 33. Minimum percentage of fuel remaining onboard between fueling events during cyclical operations for a 4-2 schedule for GD and LM PEO-OMO LCS

C.   CLF ASSET AVAILABLITY

There are several factors that need to be considered when detailing a CLF asset to refuel LCS. Two key factors among them are (1) is the asset available and (2) if it is available is it capable of reaching LCS to conduct a refueling event. The HA/DR scenarios in this chapter will adopt several 7th Fleet key logistics support assumptions to help answer these questions, though in a real planning scenario they must remain at the forefront of questions being asked by a operational logistics planner when deciding to use LCS sprint speed as an asset. In a logistics support brief given in January of 2007 (Tucker, 2007), it was assumed the first deployment of LCS would happen during an already heavily loaded schedule in the 7th Fleet AOR. Figure 34 shows the expected competing factors for CLF assets in 7th Fleet during the summer of 2007, among them is LCS. It will be assumed for the purpose of this thesis that LCS will face similar competition for CLF assets during its actual first deployment. These factors may include Extended Maritime Interdiction Operations (EMIO), Cooperation Afloat Readiness and Training exercises (CARAT), Ballistic Missile Defense/ Limited Defense Operations (BMD/LDO), Carrier (CV) operations and Carrier Strike Group and Expeditionary Strike Group (CSG/ESG) transits.

This thesis will also assume that the amount of CLF assets in 7th Fleet AOR are similar as was expected during the summer of 2007. Figure 34 shows the expected CLF employment during the summer of 2007.

Figure 34. Expected CLF employment for summer of 2007. From 7th Fleet LCS Logistics support brief (From Tucker, 2007)

For the purpose of analysis, tables are created in section D of this chapter that will allow the logistics planner to see the tradeoff between an allowable fuel reserve level and the number of CLF assets needed to maintain that fuel reserve level to complete the assigned mission. Although it may be predictable that 1.0 CLF assets may be available for LCS during this mission, it is also conceivable that there may be more or less actual assets available at any one time. It is also conceivable that although an asset is available it may not be able to reach LCS for a refueling event along the LCS planned track. The reality of this assumption becomes clear in Figure 35. This figure depicts a snapshot of fueling events and the vessels that conducted the events in the Western Pacific Ocean in 2007.   Using this figure as a possible indicator for what the snapshot will look like when LCS deploys, it is likely that if LCS is en route to an HA/DR mission outside an area

defined by Yokosuka, Japan, Sasebo, Japan, Singapore and Guam there is a high likelihood a CLF asset may not be available.
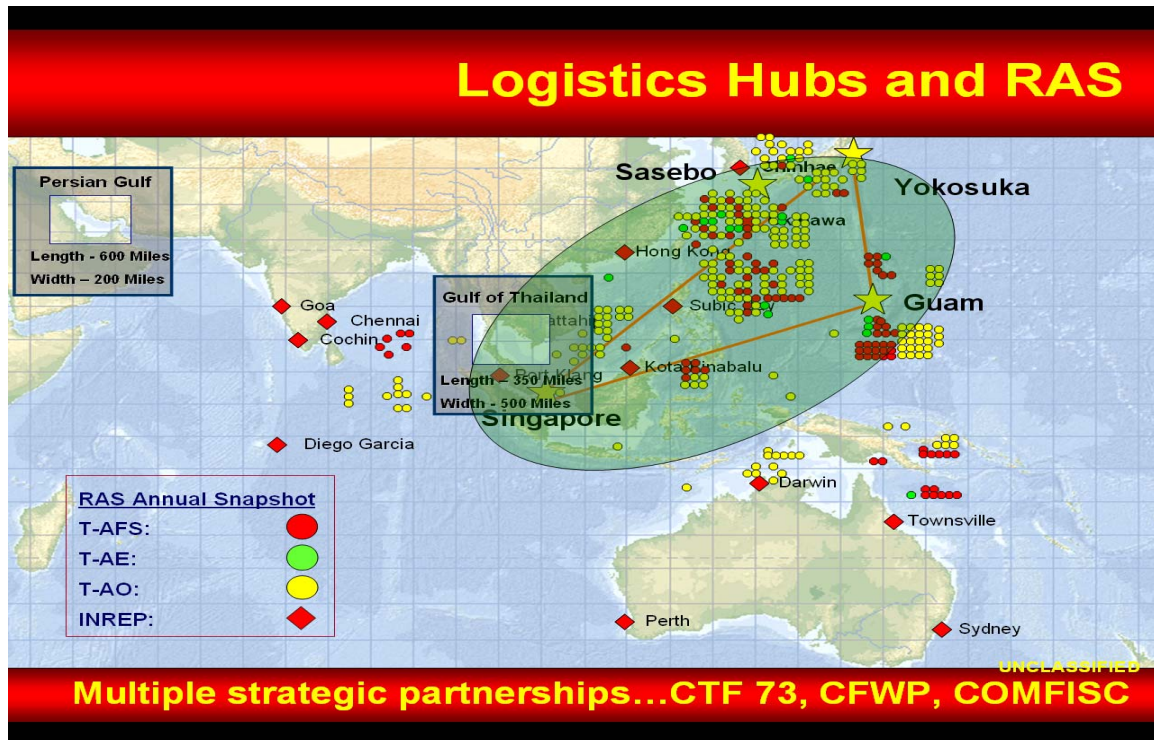
Figure 35. RAS annual snapshot in the Western Pacific theater of Operations. From 7th Fleet LCS Logistics support brief (From Tucker, 2007)

Figure 36 shows 7th Fleet supportability zones. This further emphasizes the need for a logistics planner to fully understand where LCS is coming from and where it is going to. Once the planner understands this and how the intended track of LCS will direct it through the 7th Fleet AOR, the tables in the following section may be used as a guideline to help decide what speed and fuel reserve will best fit the logistical situation LCS will face based on the number of probable CLF assets that will be available. As shown in Figure 36, if LCS begins its transit from the Indian Ocean and heads towards the northern entrance to the Straights of Malacca there is little capability for refueling in the transiting region. This may cause the planner to slow LCS or allow it to maintain a low fuel reserve or some combination of the two.

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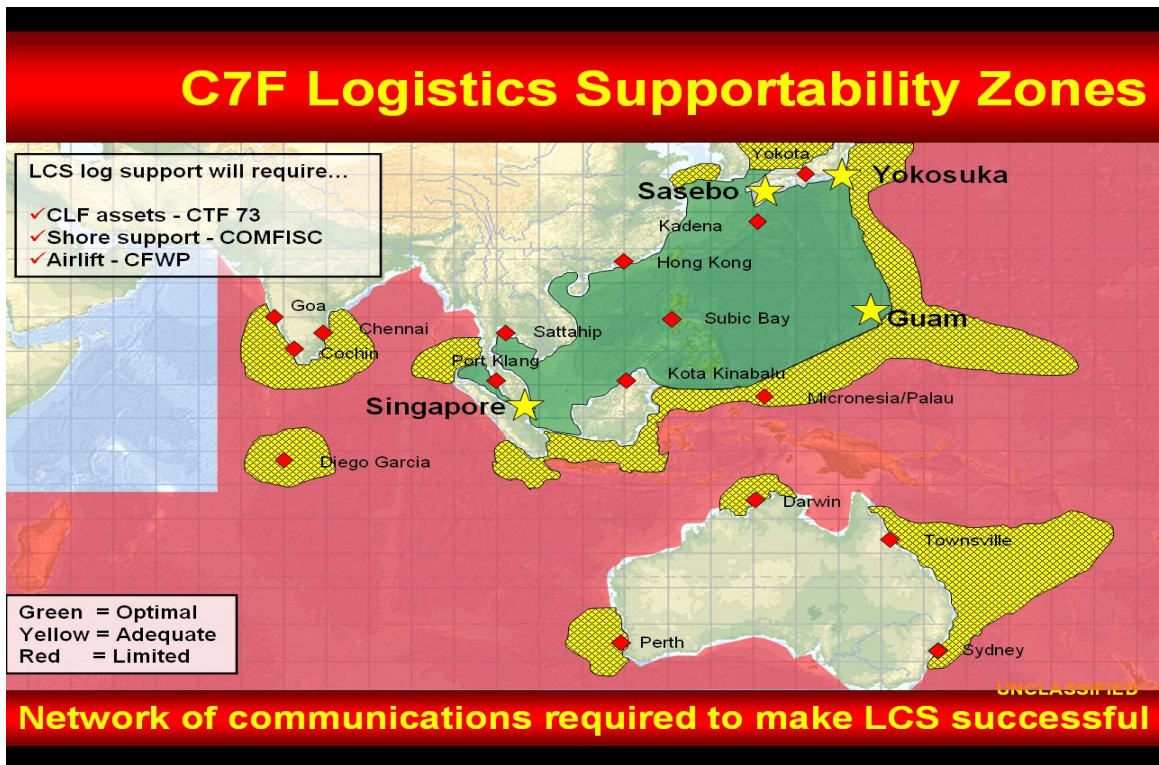
Figure 36.   CLF Logistics Supportability Zones. From 7th Fleet LCS Logistics
support brief From (Tucker, 2007)

From this assumption, it is derived for the purpose of the HA/DR scenario that there will be a maximum of 3.0 CLF assets available and a minimum of 0.0 at any one time to resupply LCS. Any mission that will require LCS to use more than 3.0 CLF assets will be considered infeasible thus negating the use of LCS sprint speed. NWP 4-01.2 will be used as the guideline for determining what assets may be used to refuel LCS, and it will be assumed that all CLF assets capable of refueling other combatants may be used to refuel LCS. This assumption is made because although the T-AFS has the capability to carry fuel and replenish ships at sea NWP 4-01.2 suggests that it cannot transfer fuel to any combatant.   Table 15 shows hourly transfer rates from CLF assets to combatants from NWP 4-01.2 (CNO, 2007). This table shows that the transfer rate from an AFS to LCS is 0 barrels per hour. Despite the published zero transfer rate, this thesis assumes that because an T-AFS can carry fuel for combatants it will be able to refuel LCS.

T-AO to	Unrep	Vertrep	Total Dry	Fuel
CVN	0	40	40	17143
LHD, LHA	0	40	40	8571
LPD	0	40	40	8571
LSD	0	20	20	4286
Surface Combatants	0	20	20	8571
LCS	0	20	20	4286
JHSV	0	40	40	4286

T-AO does not carry organic helicopter(s)

T-AFS to	Unrep	Vertrep	Total Dry	Fuel
CVN	21	40	61	0
LHD, LHA	21	40	61	0
LPD	13	20	33	0
LSD	13	20	33	0
Surface Combatants	13	20	33	0
LCS	15	20	35	0
JHSV	0	40	40	0

Table 15.   Hourly transfer rates from CLF assets to combatants. (From NWP 4-01.2, 2007)

D.   HUMANITARIAN ASSISTANCE/DISASTER RELIEF MISSION ANALYSIS

As described in the previous chapter, three generic HA/DR scenarios are created in which LCS deploys from a forward operating base or forward operating CSG/ESG in the western Pacific Ocean to render assistance to a disaster area in the AOR. Table 16 lists parameters for each intra-theater mission.

Mission	Distance to affected area from origin
A	1,500
B	2,500
C	3,500

Table 16.   Intra-theater HA/DR mission descriptions

For the purpose of analysis in each mission, and because it is still uncertain whether COMLOGWESTPAC or PEO estimated fuel curves will fit , both GD and LM LCS are applied to COMLOGWESTPAC and PEO-SMO predicted fuel consumption. To ensure optimal fuel usage the fuel optimizer created in Chapter III is then applied to each version of LCS.   In an operational situation where HA/DR is needed in an affected area speed becomes vital. The ability of the U.S Navy to get material on scene to those in need in a timely manner could mean the difference between life and death for some. LCS will not be able to provide major medical assistance to those in need but is capable of carrying food, supplies and making water.   It is assumed, for this thesis, that if LCS is deployed to an area for HA/DR that a CSG/ESG with greater capabilities will also be deployed. This CSG/ESG will be assumed to begin its transit towards the affected area at a speed of 15kts and leave at the same time as LCS. This will allow the decision maker to make a comparative analysis as to how much he or she is willing to spend on refueling assets and money to ensure LCS is given the required supplies to arrive at a distressed region prior to the CSG/ESG. Table 17 shows CSG/ESG average statistics for each mission, assuming a CSG/ESG transiting at 15kts will require RAS/FAS once every four days.

CSG/ESG statistics for HA/DR scenarios transiting at 15kts			
Intra-Theater Mission	TOA (hrs)	Days	RAS/FAS Required
A	167	4	1
B	100	7	2
C	233	10	2

Table 17.   Expected time of arrival and fueling-at-sea/replenishment-at-sea evolutions required for CSG/ESG to reach affected HA/DR mission region

1.   HA/DR COMLOGWESTPAC LCS Mission A Analysis

Mission A consists of a 1,500nm transit from a forward deployed homeport or forward deployed ESG/CSG in the western pacific to a disaster area. For analysis purposes LCS transits at speeds between 15kts, this will be used as a baseline, and 45kts. While traveling at 15kts LCS will be able to utilize CSG/ESG refueling assets and will

not require any extra CLF assets to complete the mission of delivering supplies to an affected area. Based on transit speeds used for Mission A, Table 18 shows the time saving benefit the speed of LCS can bring to the HA/DR mission area.

Speed (kts)	Time to arrival (hrs)	Time of arrival ahead of CSG/ESG (hrs)	Time of arrival ahead of CSG/ESG (days)
15	100	0	0.0
18	83	17	0.7
20	75	25	1.0
25	60	40	1.7
30	50	50	2.1
35	43	57	2.4
40	38	63	2.6
45	33	67	2.8

Table 18.   Time ahead of CSG/ESG LCS will arrive to affected region using different speed profiles during HA/DR Mission A

Though LCS can arrive up to almost three days prior to the CSG/ESG, as noted earlier in this thesis speed comes at a price of needing to refuel at relatively short intervals for LCS. This, in turn, will require CLF assets to refuel LCS along its intended track. The max speeds of a T-AO, T-AFS and T-AE are approximately 20kts. In order for LCS to maintain the speed required to arrive ahead of the CSG/ESG it is assumed that any speed over 18kts, LCS will require multiple CLF assets to meet it along PIM. Table 19 shows how many CLF assets will be required for both the LM and GD versions of LCS applied to COMLOGWESTPAC fuel data when fuel reserve levels of 50%, 35% and 20% are allowed. If only 1.0 assets are available for tasking during this mission any speed requiring more than 1.0 CLF assets is considered to be unfeasible.   At speeds of 15kts 0 assets will always be required and at 18kts no more than 1.0 asset will be required.

	CLF Assets Required to maintain FR of 50% for CLWP LM LCS	CLF Assets Required to maintain FR of 35% for CLWP LM LCS	CLF Assets Required to maintain FR of 20% for CLWP LM LCS	CLF Assets Required to maintain FR of 50% for CLWP GD LCS	CLF Assets Required to maintain FR of 35% for CLWP GD LCS	CLF Assets Required to maintain FR of 20% for CLWP GD LCS
speed						
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	0.0	0.0	0.0	0.0	0.0
20	1.0	0.0	0.0	0.0	0.0	0.0
25	1.1	0.0	0.0	0.0	0.0	0.0
30	1.2	1.1	0.0	0.0	0.0	0.0
35	1.4	1.2	1.1	1.1	0.0	0.0
40	1.6	1.4	1.2	1.3	1.1	0.0
45	1.8	1.7	1.5	1.5	1.3	1.2

Table 19.   Number of CLF assets required to complete Mission A while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%

Because certain CLF requirements were close to being feasible, for example at 25kts LM LCS would require 1.1 CLF assets if a fuel reserve limit of 50% is established, some sensitivity analysis was done to find what fuel reserve level would be needed to make Mission A possible for LCS given the CLF restriction of 1.0 assets available. For the LM version of LCS to be feasible for Mission A the greatest impact it can make is to arrive one day before the CSG/ESG if a fuel reserve of 50% is established and 2 days prior if a fuel reserve of just below 35% is established. As discussed in the endurance calculation, if LCS arrives on scene with only 35% of its overall fuel capacity remaining it will be able to continue to make water for and ferry supplies, which were loaded aboard, to an affected area by helicopter while maintaining a speed of 5-8kts for up to 4 days. Assuming a minimum fuel capacity of just below 35% is established, LCS will drop to approximately a 17% fuel level prior to being refueled by the CSG/ESG. LM LCS is unable to complete Mission A at a speed of greater than 30kts and have fuel remaining to conduct operations once on station unless the CLF availability is raised to 2.0.

The GD version of LCS can complete Mission A in the same amount of time as the LM LCS without needing a CLF asset. If allowed to drop to a fuel reserve level of 43% the GD LCS can arrive on station using a speed of 35kts, allowing it to arrive 2.4

days prior to the CSG/ESG. If allowed to drop to a fuel reserve of 29% GD LCS can transit a speed of 40kts and arrive on station 2.6 days prior to the CSG/ESG. As noted earlier, the efficiency at which GD LCS burns fuel at slow speeds combined with the size of its fuel tanks allow it to be able to continue to operate in the affected region without needing to refuel prior to the CSG/ESG arrival. Figure 37 describes how lowering the allotted fuel reserve for Mission A effects the time in which LCS can reach an affected area. This graph assumes that there is only a 1.0 CLF asset presence for tasking in theater.

As Figure 37 shows, allowing a reduction in the fuel reserve level to 40% of the GD LCS gains a maximum of only 10 hours in arrival time to the affected region assuming there is 1.0 CLF assets available and LCS will transit at the maximum allowable speed while maintaining the minimum allowed fuel reserve level. The LM version, however, benefits much more during this mission by allowing a reduced fuel reserve level. As stated earlier the LM version is only capable of transiting at 20kts if a fuel reserve level of 50% is established. By reducing this level to 41% LCS can transit at 25kts and arrive 40 hours ahead of all other scheduled assets. A reduction to 33% would enable LM LCS to arrive 10 hours earlier. Using this fuel reserve level would also require an on station mission speed slow enough to allow LCS to maintain station for over 2 days prior to being refueled upon the CSG/ESG arrival.
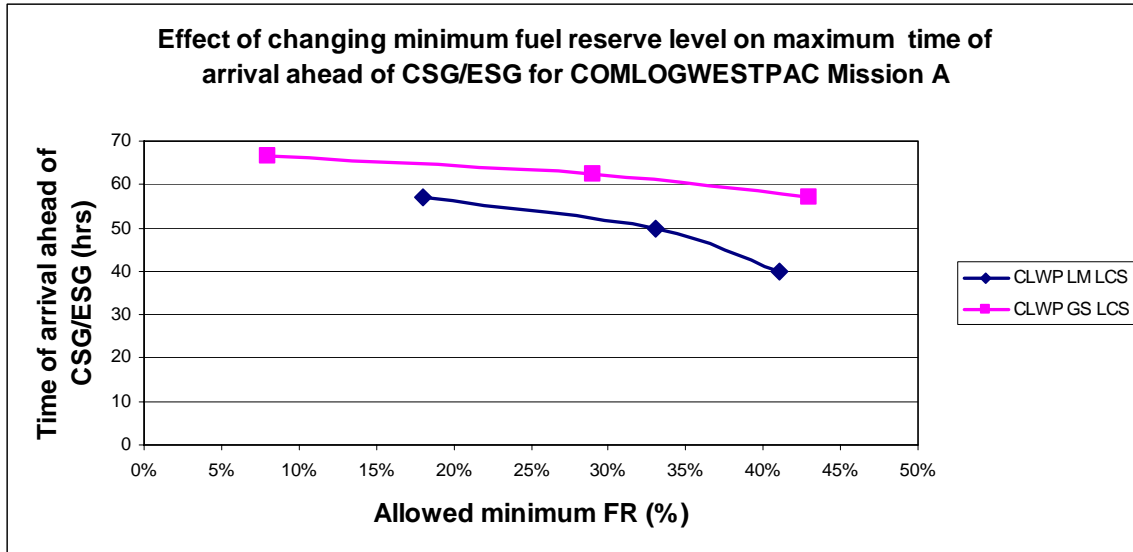
Figure 37. Effect of changing fuel reserve level on maximum time of arrival ahead of CSG/ESG for COMLOGWESTPAC Mission A

2.   HA/DR COMLOGWESTPAC LCS Mission B Analysis

Mission B consists of a 2,500nm transit from a forward deployed homeport or forward deployed ESG/CSG in the Western Pacific Ocean to a disaster area. For analysis purposes LCS transits at speeds between 15kts, this will be used as a baseline, and 45kts. While traveling at 15kts LCS will be able to utilize CSG/ESG assets and will not require any extra CLF assets to complete the mission of delivering supplies to an affected area. Based on transit speeds used for Mission B, Table 20 shows the time saving benefit the speed of LCS can bring to the HA/DR mission area.

Speed (kts)	Time to arrival (hrs)	Time of arrival ahead of CSG/ESG (hrs)	Time of arrival ahead of CSG/ESG (days)
15	167	0	0.0
18	139	28	1.2
20	125	42	1.7
25	100	67	2.8
30	83	83	3.5
35	71	95	4.0
40	63	104	4.3
45	56	111	4.6

Table 20.   Time ahead of CSG/ESG LCS will arrive during Mission B

	CLF Assets Required to maintain FR of 50% for CLWP LM LCS	CLF Assets Required to maintain FR of 35% for CLWP LM LCS	CLF Assets Required to maintain FR of 20% for CLWP LM LCS	CLF Assets Required to maintain FR of 50% for CLWP GD LCS	CLF Assets Required to maintain FR of 35% for CLWP GD LCS	CLF Assets Required to maintain FR of 20% for CLWP GD LCS
Number of CLF assets required to complete Mission B while maintaining the specified fuel reserve throughout mission.						
speed						
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	1.0	1.0	0.0	0.0	0.0
20	1.4	1.2	1.0	0.0	0.0	0.0
25	1.5	1.3	1.2	1 .1	0.0	0.0
30	1.7	1.5	1.4	1.3	1.1	0.0
35	1.9	1.8	1.6	1.5	1.4	1.2
40	2.3	2.1	1.9	1.8	1.6	1.5
45	2.6	2.5	2.3	2.1	1.9	1.8

Table 21.   Number of CLF assets required to complete Mission B while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%

Table 21 shows the analysis conducted on Mission B, relating to the amount of necessary CLF assets that must be available for mission success. If only 1.0 CLF asset is available LM LCS will not be able to complete the mission and arrive more than 1 full day ahead of the CSG/ESG unless allowed to change to a fuel reserve level of 20%. At this speed LM LCS will arrive 42 hours prior to the CSG/ESG and still maintain the ability to conduct HA/DR operations as described in section 1 of this chapter during that time period. All other advantageous speed options for LM LCS are infeasible unless the CLF assets available are at least 2.0.

The GD LCS is able to conduct operations, based on both the CLF asset availability constraint and given fuel reserve level constraints at a speed of up to 30kts if allowed to maintain a fuel reserve level of 20%. A short sensitivity analysis was done by easing the constraints placed on fuel reserve levels. If GD LCS is allowed to drop to a fuel reserve of 25% this mission can be accomplished at 30kts. Any higher speed would make the mission infeasible. By allowing LCS to drop to a fuel reserve level of 25% vice the notional 50% assumed to be required of the fleet in this thesis, supplies can reach the affected area 3.5 days prior to that of what a nominal CSG/ESG could accomplish. If a

2.0 CLF asset availability is attainable GD LCS can accomplish Mission B at a speed of 45kts and arrive with a fuel reserve level of 39%. Figure 38 describes how adjusting the allotted fuel reserve for Mission B effects the time in which LCS can reach an affected area ahead of the CSG/ESG. This graph assumes that there is only a 1.0 CLF asset presence for tasking in theater.
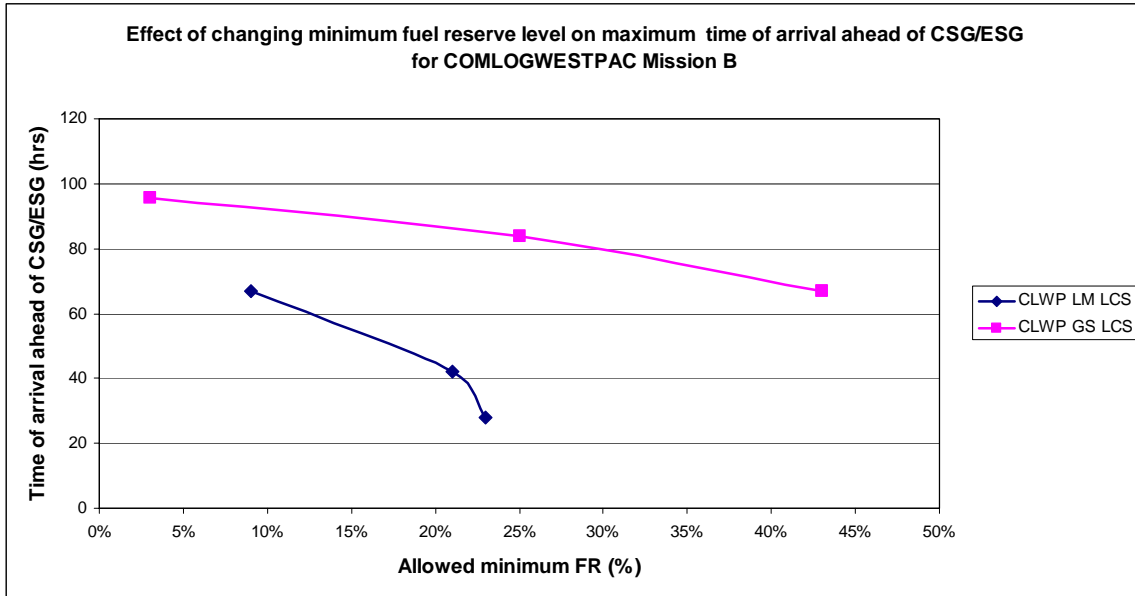
Figure 38. Effect of changing fuel reserve level on maximum time of arrival ahead of CSG/ESG for COMLOGWESTPAC Mission B

3. HA/DR COMLOGWESTPAC LCS Mission C Analysis

Mission C consists of a 3,500nm transit from a forward deployed homeport or forward deployed ESG/CSG in the Western Pacific Ocean to a disaster area. For analysis purposes LCS will transit at speeds between 15kts, and 45kts. While traveling at 15kts LCS will be able to utilize CSG/ESG assets and will not require any extra CLF assets to complete the mission of delivering supplies to an affected area. Based on transit speeds used for Mission C, Table 22 shows the time saving benefit the speed of LCS can bring to the HA/DR mission area. Mission C, due to its distance, truly allows a decision maker to see the effect speed can have on getting aid to an area in a timely manner. At its full

potential, as shown in Table 22, LCS could have aid to a disaster region almost seven days prior to what the nominal normal assets could do.

Speed (kts)	Time to arrival (hrs)	Time of arrival ahead of CSG/ESG (hrs)	Time of arrival ahead of CSG/ESG (days)
15	233	0	0.0
18	194	39	1.6
20	175	58	2.4
25	140	93	3.9
30	117	117	4.9
35	100	133	5.6
40	88	146	6.1
45	78	156	6.5

Table 22.   Time ahead of CSG/ESG LCS will arrive to affected region using different speed profiles during HA/DR Mission B

	Number of CLF assets required to complete Mission C while maintaining the specified fuel reserve throughout mission.					
speed	CLF Assets Required to maintain FR of 50% for CLWP LM LCS	CLF Assets Required to maintain FR of 35% for CLWP LM LCS	CLF Assets Required to maintain FR of 20% for CLWP LM LCS	CLF Assets Required to maintain FR of 50% for CLWP GD LCS	CLF Assets Required to maintain FR of 35% for CLWP GD LCS	CLF Assets Required to maintain FR of 20% for CLWP GD LCS
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	1.0	1.0	1.0	0.0	0.0
20	1.7	1.5	1.4	1.2	1.0	0.0
25	1.9	1.7	1.5	1.4	1.2	1.0
30	2.1	2.0	1.8	1.6	1.4	1.3
35	2.5	2.4	2.2	1.9	1.8	1.6
40	3.0	2.8	2.6	2.3	2.1	2.0
45	3.5	3.3	3.2	2.7	2.6	2.4

Table 23.   Number of CLF assets required to complete Mission C while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%

As shown in Table 23, Mission C analysis provides similar results to both A and B. When all constraints are factored in the LM LCS gives no sprint speed advantage to the combatant commander. The GD version of LCS is capable of conducting the same

mission at a speed of 25kts with only one RAS necessary. This would place aid from the GD LCS at the disaster relief area 140 hours after departing. This is a difference of 93 hours from the CSG/ESG while still maintaining feasibility within all given constraints.

If 2.0 CLF assets are available along the intended track LM LCS will be able to complete the mission at a speed of 30kts and the GD LCS will be able to complete the mission at a speed of 40kts. This will place LCS on station 6 days prior to the CSG/ESG arriving. If LCS can maintain a loiter speed of between 5-8kts while delivering water and supplies to the affected area it will be able to remain on station for 6 days if the only RAS it receives is when it reaches a fuel level of 20% during transit. This leaves no room for operational delay of the CSG/ESG arriving to the affected area. If allowed to drop to 15% during transit LCS will be able to maintain station at the relief zone long enough to allow the CSG/ESG to arrive and conduct a refueling operation prior to running critically low on fuel.

Figure 39 shows the sensitivity analysis done for Mission C. This figure shows that LM LCS in incapable of completing the mission utilizing the sprint speed capability the ship brings to a theater. The GD LCS, however, is able to gain significant time through slight reductions in its fuel reserve level. A reduction from 43% to 38% allows an increase of 19 hours ahead of the CSG/ESG. A further reduction in the fuel reserve level to 20% allows GD LCS to arrive almost 4 days ahead of the CSG/ESG.
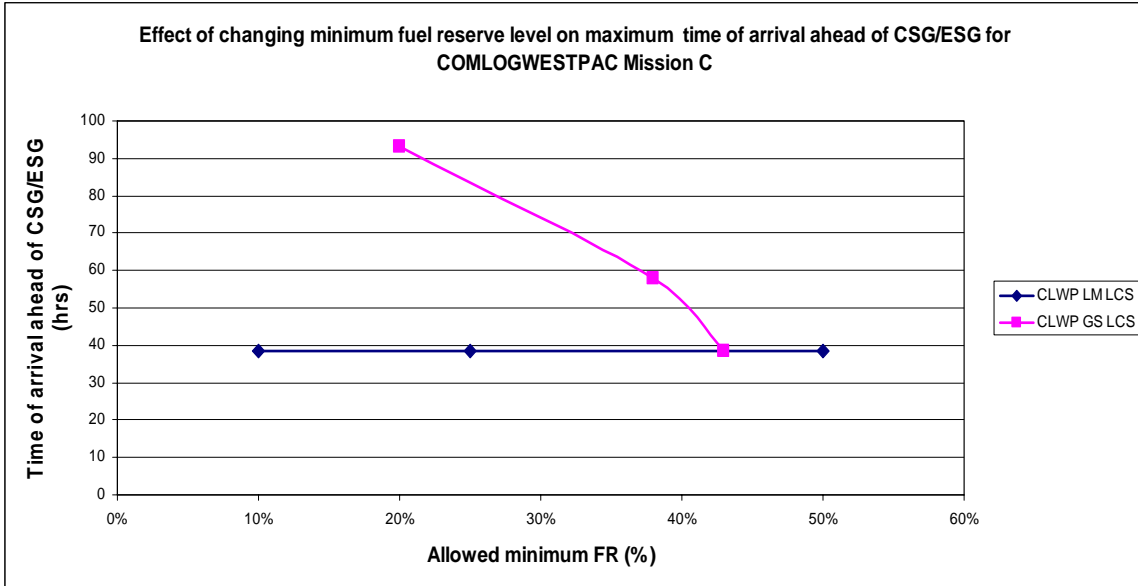
Figure 39. Effect of changing fuel reserve level on maximum time of arrival ahead of CSG/ESG for COMLOGWESTPAC Mission B

4.   HA/DR PEO LCS Mission Analysis

HA/DR PEO Mission analysis applies the same fuel consumption rates to both versions of LCS.   Tables 24, 25 and 26 show how the larger fuel capacity of the GD LCS gives the operational logistics planner greater ability in using the greatest asset LCS brings to the combatant commander, speed. Also noticeable in this analysis is that the GD LCS is not as fuel efficient at higher speeds based on the PEO fuel calculations done earlier in this chapter. This causes GD LCS to lose much of the speed advantage gained when using COMLOGWESTPAC fuel consumption data.

Figures 40 and 41 show how increasing the fuel reserve level of LCS affects ability to reach an HA/DR mission area assuming 1.0 CLF assets available for use in theater. There is no figure for Mission C in this section because neither version of LCS is able to complete the mission without being escorted. This limits both versions of LCS to a speed of 18kts and an arrival time of 39 hours ahead of the CSG/ESG.

speed	CLF Assets Required to maintain FR of 50% for PEO LM LCS	CLF Assets Required to maintain FR of 35% for PEO LM LCS	CLF Assets Required to maintain FR of 20% for PEO LM LCS	CLF Assets Required to maintain FR of 50% for PEO GD LCS	CLF Assets Required to maintain FR of 35% for PEO GD LCS	CLF Assets Required to maintain FR of 20% for PEO GD LCS
Number of CLF assets required to complete Mission A while maintaining the specified fuel reserve throughout mission.					
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	0.0	0.0	0.0	0.0	0.0
20	1.3	1.1	0.0	1.0	0.0	0.0
25	1.6	1.4	1.1	1.2	1.0	0.0
30	1.7	1.6	1.3	1.3	1.1	0.0
35	1.9	1.7	1.4	1.4	1.2	0.0
40	2.0	1.8	1.5	1.4	1.3	0.0
45	2.1	1.9	1.7	1.5	1.3	1.1

Table 24. Number of CLF assets required to complete PEO Mission A while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%

speed	CLF Assets Required to maintain FR of 50% for PEO LM LCS	CLF Assets Required to maintain FR of 35% for PEO LM LCS	CLF Assets Required to maintain FR of 20% for PEO LM LCS	CLF Assets Required to maintain FR of 50% for PEO GD LCS	CLF Assets Required to maintain FR of 35% for PEO GD LCS	CLF Assets Required to maintain FR of 20% for PEO GD LCS
Number of CLF assets required to complete Mission B while maintaining the specified fuel reserve throughout mission.					
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	1.0	1.0	1.0	1.0	0.0
20	1.8	1.6	1.4	1.3	1.2	0.0
25	2.2	2.1	1.8	1.6	1.4	1.2
30	2.6	2.4	2.1	1.8	1.6	1.3
35	2.8	2.6	2.3	1.9	1.8	1.5
40	2.9	2.8	2.5	2.0	1.9	1.6
45	3.1	2.9	2.7	2.1	2.0	1.7

Table 25. Number of CLF assets required to complete PEO Mission B while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%

Number of CLF assets required to complete Mission C while maintaining the specified fuel reserve throughout mission.						
speed	CLF Assets Required to maintain FR of 50% for PEO LM LCS	CLF Assets Required to maintain FR of 35% for PEO LM LCS	CLF Assets Required to maintain FR of 20% for PEO LM LCS	CLF Assets Required to maintain FR of 50% for PEO GD LCS	CLF Assets Required to maintain FR of 35% for PEO GD LCS	CLF Assets Required to maintain FR of 20% for PEO GD LCS
15	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	1.0	1.0	1.0	1.0	1.0
20	2.3	2.2	1.9	1.6	1.5	1.2
25	2.9	2.8	2.5	2.0	1.9	1.6
30	3.4	3.2	2.9	2.3	2.1	1.8
35	3.7	3.5	3.2	2.5	2.3	2.0
40	3.9	3.7	3.4	2.6	2.5	2.2
45	4.2	4.0	3.7	2.8	2.6	2.3

Table 26.	Number of CLF assets required to complete PEO Mission C while transiting at speeds from 15kts to 45kts and maintaining a fuel reserve level of 50%, 35% and 20%
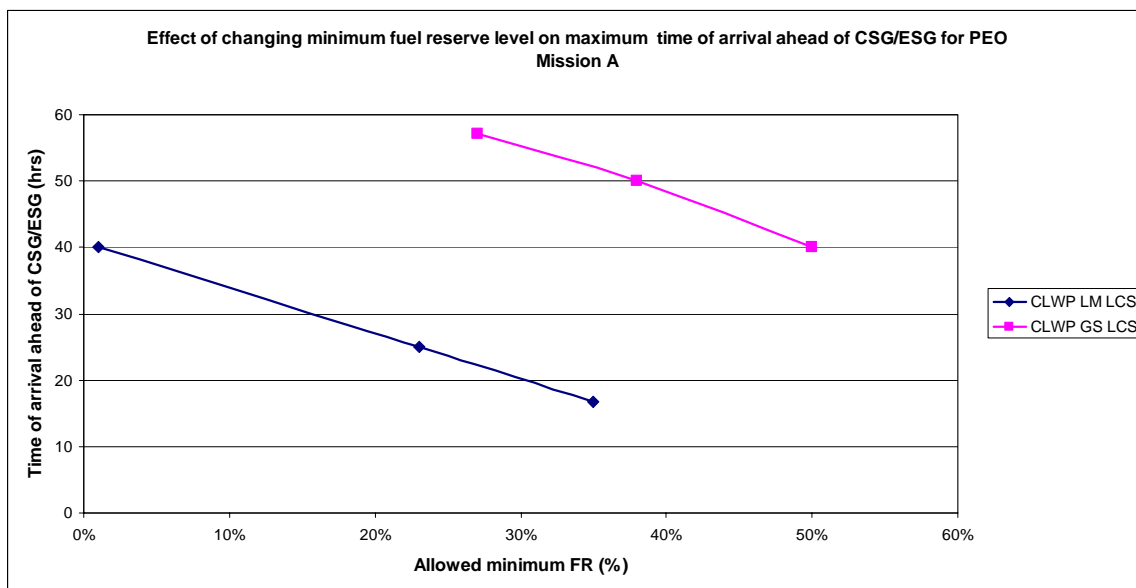

Figure 40. Effect of changing fuel reserve level on maximum time of arrival ahead of CSG/ESG for PEO Mission A

Figure 40 shows that given the same fuel reserve levels, the GD LCS is capable of transiting at higher speeds due to its larger fuel capacity. This enables the GD LCS to

arrive at the affected area over 1 day faster than the LM version, and at a fuel reserve level of 40%, and 2 days prior to the CSG/ESG. Figure 41 shows that while conducting Mission B both versions of LCS maximize their ability to increase arrival time at around a 25% fuel reserve. During this 2,500nm transit GD LCS, because of its larger fuel capacity, is able to arrive on station 14 hours prior to the LM version and 42 hours prior to the CSG/ESG

Effect of changing minimum fuel reserve level on maximum time of arrival ahead of CSG/ESG for PEO Mission B
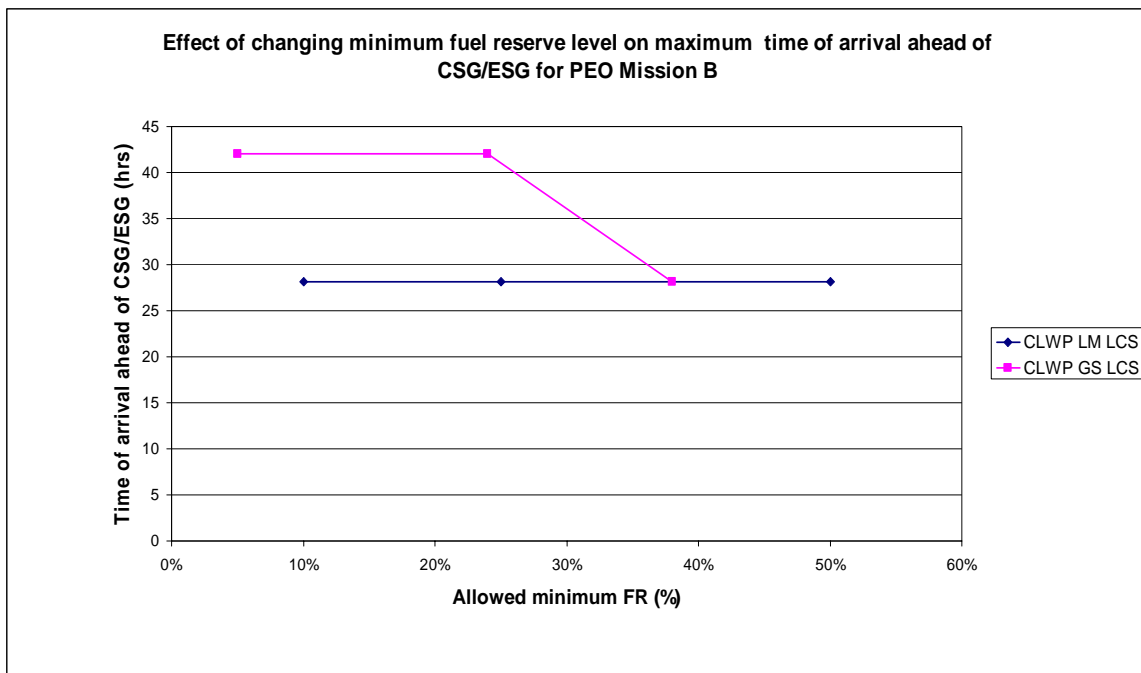
Figure 41. Effect of changing fuel reserve level on maximum time of arrival ahead of CSG/ESG for PEO Mission B

As the distance in the mission increases to 3,500nm there is little logistical advantage in one LCS over its counterpart. Neither version of LCS will be able to complete mission C utilizing its sprint speed ability. During this scenario LCS is limited to a speed of 18kts while being escorted by a CLF asset. This speed still allows LCS to arrive at the affected area 2.4 days prior to the CSG/ESG but at the cost of tying up a CLF asset the entire transit. If this is the case it seems more efficient to leave LCS with the CSG/ESG and increase the overall transit speed of the entire group. This analysis

however, is not done as part of this thesis and will be discussed further in Chapter V. This analysis also does not take into account the carrying capacity of both versions of LCS. Current mission bay specifications for both the LM and GD versions of LCS lead the author to believe that the GD version will have a much larger cargo carrying capacity for a HA/DR mission both while configured for another mission, or when specifically configured for HA/DR operations.

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V.   CONCLUSIONS AND RECOMMENDATIONS

I don't know what the hell this 'logistics' is that Marshall is always talking about, but I want some of it

--Fleet ADM E. J. King: To a staff officer. (1942)

A.   CONCLUSION

The United States Navy has come a long way in understanding logistics and its importance to mission success since ADM King made the above statement in 1942. The Navy still, however, tends to use back of the envelope type scheduling to replenish fleets around the world. There is no single logistical system or model that the Navy uses to predict when ships or strike groups will need replenishments and how they are to be replenished. There is no single program or model that is used to assist logistics planners in optimizing how to schedule a thinly stretched CLF to best support the fleet and its numerous missions. NWP 4-01.2 Sustainment At Sea, is considered by the Navy the publication to be used by logistics planners and line officers to ensure that proper logistics planning factors are being considered and schedules are being created around those factors in order to sustain strike groups at sea.

The information contained in NWP 4-01.2, SUSTAINMENT AT SEA, is directed at Navy operational logisticians, line officers, and logistics planners from other services and provides an in-depth overview of the organizational framework and structure of Navy sustainment at sea. Further, NWP 4-01.2 addresses the sustainment at sea systems and the organizations that provide support to the carrier strike group (CSG)/expeditionary strike group (ESG) at the strategic, operational, and tactical levels. This publication provides a readily available resource that describes naval sustainment and the doctrinal foundations. (CNO, 2007)

This publication, however, leaves logisticians on their own to figure out what the true logistics planning factors for a CSG/ESG may be. In a note listed under each

planning factors table in NWP 4-01.2 it is stated that planning factors provided in this NWP must be reviewed, assessed and adjusted as required to reflect the context of the mission and other factors that could alter consumption over time (CNO, 2007). It is recognized that there can be no canned answer for every CSG/ESG that deploys as to how they will logistically need to be maintained, but there is little reference for a logistician to rely on besides his or her own experience.

In the mid 1990's, David R. Schrady authored a user's guide for a computer based program called TACLOG which had the primary functions of planning, tracking and predicting the usage and replenishment of fuels and ordnance (Schrady, 1996). The program was tested but eventually never adopted by the Navy. With the introduction of LCS to the fleet, it becomes more important that a logistics planner be capable of predicting how the employment of LCS will affect the ship logistically.

This thesis has shown using the fuel consumption prediction model described in Chapter II that LCS will not meet some of the key parameters discussed in the Littoral Combat Ship Critical Design Parameters (PEO 420, 2004). The endurance analysis shows that at 50kts none of the LCS models is able to meet the objective endurance of 1,500nm. At the objective economical speed of 20kts only the GD version of LCS; using both the COMLOGWESTPAC and PEO-OMO data is able to meet an endurance range of 4,300nm. At the threshold sprint speed value of 40kts both versions of LCS applied to both COMLOGWESTPAC and PEO-OMO data are able to meet the threshold endurance requirement of 1,000nm.   Only the GD version of LCS meets the threshold requirement of a 3,500nm range at speed of greater than 18kts.

The endurance analysis for LCS also shows that the most economical speeds, the speed at which LCS has the longest range, for both the GD and LM versions are below the 18kt threshold value. For both the LM PEO-OMO and GD PEO-OMO versions of LCS the most economical speed is at 7kts.

This thesis has also shown in two separate employments of LCS that the sprint speed capability the ship brings to the combatant commander could potentially strain the logistics system if proper planning or allowances in the adjustment of fuel reserve levels

are not closely monitored. The MIW scenario has shown that with allowing fuel reserve levels to drop below the notional 50% level, the time between refueling events can be extended by up to three times the normal cyclical refueling schedule. This will result in the use of one third the CLF and inport refueling assets. This scenario also showed that logistics may not be the limiting factor in allowing LCS to complete an assigned task. Even though LCS is capable of refueling less frequently than a current mine warfare asset, current assets are able to maintain at least a 03% greater on station availability because of LCS crew rest requirements.

In the HA/DR mission, this thesis offers the logistics planner the tools to enable them to compare tradeoffs between using LCS sprint speed capability and allowed fuel reserve levels. These tables also allow the planner to factor in the number of available CLF assets to help in the decision making process. This thesis shows that slight adjustments in the allowed fuel reserve level can result in either less CLF assets needed, arriving on station with aid in a shorter time period or even a combination of the two.

Finally, this thesis has shown that with predictive planning on behalf of logistics operation planners, LCS can place minimal impact on the CLF fleet in the Pacific. In knowing where and how LCS will be employed a logistics planner can offer recommendations to naval component commanders as to how to adjust fuel reserve levels for LCS to minimize the need for refueling or resupplying events, while still enabling the ship to maintain full mission capability, or recommend the CLF assets needed to ensure LCS can conduct a mission while maintaining a specified fuel reserve level.

B.   RECOMMENDATIONS FOR FURTHER STUDY

As of the completion of this thesis, USS FREEDOM (LCS 1) remains pier side in Wisconsin waiting to make its maiden voyage out to sea in the summer of 2008. USS INDEPENDENCE (LCS 2) is also facing problems and delays of its own. In February 2008, Defense Daily reported,

Recently, Navy Supervisor of Shipbuilding (SUPSHIP) personnel observed various degrees of bowing in the transverse beams that support the flight deck on LCS-2. A Navy/Industry team is reviewing the cause of these deflections, verifying that the ship structure is stable, and developing any corrective actions that might be required (Fein, 2008).

The article also noted on how the cost of the two ships has grown significantly since the original contracts were awarded.

Budget documents released last week showed Independence, with a construction cost of $440 million, is lower than the $471 million cost to build Freedom. However, adding in the final system design, mission system and ship integration, outfitting and post delivery, the cost for Independence was $636 million compared to $631 million for Freedom (Fein, 2008).

Though LCS continues to struggle in its infancy, both the Secretary of the Navy and the Chief of Naval Operations remain steadfast that LCS is the future of the Navy. Assuming this remains the case, the full potential of LCS is still yet to be understood through analytical study. This thesis recommends the following as some areas for further study with regards to LCS logistics as follow-on questions to this thesis:

- Are there enough CLF assets in the Pacific to handle a large number of LCS independent deployers or SAGs

- What is the right CLF force structure to maintain operations in the Pacific once LCS is introduced into the fleet in substantial numbers

- Where will LCS be deployed and how will it affect the overall operational availability and logistics sustainment of LCS

In addition to questions left unanswered by this thesis LCS leaves a host of questions still needing concrete analytical answers. Some of these questions include:

- How will the placement of mission modules affect the ability of LCS to conduct missions around the globe

- If LCS is forward deployed what infrastructure changes must be made to accommodate the vessels and crews

- If LCS is forward deployed what type of crew-seaframe rotation is the most optimal to ensure a high rate of operational availability

- What size squadrons will LCS deploy in as a surface action group (SAG) in the future for different missions and how will this affect the CLF fleet

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