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ALTERNATIVE PRACTICES TO IMPROVE SURFACE FLEET FUEL EFFICIENCY

by

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September 2014

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We explore the United States Navy's surface fleet policies and practices that, if changed, could provide significant fuel savings for fossil fuel ships. Recent and potential future budget cuts give fuel conservation and efficiency extreme importance. The policies and practices explored incur no overhead cost, and to reap the benefits of these changes, we simply need to prudently change in the way we operate. Conducting drift operations 10% of the nights while underway can save the Navy $14.1 million per year, and conducting single-generator operations 25% of the time underway can save $27.4 million per year. Removing the "moving window" requirement during a transit can reduce fuel consumption by as much as 21%. Utilizing the Transit Fuel Planner shows fuel savings as high as 19% during transits. Lowering the minimum fuel safety levels in 5th and 7th Fleets from 60% to 50% reduces fuel consumption for Military Sealift Command ships by $18.5 million per year. Changing or removing outdated policies and practices utilized by the surface fleet can save significant amounts of fuel, and therefore dollars, and can be done with the stroke of a pen.

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ALTERNATIVE PRACTICES TO IMPROVE SURFACE FLEET FUEL EFFICIENCY

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ABSTRACT

We explore the United States Navy's surface fleet policies and practices that, if changed, could provide significant fuel savings for fossil fuel ships. Recent and potential future budget cuts give fuel conservation and efficiency extreme importance. The policies and practices explored incur no overhead cost, and to reap the benefits of these changes, we simply need to prudently change in the way we operate. Conducting drift operations 10% of the nights while underway can save the Navy $14.1 million per year, and conducting single-generator operations 25% of the time underway can save $27.4 million per year. Removing the "moving window" requirement during a transit can reduce fuel consumption by as much as 21%. Utilizing the Transit Fuel Planner shows fuel savings as high as 19% during transits. Lowering the minimum fuel safety levels in 5th and 7th Fleets from 60% to 50% reduces fuel consumption for Military Sealift Command ships by $18.5 million per year. Changing or removing outdated policies and practices utilized by the surface fleet can save significant amounts of fuel, and therefore dollars, and can be done with the stroke of a pen.

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LIST OF ACRONYMS AND ABBREVIATIONS

BBLs	barrels
CG	guided missile cruiser
CLF	combat logistics force
DDG	guided missile destroyer
DFM	diesel fuel marine
DOD	Department of Defense
FFG	guided missile frigate
FFV	fresh fruits and vegetables
FITREP	fitness report
FY	fiscal year
GPH	gallons per hour
GTG	gas turbine generator
hr	hour
JP5	jet propulsion fuel, type 5
kts	knots
kW	kilowatt
LHA	landing helicopter assault
LHD	landing helicopter dock
LPD	landing platform dock
LSD	dock landing ship
MOVREP	movement report
MSC	Military Sealift Command
nm	nautical miles
OPORD	operation order
OPS	operations
PIM	Plan of Intended Movement
RAS	replenishment at sea
RASP	Replenishment At Sea Planner
SGO	single-generator operations
T-AO	fleet replenishment oiler

T-AOE	fast combat support ship
T-AKE	dry cargo/ammunition ship
TFP	Transit Fuel Planner
TYCOM	Type Commander
VAMOSC	Visibility and Management of Operating and Support Costs

EXECUTIVE SUMMARY

As the price of fuel continues to rise and the government's efforts to reduce spending puts a tighter strain on the Navy's budget, reducing fuel consumption is of great importance. This thesis explores alternative ways of operating to increase the Navy's fuel efficiency and reduce the Navy's overall fuel consumption. Simulation and mathematical modeling are used to quantify fuel savings, and analysis is conducted on the findings to determine their significance.

The objective of this thesis is to analyze the financial impact of changes to the Navy's current surface fleet policies and practices, assess their effectiveness, and provide an analysis of the potential impact that changes in policy and practices might have in enhancing fuel efficiency for Navy ships.

The scope of this thesis is limited to United States Navy surface fleet fossil fuel ships and Military Sealift Command (MSC) ships. The ideas discussed can be used for most naval vessels, but Arleigh Burke-class destroyers and Ticonderoga-class cruisers dominate our attention. The policies and practices discussed do not take priority over tactical situations or operational requirements and are intended to be used when the conditions and situations permit.

Four topics are addressed in this thesis: drift operations, single-generator operations, transits, and minimum fuel safety levels.

Drift operations are not conducted often, but can be very beneficial in saving fuel. If the Navy's destroyers (DDGs) and cruisers (CGs) conduct six hours of drift operations on 10% of their nights underway, the Navy will save $14.1 million per year.

Single-generator operations are rarely conducted by the fleet's DDGs and CGs even though they have significant fuel saving potential and the electrical load can often be supported by one gas turbine generator (GTG). If the Navy's DDGs and CGs engage in single-generator operations 25% of the time they are underway, the Navy will save $27.4 million per year.

During a transit a ship is required to stay within a moving window of four hours ahead or behind her plan of intended movement (PIM). This restriction causes many ships to burn more fuel than needed to complete the transit. Relaxing or removing this moving window requirement gives a ship the flexibility to conduct drills that require stopping the ship's propulsion, investigate contacts of interest in the vicinity, slow for reduced visibility, respond to distress calls from another ship, and numerous other reasons, without the concern of leaving the moving window. This increased flexibility removes the need to use excessive speeds to maintain position within the moving window and can reduce fuel consumption by more than 19%.

The Transit Fuel Planner (TFP) was created by the Naval Postgraduate School's Operations Research Department. The TFP takes advantage of multiple engine configurations and multiple speeds instead of utilizing a constant speed during a transit and can save as much as 21%. This tool can and should be adjusted for each ship in the Navy by simply applying each ship's specific fuel curves.

The minimum fuel safety levels in 5th Fleet and 7th Fleet significantly affect the quantity of fuel consumed by MSC ships in order to replenish the Navy's deployed surface ships. The Replenishment At Sea Planner (RASP) is used in scheduling MSC ships to refuel Navy ships. Using actual 5th Fleet and 7th Fleet data and simulating different RASP minimum fuel safety levels, we show that reducing the minimum fuel safety levels of Navy ships reduces MSC ships' fuel consumption. When 5th Fleet and 7th Fleet minimum fuel safety level were simulated being reduced from 60% to 50%, MSC ships reduced their fuel costs by $18.5 million per year.

These changes in policies and practices have no overhead costs, are simply a change in how we operate, and can provide substantial fuel savings if implemented. In summary, the effects of these policy changes are shown in the Table 1.

Policy	**Platform**	**Change to Policy**	**Impact**
Drift Operations	DDGs/CGs	Encourage six hours per night of drift operations during 10% of underway nights	$14.1 million/year saved
Single-Generator Operations	DDGs/CGs	Encourage single-generator operations 25% of the time underway	$27.4 million/year saved
Minimum Fuel Safety Level	MSC Ships	Using RASP, reduce the minimum fuel safety level from 60% to 50% in both 5th Fleet and 7th Fleet	$18.5 million/year saved
Transits	DDGs/CGs	Utilize TFP for all transits	Up to 21% reduction in transit fuel consumed
Transits	DDGs/CGs	Relax or remove the moving window within PIM	May be greater than 19% reduction in transit fuel consumed

Table 1. Over $60 million can be saved annually by implementing these policy changes.

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I. INTRODUCTION

This thesis will explore alternative ways of operating to increase the Navy's fuel efficiency and reduce the Navy's overall fuel consumption. In fiscal year 2013, the Navy spent over $4.5 billion on fossil fuel (Dhoran 2014). Over $1.7 billion of that was spent on providing 478 million gallons of fossil fuel for use by surface ships at an average price of $3.69 per gallon (Dhoran 2014). As the price of fuel continues to rise and the government's efforts to reduce spending puts a tighter strain on the Navy's budget, the need to reduce fuel consumption is of great importance. Figure 1 illustrates the Navy's fossil fuel expenditure in FY 2013.

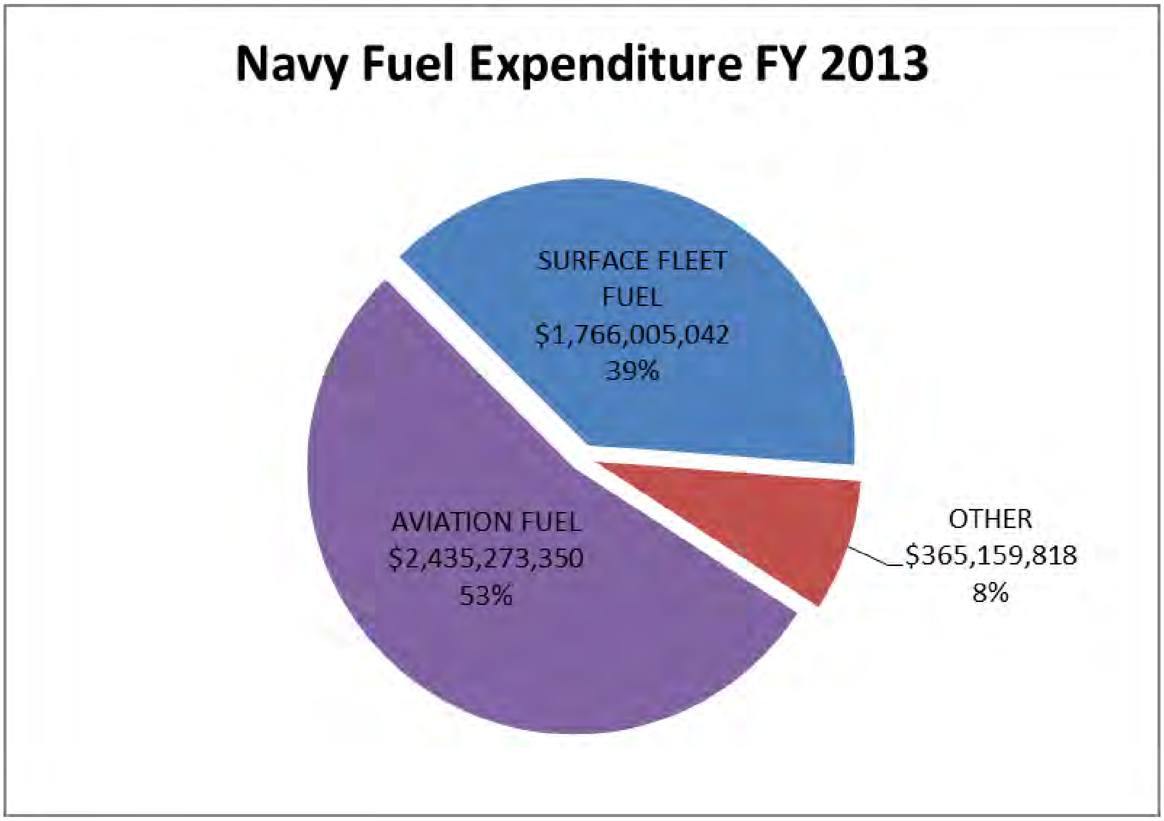

Figure 1. Navy fossil fuel expenditure for FY 2013 (after Dhoran 2014).

A. DOD SPENDING ON FUEL

Due to recent budget cuts to the Department of Defense (DOD), minimizing fuel consumption has become an issue of paramount importance. Chapter 3 of the FY 2013 Budget Request Overview is titled “More Disciplined Use of Resources.” The Office of the Undersecretary of Defense believes this topic is of such importance that an entire chapter of the budget is dedicated to using our resources more efficiently and with greater discipline in order to reduce spending. “This budget continues the reform agenda advanced in the previous three budgets, but with more emphasis now on enhancing how DOD does business. The Department must continue to reduce the ‘cost of doing business’… before taking further risk in meeting the demands of the strategy” (Office of the Undersecretary of Defense 2012, p. 1-1).

In FY 2013–FY 2017, the military is expected to save \$30.8 billion dollars by improving its efficiency and reducing overspending; \$5.7 billion of that savings is expected to come from Navy (Office of the Undersecretary of Defense 2012). To achieve this spending reduction, the Navy will need to increase its efficiency.

B. SPEED IS EXPENSIVE

The Navy’s most numerous class of warship is the Arleigh Burke-class guided missile destroyer (DDG). There are currently 62 DDGs commissioned and in active service (Global Security 2014a). The rate of fuel consumption of a DDG is a function of the speed at which the ship is traveling and the engine configuration. Figure 2 shows the fuel curves for a DDG with gallons per hour (GPH) burned as a function of speed. The amount of fuel burned increases exponentially as speed is increased. At 10 kts using a trail shaft engine configuration, a DDG burns approximately 730 GPH; however, if she doubles her speed to 20 kts, she burns approximately 1,600 GPH (Bennett 2014). This is 2.2 times as much fuel burned for two times the speed. If she triples her speed from 10 kts to 30 kts, the engine configuration must change from trail shaft to full power, and she will burn approximately 6,400 GPH, or about 8.8 times the amount burned at 10 kts (Bennett 2014). That is a 200% increase in speed, but a 777% increase in fuel consumption.

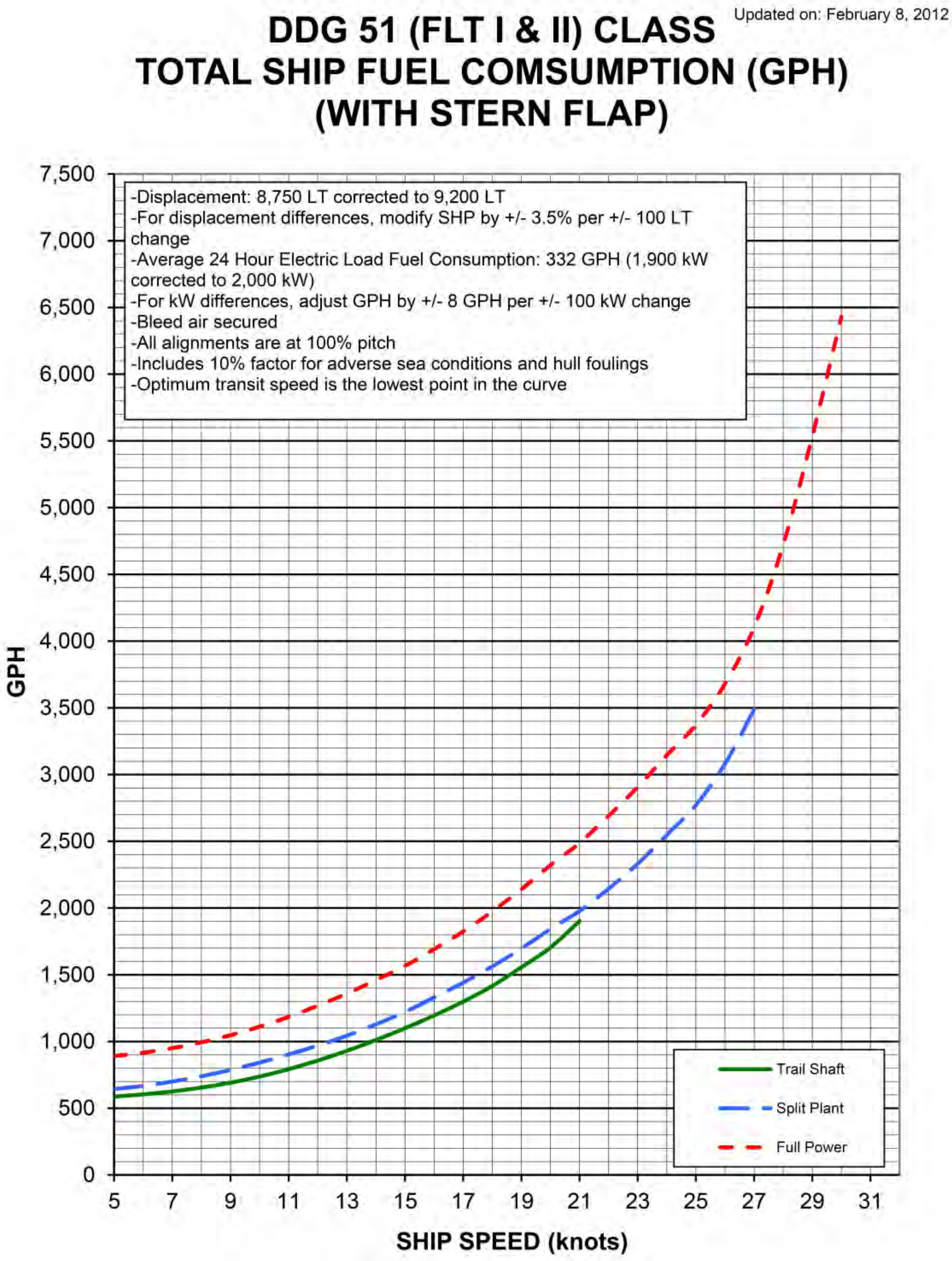

Figure 2. Fuel curves for a DDG showing GPH burned as a function of ship speed using different engine configurations (from Bennett 2014). From Figure 2, we can see that operating in trail shaft engine configuration at 21 kts, saves approximately 600 GPH compared to full power configuration. From 21—27 kts, split plant configuration saves approximately 500—600 GPH over full power configuration.

Fuel curves differ between ships and between ship types, but all deep-draft vessels have the same general characteristic of an exponentially increasing amount of fuel burn as a function of the ship's speed. The significance of these fuel curves must be emphasized, because one of the most important aspects to reducing fuel consumption is reducing a ship's speed. Speeds of over 20 kts dramatically increase fuel consumption (Bennett 2014) and should be limited when not operationally required.

C. OBJECTIVES

The Navy operates under certain protocols, some being written into policy and others by tradition, habit, or a superior's expectations. The purpose of this thesis is to explore the Navy's current surface fleet policies and practices, assess their effectiveness, and provide an analysis of the potential impact that changes in policy and practices might have in enhancing fuel efficiency for Navy ships. The changes considered will have no set hardware costs and will simply change how the Navy operates in order to save fuel and subsequently save money. Simulation and mathematical modeling are used to quantify fuel savings, and analysis is conducted on the findings to determine their significance.

D. SCOPE AND LIMITATIONS

The scope of this thesis is limited to United States Navy surface fleet fossil fuel ships and Military Sealift Command (MSC) ships. Arleigh Burke-class destroyers and Ticonderoga-class cruisers dominate our attention. The ideas discussed can be used for most naval vessels, but destroyers and cruisers are the focus of this research.

The Navy operates in many parts of the world under a vast array of conditions and in continuously changing situations. Safety of a ship and its crew always takes precedence over operational practices intended to save fuel. The policies and practices discussed do not take priority over tactical situations or operational requirements and are intended to be used when the conditions and situations permit. The issue of combat effectiveness, such as the ability for a ship to convert the saved fuel into the ability to stay on station for additional days, is an important issue, but one left for future research.

II. BACKGROUND

The Navy continually strives to reduce fuel consumption, both through changes in business practices and through engineering improvements. Some of the recent changes in how the Navy operates and engineering improvements that have been made are discussed in this chapter.

A. IENCON

iENCON (Shipboard Incentivized Energy Conservation) is a program developed in 1993 with the goal of reducing ship energy usage by changing the way equipment onboard is operated. "The objective of U.S. Navy shipboard energy conservation is to make ships more fuel efficient. Increased fuel efficiency helps stretch the fuel budget dollars as far as possible and also makes our ships more environmentally friendly" (iENCON 2014). In 2002, the iENCON program won the Presidential Award for Leadership in Federal Energy Management. iENCON advises ships on energy-saving strategy and techniques through changes in procedures and operational modifications. iENCON uses BBLs/hr (barrels per hour) to evaluate the change in fuel efficiency (Pehlivan 2014).

1. Saving as a Fleet

iENCON tracks the fuel burn rate for every non-nuclear surface ship in the Navy. Ship's burn rates vary depending on their efficiency, but most of the variation is due to the operations being conducted. iENCON looks at the Navy as a whole and tracks the average burn rate on a yearly basis. The lowest burn rate of any year was 2009 at 19.96 BBLs/hr, which is down from 25.84 BBLs/hr in 1999 when iENCON began (Pehlivan 2014).

2. Awards

iENCON gives cash awards totaling $1 million every year for ships that perform best within their ship class. The funds are provided to the ship's OPTAR (operating target) fund, which can be used at their discretion for consumable items. The highest dollar amount given to any one ship in a year is $60,000 (Pehlivan 2014).

Every year the SECNAV (Secretary of the Navy) Energy Award is given to eight ships, broken into two categories, large hull (crew size greater than 400) and small hull (crew size 400 or less). The top award winner in each of the two categories receives $30,000 and $20,000, respectively (Pehlivan 2014).

3. Other Incentives

Saving fuel and cash awards are not the only incentives to being fuel efficient, "Ships can use energy conservation results in their fitness report (FITREP) which will help in obtaining the Battle "E" for Engineering" (Pehlivan 2014). The "E" for engineering is given to ships with sustained superior operational performance in the engineering department and is one of the six command excellence awards that a ship can obtain in pursuit of the Battle "E" (Battle Effectiveness) Award. A ship must obtain four out of the six command excellence awards to be eligible for the Battle "E".

4. Results

Since the start of iENCON, the total fleet underway fuel consumption rate has decreased by approximately 23%, as can be seen in Figure 3 (Pehlivan 2014).

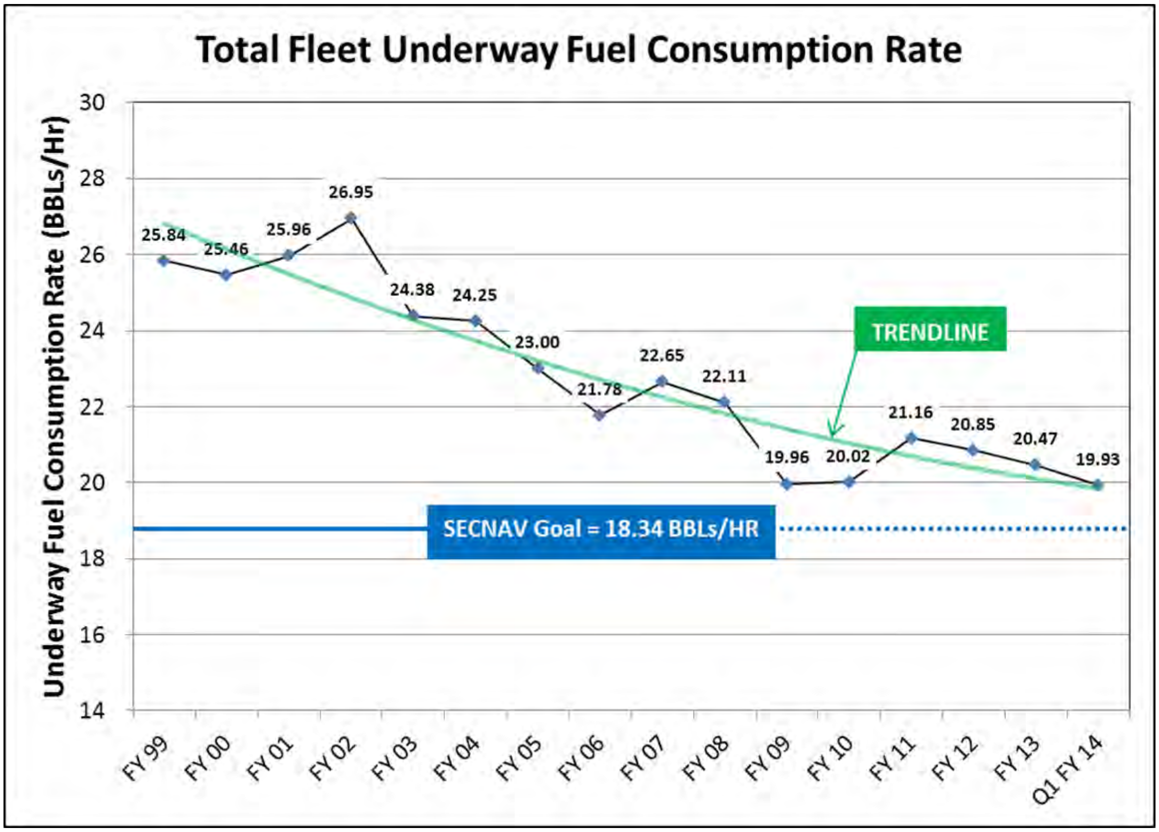

Figure 3. Since iENCON commenced advising the fleet on energy conservation in FY 99, total fleet underway fuel consumption per hour has continued on a downward trend (from Pehlivan 2014).

B. A SYSTEMS ENGINEERING ANALYSIS OF ENERGY ECONOMY OPTIONS FOR THE DDG-51 CLASS OF U.S. NAVAL SHIPS

In 2010, a group of Naval Postgraduate School students completed a capstone project titled "A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships" (Cannon et al. 2010). The students looked at eight different engineering subsystems and their fuel types as potential sources for energy savings. Their goal was to find subsystems that yielded the highest net savings over a 10-year period by using an alternative power or fuel source or replacing the equipment with more efficient comparable equipment. Table 1 shows their findings.

Subsystem	**Subsystem Analysis Notation**	**Best Alternative**	**Five-Year ROI ($ Saved/$ Invested)**	**Ten-Year Net Savings($M)/per Ship**
1. Pre-Heaters	A1	Chromolax	23	5.65
2. Fire Pumps	A9	Vertical InLine	72	4.37
3. Fuel Type	A18	Biodiesel B20	Infinite	2.27
4. Dryers	A13	Gas Conversion	29	2.00
5. AC Chill-Water Pumps	A2	Variable Frequency Drive	40	1.78
6. Lighting Fixtures	A15	CFB Distribution	37	1.61
7. Fuel Transfer Heater	A8	20% Efficiency	6	1.13
8. Ovens	A12	Halogen Microwave	29	0.54
9. Hot Water Heaters	A0	Baseline	0	0.00

Table 1. “This table shows the subsystems researched and analyzed (including fuel alternatives) along with their five-year return on investment and projected ten-year savings per ship” (from Cannon, et al. 2010). The “Best Alternative” column lists the change to the subsystem that creates the greatest net savings over a 10-year period. Changing the air conditioning preheaters to a more efficient Chromolax brand preheater yields the greatest return on investment of 23%, which is $5.65 million.

The study finds that if all recommendations to improve the current inefficiencies in these eight subsystems were made on 50 Arleigh Burke-class destroyers, the Navy would save $950 million above its investment over a 10-year period (Cannon, et al. 2010).

C. ENGINEERING IMPROVEMENTS

This thesis is not focused on engineering improvements, but significant reductions in fuel usage and improvements in fuel efficiency have come from engineering improvements; therefore, three recent engineering improvements will be discussed in this section. Ships are designed with the intent to be able to go fast when needed, with fuel efficiency as a secondary design goal. After the ship is built, technological advancements provide ways to make ships more fuel efficient but require the ships to be refitted to reap the benefits of the latest technological advancements. The cost of the refit is weighed against the fuel savings over time to see if the refit is worth implementing. Some of these engineering improvements have yielded significant fuel savings with minimal refit costs and are discussed below.

1. Stern Flaps

Of all the technological engineering advancements made to retrofit a ship, the stern flap arguably has the biggest savings-to-cost ratio. “A stern flap, located on the aft end of a ship, makes the ship more hydrodynamic, reducing drag and the energy required to propel them [sic] through the water” (Naval Sea Systems Command 2009). “Previous installations on other Navy ships generated annual fuel savings of $365,000 to $450,000 per ship” (Naval Sea Systems Command 2009). The installation of a stern flap on an Arleigh Burke-class destroyer costs approximately $170,000 (Global Security 2014c), which can be recouped within three – six months, which is a short period of time.

2. Hydrodynamic Bow Bulb

As a ship moves through the water, the friction between the ship and the water is referred to as drag. This friction is one of the largest factors in a ship’s fuel efficiency; as the ship’s speed increases the drag increases exponentially for large-displacement ships. The bow wave of a ship causes significant drag and can be reduced by installing a bow bulb seen in Figure 4 (Global Security 2014b).

Figure 4. Bulbous bow installed on USS George H.W. Bush (CVN 77) (from Global Security 2014b).

> Located near the waterline, the bow bulb is an inverted tear drop shape that protrudes from the hull and is designed to reduce the ship's wave resistance. Specifically, the bow bulb creates a wave designed to interfere with the existing bow wave which reduces the amount of drag on the ship as well as fuel consumption and engine exhaust emissions (Naval Sea Systems Command 2012a).

Figure 5 shows the natural bow wave without the bow bulb installed, the bow wave that the bow bulb creates on its own, and the combination of the two, which is the actual wave created when the bow bulb is installed. The sum of the natural wave and the wave created by the bow bulb is significantly less than the natural wave of the hull. This reduced bow wave decreases the drag and improves fuel efficiency.

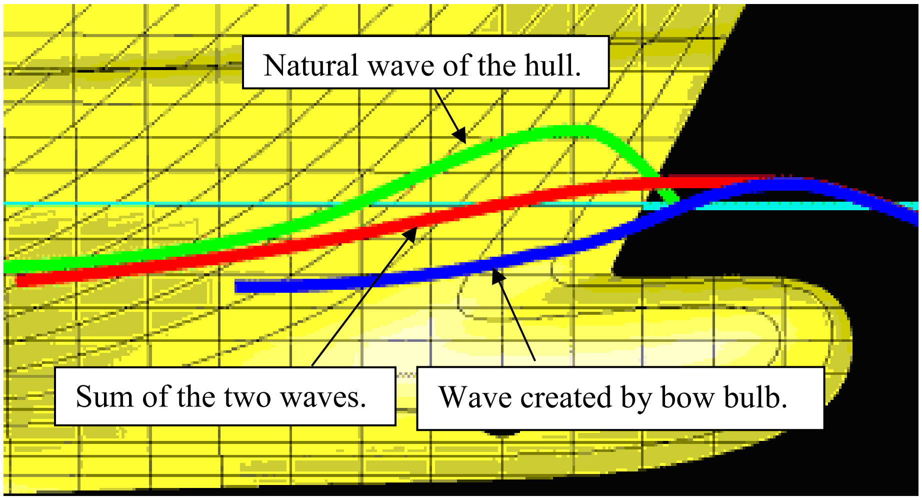

Figure 5. Bow wave reduction by addition of a bow bulb (after Selene 2014).

a. Installation Schedule

The *USS Kidd* will be the first DDG to receive the install of a Bow Bulb, which is scheduled for FY 2015 (Reber 2014). Additional installs are not confirmed but are expected in FY 2017. There are currently no plans for installs during new construction; all bulbous bows are expected to be installed as refits.

3. USS Makin Island Propulsion System

The *USS Makin Island* (LHD-8) is the Navy’s first ship with a Hybrid Electric Drive (HED), which uses diesel-electric propulsion for speeds below 12 kts and gas turbines for speeds above 12 kts (Marine Link 2013). Over a 40-year-service life, the Makin Island is expected to save more than $250 million in fuel costs (Marine Link 2013). The LHA 6-class will use this same HED system (Naval Sea Systems Command 2012b).

The *USS Makin Island* has already shown significant savings. “During the seven-month deployment, the ship’s hybrid-electric propulsion system saved more than four million gallons of fuel resulting in an estimated cost savings in excess of $15 million” (Marine Link 2013).

D. MILITARY SEALIFT COMMAND

The Military Sealift Command (MSC) is an organization within the United States Navy and an integral part of the Navy's logistics and supply chain. "Military Sealift Command is the leading provider of ocean transportation for the Navy and the rest of the Department of Defense—operating approximately 110 ships daily around the globe" (Military Sealift Command 2014). Underway replenishment by MSC shuttle ships enables Navy ships to remain at sea for extended periods. MSC has the following mission: "Operate the ships which sustain our warfighting forces and deliver specialized maritime services in support of national security objectives in peace and war" (Military Sealift Command 2014).

1. Parts of Military Sealift Command

MSC operates under five main areas: combat logistics force (CLF), special mission, prepositioning, service support, and sealift.

a. Combat Logistics Force

"The ships of our Navy's Combat Logistics Force (CLF) are the supply lines to U.S. Navy surface combatant ships at sea. They provide fuel, food, ordnance, spare parts, mail and other critical supplies enabling the fleet to remain at sea, on station and combat ready for extended periods of time" (Military Sealift Command 2014).

2. CLF Ships

CLF has 31 ships of three classes, each with a different purpose: fleet replenishment oilers, dry cargo-ammunition ships, and fast combatant support ships. The type and volume of cargo that a ship can carry varies among ship types (Military Sealift Command 2014).

a. Fleet Replenishment Oilers

"Fleet replenishment oilers, the largest subset of CLF ships, provide fuel to deployed Navy combatant ships and their assigned aircraft via connected replenishment" (Military Sealift Command 2014). The fleet replenishment oilers consist of 15 T-AOs.

"T-AOs provide underway replenishment of fuel, fleet cargo and stores to customer ships at sea" (Military Sealift Command 2014). The T-AOs are Henry J. Kaiser-class oilers and are 677 ft. in length, have 42,000 tons of displacement (full), can carry between 6.6 and 7.6 million gallons of DFM, and have a maximum speed of 20 kts.

b. Dry Cargo—Ammunition Ships

"These ships are capable of delivering ammunition, provisions, stores, spare parts, potable water and petroleum products to carrier strike groups and other naval forces worldwide" (Military Sealift Command 2014). There are 12 Lewis and Clark-class T-AKEs; they are 689 ft. in length, have 42,000 tons of displacement (full), can carry 984,000 gallons of DFM, and have a maximum speed of 20 kts.

c. Fast Combatant Support Ships

"Fast combat support ships, the largest and fastest CLF vessels, carry all the essentials for a ship at sea, including fuel, ammunition and food" (Military Sealift Command 2014). There are four Supply-class T-AOEs, they are 754 ft. in length, have 49,000 tons of displacement (full), can carry 1.9 million gallons of DFM, and have a maximum speed of 25 kts.

3. Visibility and Management of Operation and Support Cost

Visibility and Management of Operation and Support Cost (VAMOSC) is a cost estimating database, developed and managed by the Navy Center for Cost Analysis (NCCA). It is not part of MSC. "The Navy Visibility and Management of Operating and Support Costs (VAMOSC) management information system collects and reports US Navy and Marine Corps historical operating and support (O&S) costs" (VAMOSC 2014). In FY 2013 MSC used 8,532,524 gallons of fuel to deliver 377,434,191 gallons to U.S. Navy combatants (Toorn 2014). This means that on average, MSC burned one gallon of fuel for every 44.2 gallons of fuel delivered.

E. CONCLUSION

There are many efforts being made throughout the Navy to save fuel. The remaining chapters are dedicated to policies and procedures that can be changed to continue the Navy's efforts in the reduction of fuel consumption. Chapter III addresses drift operations, Chapter IV discusses single-generator operations, Chapter V analyzes the efficiency of transits, and Chapter VI shows the benefits of adjusting the Minimum Fuel Safety Level.

III. DRIFT OPERATIONS

During underway periods, a ship typically keeps its propulsion operating at night even if she is not conducting specific operations or transiting to a new location. Stopping her engines and drifting when propulsion is not needed can save a significant amount of fuel. The paragraphs below describe normal operations, engine configurations, potential fuel savings from drift operations, and safety considerations.

A. NORMAL OPERATIONS

At night when not transiting, a ship will often operate in a “night steam box,” which is usually 10 nautical miles (nm) by 10 nm. There are a number of reasons why a ship would need or want to have its propulsion operating at night when there is no direct operational need, a few of which are listed below:

- Numerous contacts requiring avoidance,
- The tactical situation depending on the location,
- High winds or sea state causing excessive rolls, or
- Safety of ship due to the vicinity of shoal water.

Ships have the ability to stop their main engines, thereby eliminating fuel consumption, although the gas turbine generators remain online for electrical power. This is known as drift operations, and it can significantly reduce fuel consumption when the ship is continuously at sea for extended periods without conducting nighttime operations or transits. Drift operations can be conducted during the day, but ships are typically engaged in other operations during daytime hours.

B. SAFETY CONSIDERATIONS

Drift operations can offer significant fuel savings, but there are potential negative impacts from drift operations, including safety of ship and safety of the crew. In a situation where a risk of collision exists, the ship needs to be maneuvered into safety in a timely manner. If drift operations are being conducted, there are no main engines online, and the emergency starting of a main engine takes approximately 90 seconds. Due to the increased risk involved with drift operations, a commanding officer should take into account visibility, sea state, weather conditions, tactical situation, contact density, and many other factors that can affect the safety of the ship. Drift operations can be dangerous for the crew depending on the sea state. A ship rolls significantly more if the seas are coming from its beam. This motion is exacerbated if the ship is not moving forward. During drift operations a large swell from the beam can cause excessive rolls, which can potentially lead to crew injures. It is ideal to keep the bow pointed into the waves to minimize the effects on the crew. This is not possible during drift operations, due to lack of steerage caused by no propulsion.

C. ENGINE CONFIGURATIONS

Ticonderoga-class cruisers and Arleigh Burke-class destroyers have two shafts and four main engines. In a “full power” lineup all four engines are online. In a “split plant” lineup two engines remain online, one per shaft. In a “trail shaft” lineup three of the four engines are secured and one engine remains online on either the port or starboard shaft. A normal transiting speed while in a night steam box is between five and 10 knots. At these speeds, a Ticonderoga-class cruiser consumes between 640-810 GPH, respectively, as seen in Figure 6.

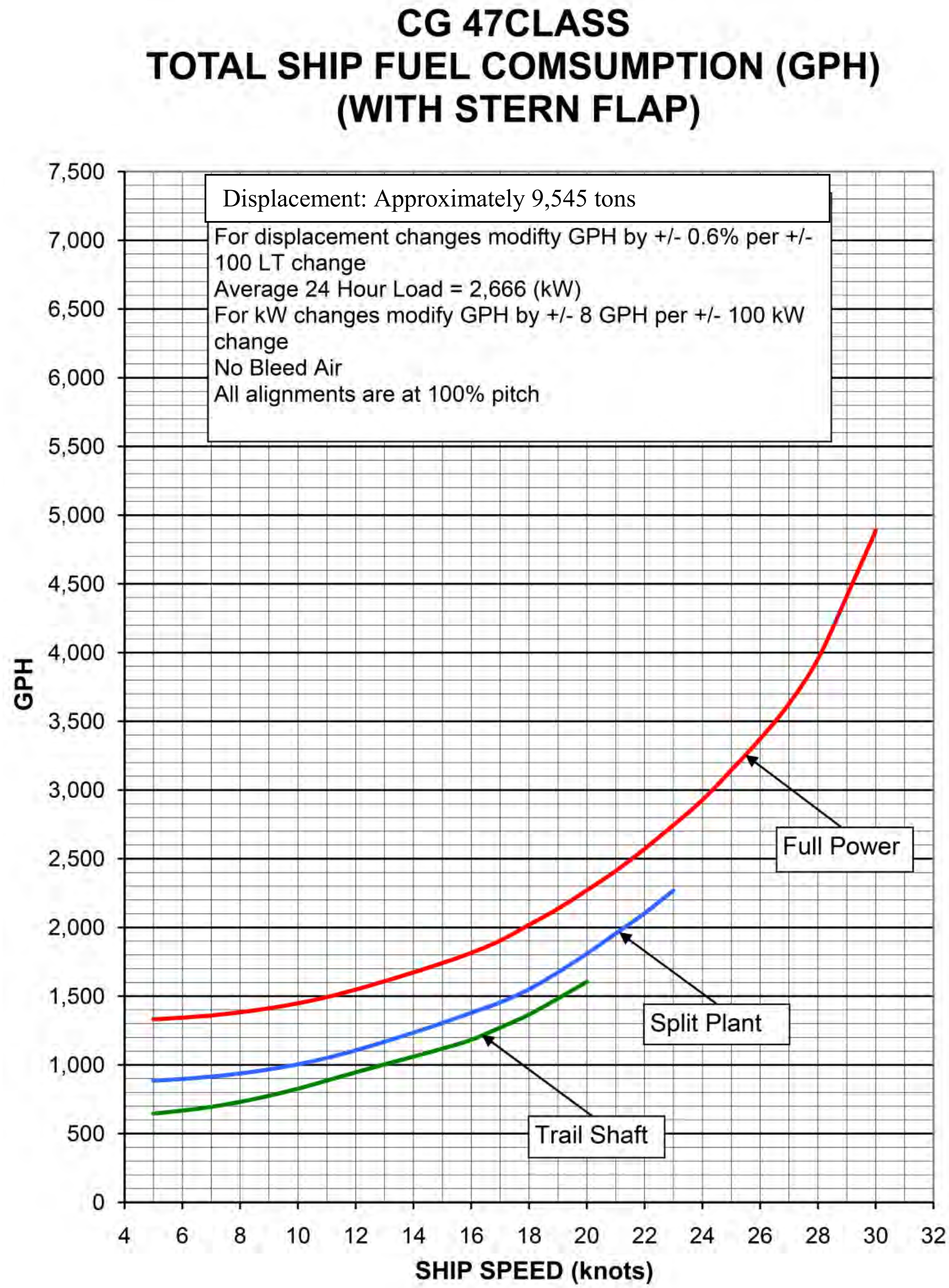

Figure 6. Fuel curves for a CG showing GPH burned as a function of ship speed with different engine configurations (after Bennett 2014). Operating between five and 10 kts in trail shaft burns approximately 640-810 GPH.

D. POTENTIAL FUEL SAVINGS

If a CG conducts drift operations six hours per night, it saves 3,900 gallons or approximately $14,400 per night, compared to normal steaming operations of five kts in a trail shaft configuration consuming 640 GPH as see in Figure 6. If she maintains a nighttime main propulsion lineup in a common split plant configuration and traveling at 10 kts, she burns approximately 1,000 GPH. If she conducts six hours of drift operations instead of operating in a split plant lineup at 10 kts, she saves 6,000 gallons of fuel or approximately $22,000. Figure 7 shows the fuel burn for multiple engine configurations for up to 12 hours.

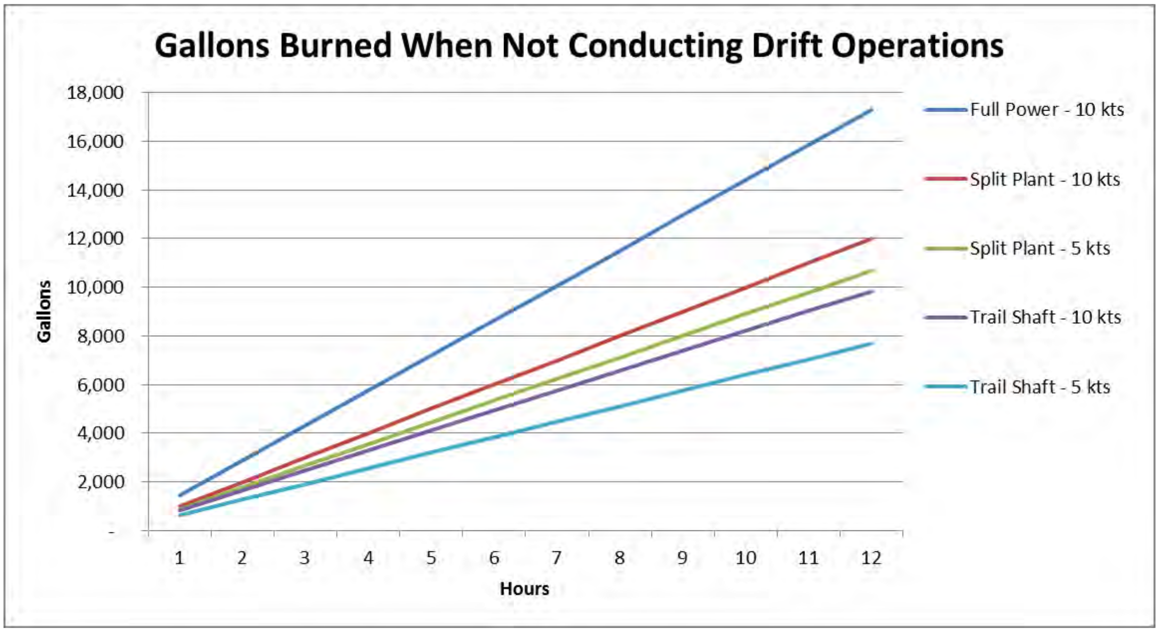

Figure 7. Excess fuel burned when a ship chooses not to conduct drift operations when they are feasible.

There are 22 CGs in the Navy with an average of 113 days underway per year (iENCON 2014). If all 22 CGs conducted six hours of drift operations per night on just 10% of the nights they are underway instead of operating at five kts in a trail shaft configuration, it would save the Navy $3.6 million per year in fuel.

Figure 2 shows that using the trail shaft configuration at five kts for a DDG consumes approximately 600 GPH, all of which can be saved if the ship conducts drift operations. There are 62 DDGs in the navy spending an average of 127 days underway per year (iENCON 2014). If all 62 DDGs conducted six hours of drift operations per night during 10% of the nights underway, the Navy would save $10.5 million annually. That produces a total of over $14.1 million per year with CGs and DDGS combined.

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IV. SINGLE-GENERATOR OPERATIONS

Arleigh Burke-class destroyers and Ticonderoga-class cruisers have three Allison gas turbine generators (GTG), which supply electrical power to the ship. Each of the GTGs onboard can supply 2,500 kilowatts (kW) of power. When the electrical demand is below 2,500 kW, the ship can operate on one gas turbine generator; however, the current business practice is to keep a minimum of two GTGs running to provide redundancy. If the ship is conducting single-generator operations and the one GTG fails, then the ship loses all electrical power until another GTG can be started to support the electrical load. A GTG can be started and provide electrical power in approximately 90 seconds.

The business practice of running two GTGs provides safety for the ship and the crew. Single-generator operations can significantly increase risk to the ship and crew depending on the tactical situation and current operations. In a tactical situation where attack is imminent, the loss of all radars and combat systems could be catastrophic. During nighttime operations, the danger is compounded by the potential loss of navigation lights, which increases the risk of collision with another ship. The use of single-generator operations should only be used in benign situations, minimizing the danger to the ship and crew.

A. OPERATING COSTS

In the capstone project previously mentioned, “A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships,” Cannon et al. (2010) studied the ship class average energy costs for running two generators rather than one. They found that a ship operating two generators in parallel instead of single-generator operations with a 2500 kW load, incurs a 34% penalty in fuel use.

Figure 8 shows the fuel consumption of Allison model 501-K17 generators onboard Ticonderoga-class cruisers (Bennett 2014). The increase in fuel consumption is linear with regards to the increase in electrical load placed on a single GTG or on two GTGs in parallel.

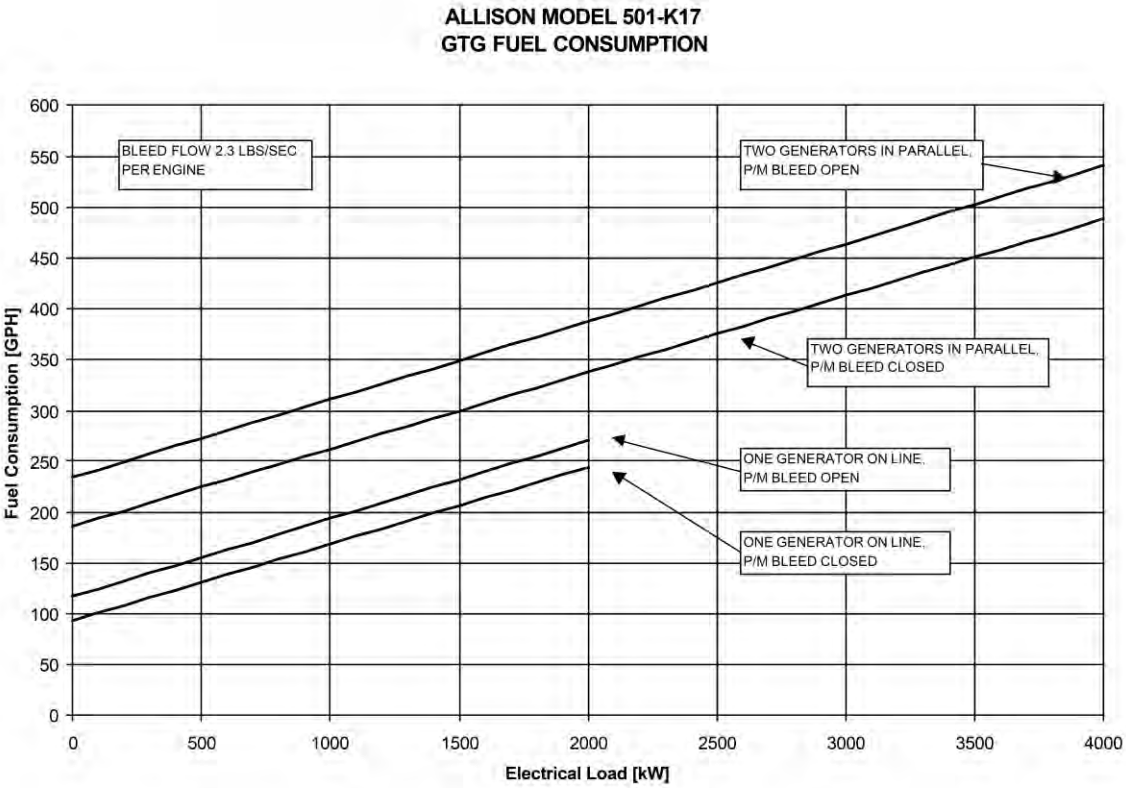

Figure 8. Fuel consumption of single-generator operations and two generators operated in parallel using Allison GTGs. These GTGs are used onboard Ticonderoga-class cruisers (from Bennett 2014). Approximately 95-120 GPH less fuel is burned when operating one GTG vice two.

B. POTENTIAL FUEL SAVINGS

A GTG can operate with the bleed air valve open or closed. When the bleed air valve is open, some of the compressed gasses from the turbine are used to provide power to auxiliary equipment, which increases the fuel consumption of the GTG. When the bleed air valve is closed all of the compressed gasses are used to turn the generator creating electrical power. The difference in fuel consumption between single-generator operations and two generators operating in parallel depends on whether or not the bleed air valve is open or closed. If the bleed air valve is open, the difference in fuel consumption is approximately 120 GPH. If the bleed air valve is closed, the difference is approximately 95 GPH. With the bleed air open this is equivalent to 2,880 gallons per day or over $10,600 in fuel per day. Added benefits of conducting single-generator operations beyond the fuel saving benefit are the reduction of wear and tear on the GTGs and the reduced GTG maintenance man-hours required by the crew.

There are 22 CGs in the Navy with an average of 113 days underway per year (iENCON 2014). If all 22 CGs conducted single-generator operations 25% of the time they are underway, it would save the Navy over $6.5 million per year.

There GTGs on DDGs are the Allison model 501-K34, which is very similar to the Allison model 501-K17 found on CGs (Bennett 2014). The DDGs also have a reduced fuel consumption of 120 GPH when conducting single-generator operations with the bleed air open rather than operating two GTGs in parallel. The 62 DDGs have an average of 127 days underway per year (iENCON 2014). If all DDGs and all CGs conducted single-generator operations 25% of the times they are underway, the Navy would save over $27.4 million per year.

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V. TRANSITS

Transits make up a substantial portion of the nautical miles traveled by a ship during a deployment. This section addresses changes that can produce significant fuel savings during transits. In this chapter, an example transit distance of 3,300 nm is used because this is the approximate distance for a common transit from Pearl Harbor, Hawaii to Yokosuka, Japan.

A. PLAN OF INTENDED MOVEMENT

On July 30, 1945, a Japanese submarine sank the USS Indianapolis (CA-35), enroute from Guam to Leyte, Philippines. Of the 1,196 men onboard, approximately 900 escaped into the water (Indianapolis 1999). When the *USS Indianapolis* did not arrive on time to its destination, there was no immediate reaction from the Navy: "The faulty directive—which required only reporting the arrival of non-combatant ships—was corrected days after the Indianapolis survivors were discovered to require reporting the arrival of combatant ships as well" (Indianapolis 1999). After four days, a patrol aircraft spotted the floating survivors and the rescue efforts began, but by then, only 317 sailors remained alive after floating in the open ocean for four days (Indianapolis 1999). In response to this event, the Navy promulgated the MOVREP (movement report), which includes a Plan of Intended Movement (PIM). This new requirement ensures that the Navy knows where every ship is intended to be at all times.

The PIM is used to keep track of a ship's position during a transit. Prior to starting the transit, the ship submits a message called a MOVREP that gives the ship's starting location, speed, destination, and the dates and times of all waypoints. As the ship transits along its PIM, there is a moving window within which the ship must stay; this window includes four hours ahead of PIM, four hours behind PIM, and 100 miles on either side of the track. If the ship's transit speed reported on the MOVREP is 15 knots (kts), the ship can be 60 nautical miles (nm) ahead or behind PIM and 100 nm left or right of track and still be in the moving window. If the ship leaves this moving window, the ship must send out a MOVREP message that updates her current position, speed, destination and waypoints including dates and times.

A ship typically aims to stay within this moving window vice sending off a new MOVREP, both in the spirit of good seamanship and to ensure it reaches its destination on time. Notwithstanding these motivations to stay within the PIM window, a ship may have to move out of it for many reasons, which include, but are not limited to:

- Engineering drills that require stopping the ship's propulsion plant(s),
- Engineering casualties affecting ship's propulsion,
- Being directed to locate and investigate a contact of interest in the vicinity,
- Slowing due to reduced visibility, or
- A distress call from a ship in the vicinity.

For the examples in this chapter, delays in a transit will be referred to as drills, although they could be caused by many reasons. This assumes the engines are stopped and that there is zero fuel consumption during these delays.

1. GPS (Global Positioning System)

Naval ships have near-constant satellite communication and GPS coordinates for position reporting. A ship's position is obtained from GPS and reported to shore facilities many times per day. This calls into question the requirement for the antiquated PIM moving window.

a. Illustrative Example of a 3,300 nm Transit

Table 2 shows how much fuel is burned if the *USS Chosin* follows a traditional PIM speed of 15 kts for a 3,300 nm transit in 220 hours. It also shows how much fuel is burned on the same traditional PIM transit if the ship travels at 25 kts for six hours per day to make up for four hours of engineering drills, which requires the engines to be stopped. Four hours of drills per day causes a fuel overburn of 52% (85,860 gallons) with a goal of staying near the center of the traditional moving PIM window.

3,300 nm Transit in 220 hrs - PIM speed 15 kts				
Operation	Distance (nm)	Speed (kts)	Time (hrs)	Fuel Burned (gal)
Transit	3,300	15	220	**164,355**
3000 nm Transit in 200 hrs - PIM speed 15 kts - Transiting at 25 kts for 6 hours/day to allow 4 hours per day at 0 kts for drills				
Operation	Distance (nm)	Speed (kts)	Time (hrs)	Fuel Burned (gal)
Getting Ahead	1,350	25	54	153,096
Transit	1,950	15	130	97,119
Drills	-	0	36	-
Total	**3,300**		**220**	**250,215**
			% fuel overburn	**52%**

Table 2. 3,300 nm transit at a constant speed of 15 kts and a 3,300 nm transit with drills requiring the engines to be stopped for four hours per day, requiring a speed of 25 kts for six hours per day to make up for the drills.

b. 3,300 nm Transit—PIM Relaxed or Modernized

If the PIM moving window requirement is relaxed or modernized, the ship can conduct four hours of drills per day with the engines stopped and still make it to its final destination on time. This allows the ship to travel at 17.9 kts when not conducting drills. This also allows a ship to plan ahead for drill periods at its convenience, make it to its destination on time, and save 39,327 gallons of fuel during the transit. Table 3 shows the 19% fuel savings of 39,327 gallons, which can be saved by removing the PIM moving window requirement or by planning the transit with waypoints placed such that the drills are anticipated, rather than evenly spaced waypoints connected by a track made good at a constant speed.

3,300 nm Transit in 220 hrs - PIM moving window requirement removed - 4 hours per day at 0 kts for drills				
Operation	Distance (nm)	Speed (kts)	Time (hrs)	Fuel Burned (gal)
Transit	3,300	17.9	184	210,888
Drills	-	0	36	0
Total	**3,300**		**220**	**210,888**
	% saved with PIM removed			**19%**
	% overburn with PIM removed			**28%**
	Gallons saved with PIM removed			**39,327**

Table 3. This shows the fuel consumption for a 3,300 nm transit without the PIM moving window requirement, which allows the ship to travel at constant a speed when not conducting drills. This saves 39,327 gallons of fuel.

B. Transit Fuel Planner

It turns out that to save fuel during a transit, it is sometimes more efficient to steam at two distinct speeds, one slow in an efficient plant configuration, and one fast in a less-efficient configuration, but one required to achieve the overall transit time goal. The Transit Fuel Planner (TFP) is a tool that calculates for a given transit the optimal mix of slow and fast transit speeds to complete the transit on schedule, using the best available engine configurations. (Brown, et al. 2007, 2011) This planner has been customized for the *USS Chosin* (CG-65) and was used in the calculations for the constant speeds used in Table 2 and Table 3.

The Fuel curves were developed for all of *USS Chosin*'s engine configurations and used in the TFP model. Ships from the same class will typically have similar fuel curves, but ship-specific fuel curves should be utilized to make best use of this tool.

1. Optimum Transit Speed

The optimum transit speed to minimize fuel consumption on a transit for the USS Chosin is 11 kts, as shown in the Figure 9. There are two curves, a dotted line showing the fuel consumption without utilizing the TFP by transiting at a constant speed and a solid line showing fuel consumption while utilizing the TFP. The speeds where the lines separate from each other are the speeds at which the USS Chosin can save fuel by utilizing the TFP during a transit. The greatest fuel savings occurs where the lines are separated by the greatest distance, which is at approximately 22 to 23 kts.

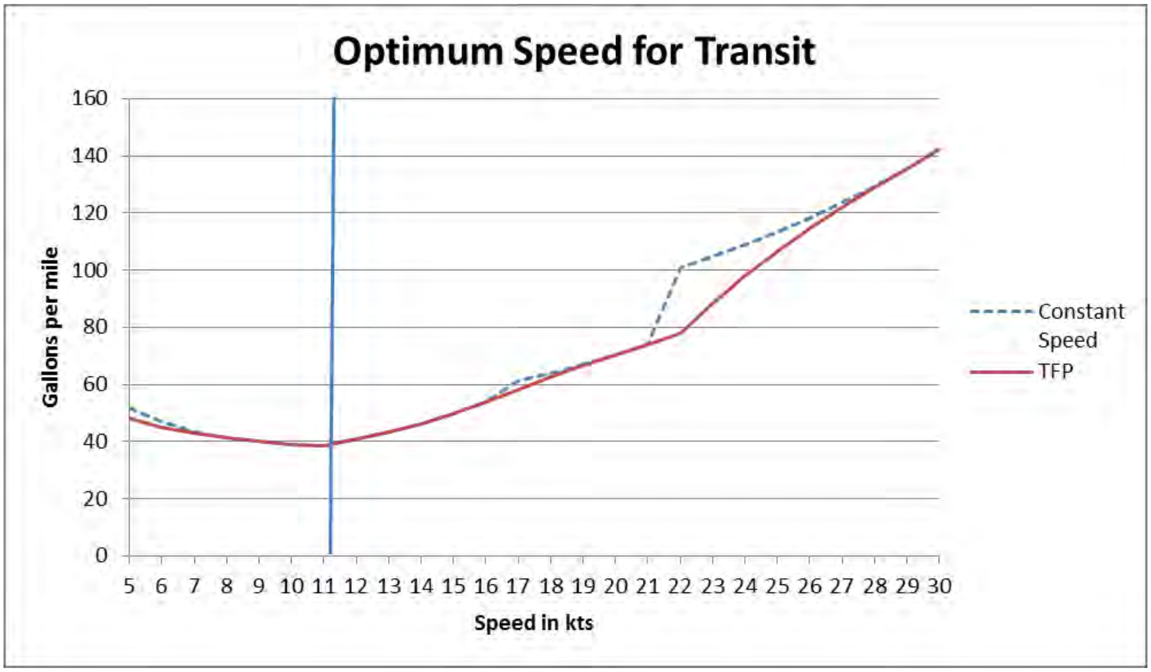


Figure 9. This shows the optimum speed to minimize fuel consumption for USS Chosin (CG 65). The TFP line optimizes the use of the Chosin's main engines at all speeds, so the curve will always be equal to or less than the line that shows constant speed. Data for this figure can be found in Appendix A.

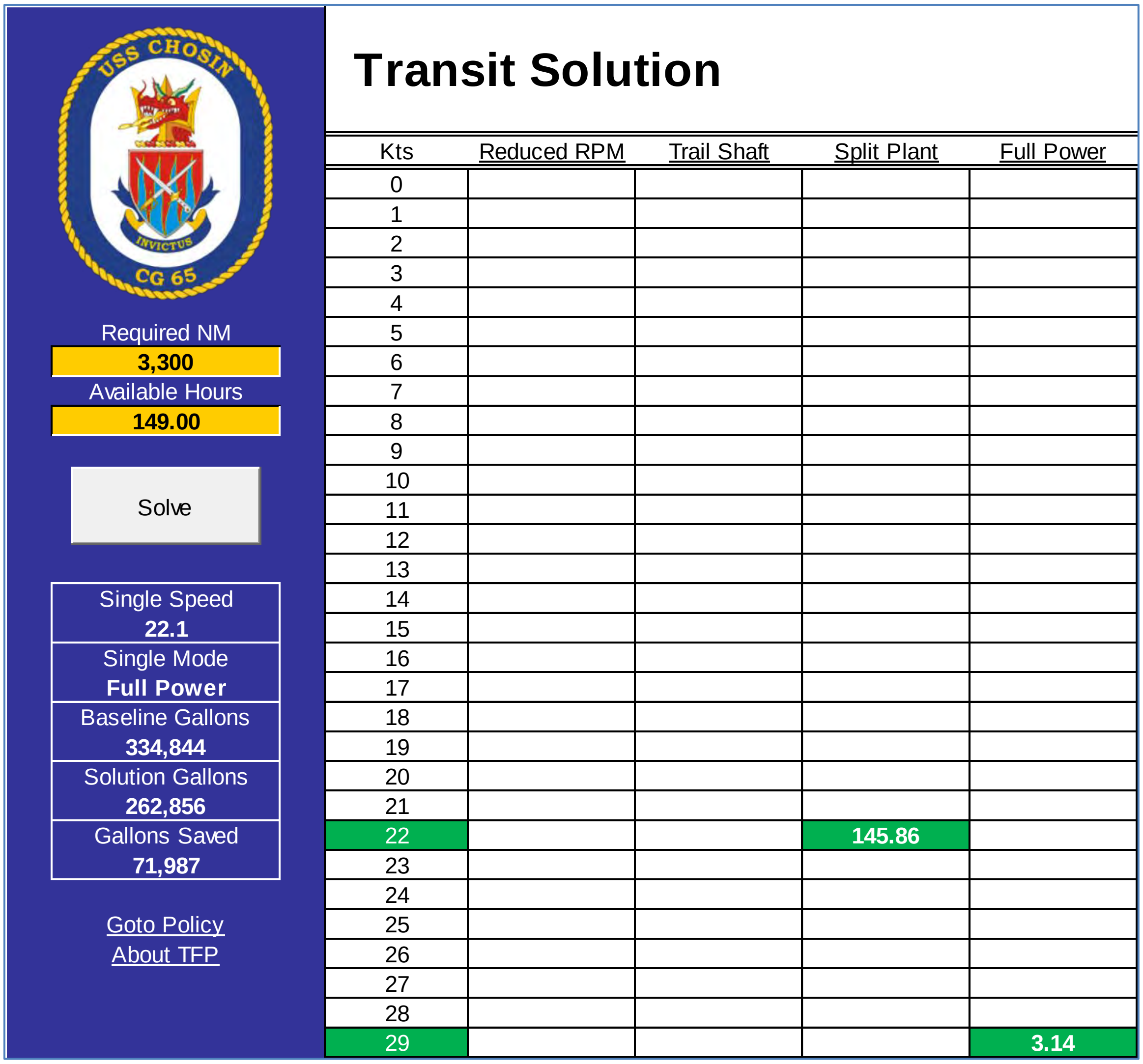
On both lines in Figure 9, the optimum speed to minimize fuel consumption during a transit is 11 kts at which the *USS Chosin* burns 38.7 gallons per nm.

2. Relaxing the Antiquated PIM Moving Window

Either relaxing the antiquated, inflexible PIM moving window requirement, or modernizing it with waypoints reached using varying speeds suggested by the Transit Fuel Planner, would in many cases save a lot of fuel. A modernized PIM would be reinforced by periodic GPS coordinate reports. The requirement to stay within 100 nm left or right of track does not need to be relaxed.

3. 3,300 nm Transit Utilizing the TFP

The most significant fuel savings produced by using the TFP is where the two curves in Figure 9 are separated by the greatest distance; this occurs between 22 and 23 kts. Such an extreme example would be a 3,300 nm transit completed in 149 hours, the USS Chosin would have to transit at a constant speed of 22.1 kts at a full power engine configuration and burning 334,844 gallons of fuel. A split plant configuration will not allow greater than 22 kts. Utilizing the TFP, the USS Chosin could transit at 22 kts in a split plant configuration for 146 hours and transit at 29 kts in a full power configuration for three hours and save 71,987 gallons of fuel over the course of the transit. This is a 21% savings in fuel and can be seen in Figure 10, a screen shot of the TFP.



Required NM: **3,300**
Available Hours: **149.00**

Single Speed: **22.1**
Single Mode: **Full Power**
Baseline Gallons: **334,844**
Solution Gallons: **262,856**
Gallons Saved: **71,987**

Transit Solution

Kts	Reduced RPM	Trail Shaft	Split Plant	Full Power
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22			**145.86**	
23				
24				
25				
26				
27				
28				
29				**3.14**

Figure 10. Utilizing the TFP for a 3,300 nm transit completed in 149 hours can reduce fuel consumption by 71,987 gallons, which is a 21% savings.

Figure 11 shows the fuel curves for the *USS Chosin* and highlights the speeds and the different engine configuration fuel curves for the 3,300 nm transit.

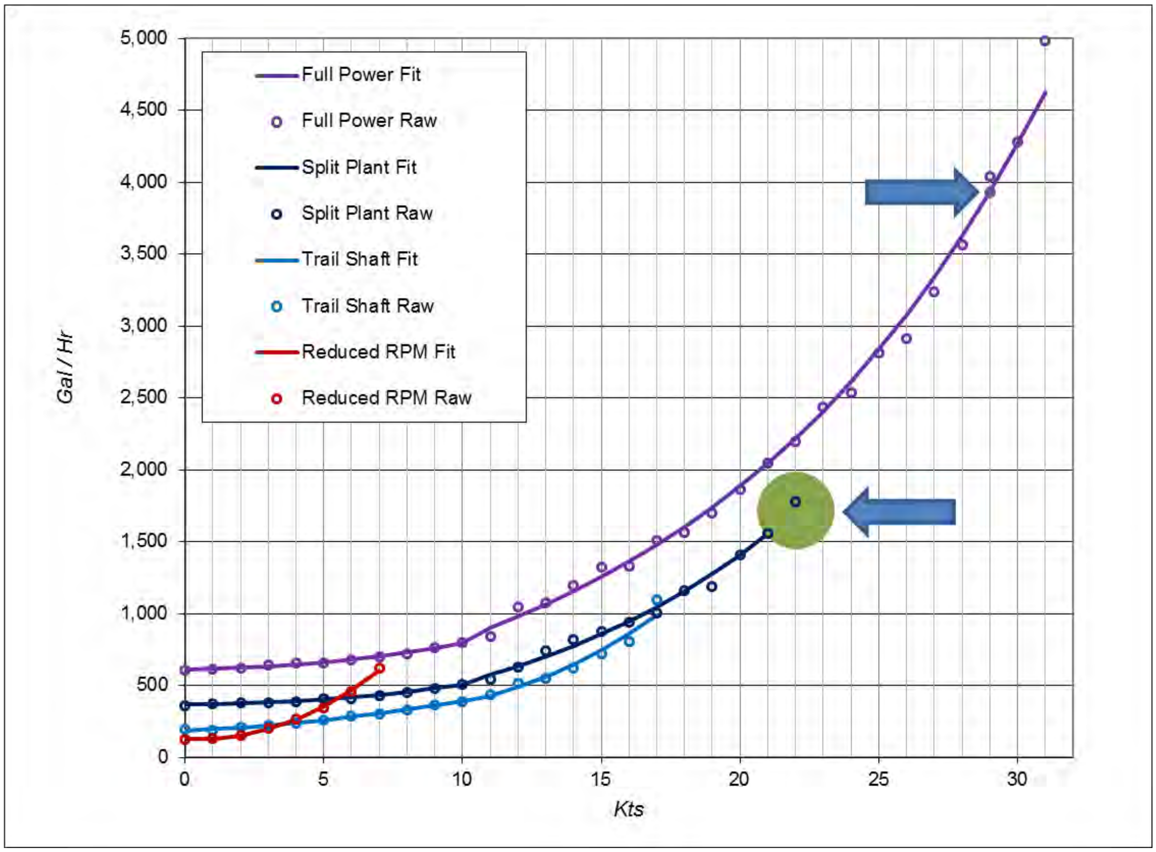


Figure 11. The TFP fuel curves are shown for the USS Chosin. The large circle at 22 kts and 1,700 Gal/hr represents the slower of the two transit speeds. The small circle at 29 kts and 3,900 Gal/hr represents the faster of the two transit speeds. The relative size of the circles represents what portion of the transit is spent at the two speeds; 146 hours at 22 kts and three hours at 29 kts.

4. Combined Fuel Savings—PIM Relaxed, or Modernized and Using TFP

Combining the utilization of the TFP and relaxing or modernizing the PIM moving window, the fuel savings is increased from 39,327 gallons to 44,188 gallons, an increase of almost 5,000 gallons saved. These numbers are shown in Table 4.

3,300 nm Transit in 220 hrs - PIM moving window requirement removed - 4 hours per day at 0 kts for drills and utilizing the TFP for optimum speed

Operation	Distance (nm)	Speed (kts)	Hours	Fuel Burned
Transit	2,153	17	127	125,342
Transit	1,147	20	57	80,685
Drills	-	0	36	0
Total	**3,300**		**220**	**206,027**
	% saved w/ PIM removed and using TFP			**21%**
	% overburn w/ PIM removed and using TFP			**25%**
	Gallons Saved with PIM removed and using TFP			**44,188**

Table 4. Combining the relaxing or modernized PIM moving window requirement and the use of the TFP, the savings on a 3,300 nm transit in 220 hours with 4 hours of drills per day is increased to 44,188 gallons which is a 21% savings in fuel.

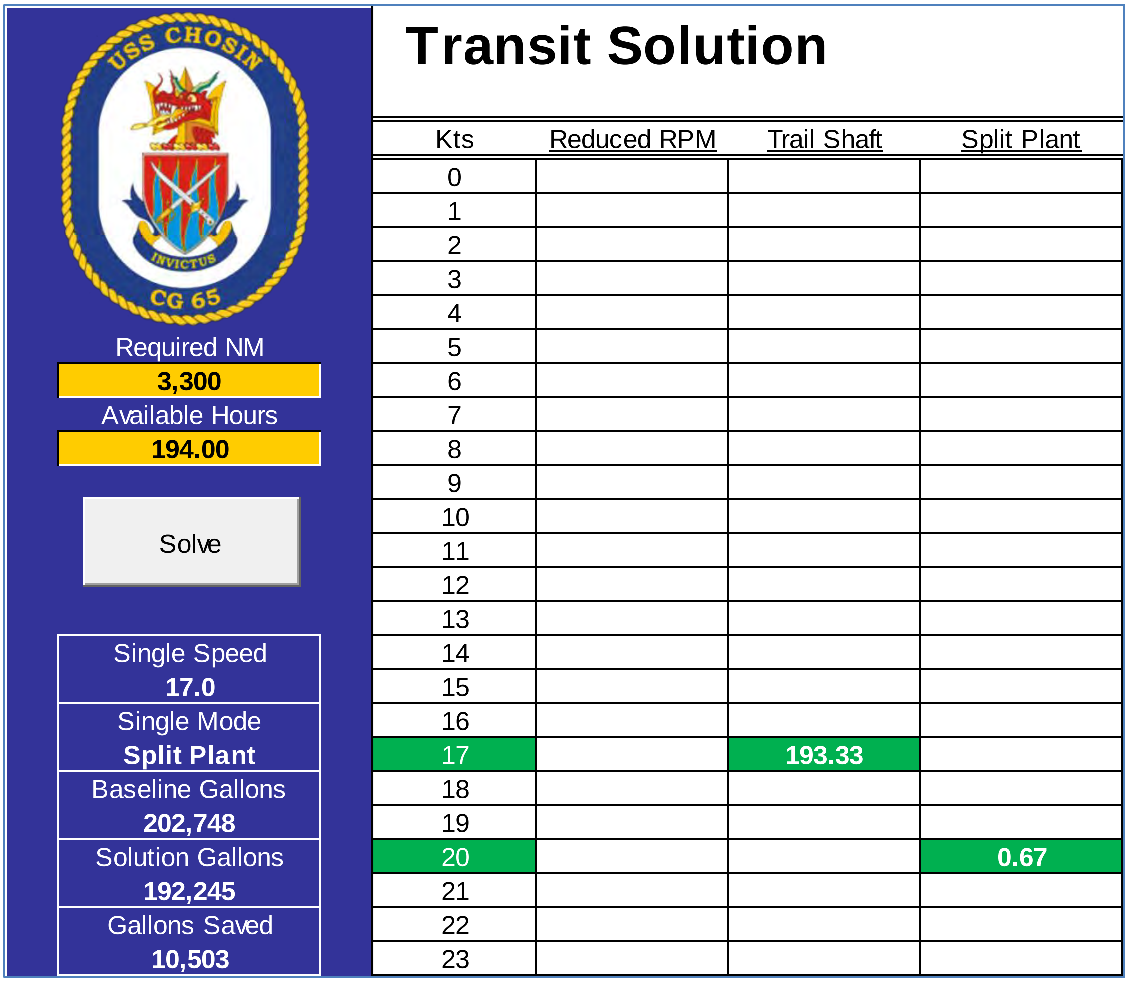
C. A Day Earlier or a Day Later

Transits are typically conducted between 14 and 16 kts depending on the tasking and the tactical situation. Using the same 3,300 nm transit from Pearl Harbor, Hawaii to Yokosuka, Japan in 220 hours (approximately nine days) at 15 kts, we will look at the difference in fuel consumption if the transit were to be completed one day earlier or one day later. As seen in Table 2, the nine-day transit consumes 164,355 gallons of fuel. Assuming the USS Chosin has an extra 24 hours to complete this transit (244 hours, approximately 10 days) the transit speed would be lowered to 13.5 kts and she would burn 148,515 gallons, which is 15,840 less gallons of fuel used for a 9.7% savings. If she were required to complete the transit 24 hours early (196 hours, approximately eight days), she would travel at a speed of 16.8 kts and burn 189,794 gallons of fuel for an overburn of 25,439 gallons or approximately 15.5%, which is seen in Figure 12.

Required NM	Required NM	Required NM
3,300	3,300	3,300
Available Hours	Available Hours	Available Hours
196.00	220.00	244.00
Single Speed	Single Speed	Single Speed
16.8	15.0	13.5
Single Mode	Single Mode	Single Mode
Trail Shaft	Trail Shaft	Trail Shaft
Baseline Gallons	Baseline Gallons	Baseline Gallons
189,794	164,355	148,515
Solution Gallons	Solution Gallons	Solution Gallons
189,794	164,355	148,515
Gallons Saved	Gallons Saved	Gallons Saved
0	0	0
~ 8 days	**~ 9 days**	**~ 10 days**

Figure 12. Fuel burned on a 3,300 nm transit in nine days +/- one day. A one day reduction in transit time will cause overburn of 25,439 gallons.

For the transit from Pearl Harbor, Hawaii to Yokosuka, Japan, the USS Chosin does not benefit from mixed engine configurations because the speeds fall in a range where there a single configuration dominates, and therefore the "Gallons Saved" in Figure 12 is "0". This is explained in Figure 9, where the two lines are not separated for the speeds used in the transit. If the 196-hour transit is shortened by just two hours to 194 hours, the USS Chosin burns 202,748 gallons of fuel, which is an increase of 6.8% over the 196 hour transit. This requires a speed where the lines in Figure 9 are separated allowing the benefit of saving fuel by using the TFP, which yields a savings of 10,503 gallons or 5.2%, as shown in Figure 13.



Transit Solution

Required NM
3,300
Available Hours
194.00

Single Speed
17.0
Single Mode
Split Plant
Baseline Gallons
202,748
Solution Gallons
192,245
Gallons Saved
10,503

Kts	Reduced RPM	Trail Shaft	Split Plant
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17		193.33	
18			
19			
20			0.67
21			
22			
23			

Figure 13. Conducting the 3,300 nm transit in 194 hours instead of 196 hours increases the fuel consumption by 5.2% (189,794 to 202,748 gallons), but can be lowered to a 1.3% increase (192,245 gallons) if the TFP is utilized.

The full extent of excess fuel burned by not transiting at the optimum speed of 11 kts, on a 3,300 nm transit for speeds varying from 5 to 30 kts can be seen in Figure 14.

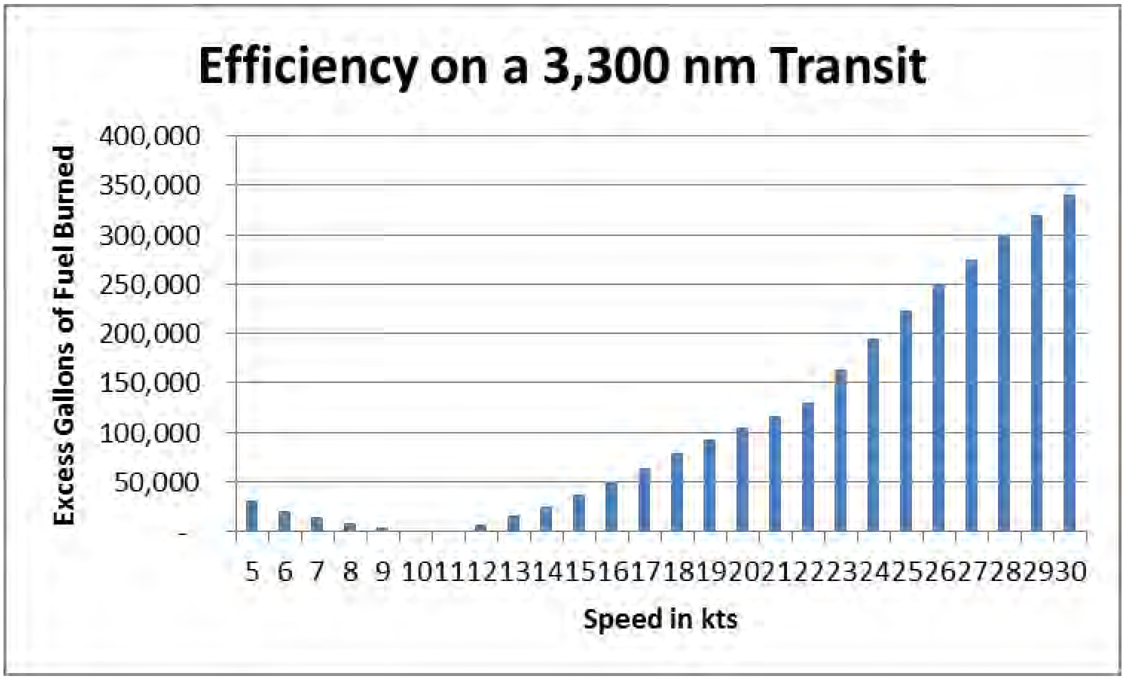


Figure 14. The optimum transit speed for the USS Chosin is 11 kts. Transiting slower or faster can cause excess fuel burn of more than 300,000 gallons on a 3,300 nm transit.

In Figure 15, the excess dollars spent by not transiting at the optimum speed is shown by transit days. The days are translated from speeds between five kts and 27.5 kts for the 3,300 nm transit.

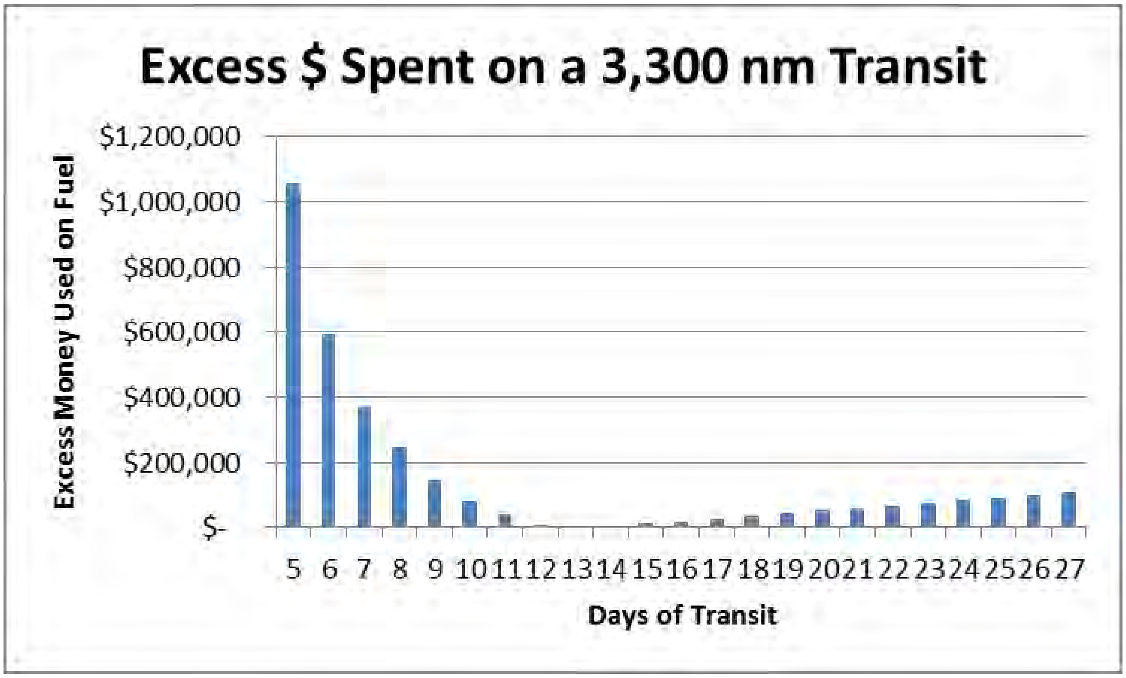


Figure 15. The optimum transit time for the *USS Chosin* is between 12 and 13 days. Transiting in more or less time causes excess dollars spent and can reach more than $1,000,000 on a 3,300 nm transit.

D. TRANSITS CONCLUDED

Transits can make up a significant portion of a ship's deployment depending on its tasking. If the three policies discussed above are promulgated, the savings can be significant. Relaxation or modernization of the PIM moving window requirement can allow flexibility in the ship schedule and can produce savings of 19%; even with the engines stopped for four hours per day for drills or unforeseen reasons. A ship's current position, speed, and direction can be frequently reported to shore facilities via satellite communications, which makes the moving window requirement no longer relevant.

The Transit Fuel Planner can save up to 21% of fuel by simply operating the ship at different speeds and engine configurations rather than employing a constant speed for a transit. A change of one day of time to complete a transit can render big fuel savings. While the example given saved as much as 15%, this change in fuel consumption increased when the required transit speed is over 20 kts.

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VI. MINIMUM FUEL SAFETY LEVELS

A ship's minimum fuel safety level is the lower limit of fuel onboard a Navy ship that is considered to be a safe level to support emergent continued operations. Below the safety level is an even lower level referred to as the extremis level. At the extremis level, a ship will need to be refueled very soon or be in danger of running out of fuel. The numbered fleet commanders prescribe the safety and extremis levels for their Area of Responsibility (AOR). This thesis uses an assumed safety level of 60% and an extremis level of 30%.

While underway, a naval vessel attempts to keep its fuel levels at a safe and reasonable level. Current operations and the availability of replenishment at sea (RAS), may require a ship to operate below the minimum fuel safety level and possibly below the extremis level. If a ship's fuel level goes below this minimum fuel safety level, she typically has priority over other ships in the AOR to obtain fuel either from a RAS or by pulling into a port. If a ship's fuel level goes below the extremis level, she has the highest priority to receive fuel.

A. REPLENISHMENT AT SEA PLANNER (RASP)

RASP is an EXCEL-based, mixed-integer heuristic optimization program, used as a decision support tool to minimize the fuel used by Military Sealift Command's (MSC) CLF ships delivering fuel to Navy ships. It takes into account all of the ships in the AOR that require refueling along with all of the CLF ships in the AOR that can provide refueling. While CLF ships have the ability to deliver diesel fuel marine (DFM), jet propulsion fuel type 5 (JP5), fresh fruits and vegetables (FFV), dry food and cargo, chilled and frozen food, along with mail and repair parts, this research deals strictly with the delivery of DFM. When RASP is executed, the output provides the gallons consumed by the CLF ship. The objective of RASP is to minimize this number. RASP is currently used in the 5th Fleet and 7th Fleet AORs, so these two AORs are used in this thesis for analysis.

Navy ships are often refueled on a fixed schedule when they are at sea for long periods. This cycle normally lasts about one week. Most DDGs and CGs will burn 5-6% of their fuel per day, putting the ship at approximately 60-70% of its fuel capacity at the time of refueling. Varying the minimum fuel safety level and in turn the cycle time to refuel ships at sea, can not only substantially change the amount of fuel burned by CLF ships, but it can also change the number of CLF ships required to deliver the fuel needed.

B. VARYING FUEL SAFETY LEVELS

RASP has many inputs such as ship type, location, tasking, cycle days, DFM, JP5, dry food and cargo, and chilled and frozen food. In experiments using RASP, the frequency of delivery of DFM was varied to simulate different fuel safety levels; the requirements for delivery of items other than DFM are removed for the purpose of this analysis. It is based on the fuel safety level and is calculated from the average daily fuel consumption for the class of ship. The cycle days for each ship are adjusted to simulate refueling at different safety levels. For this analysis, actual 5th Fleet and 7th Fleet data are used for a 62-day period from 15 April to 15 June of 2014. The names and locations of ships have been removed for classification purposes.

1. 5th Fleet

The 5th Fleet AOR covers ships operating in the vicinity of the Middle East. In this analysis there are 11 ships consisting of six DDGs, two LPDs (landing platform dock), one CG, one LHD (landing helicopter dock), and one LSD (dock landing ship). During this timeframe MSC had 10 CLF ships in the AOR consisting of seven T-AOs (fleet replenishment oiler) and three T-AKEs (dry cargo-ammunition ship).

In the 62-day period from April 15th, 2014 to June 15th, 2014, using a 60% safety level for the 11 Navy ships in the AOR, RASP scheduled the CLF ships to have 11,104 hours underway, conducting 80 RAS events and burning 2,847,599 gallons of fuel in the process. Varying the safety level makes a significant change in the amount of fuel consumed by the CLF ships. The variation between 80% and 20% in 10% increments is seen in Figure 16.

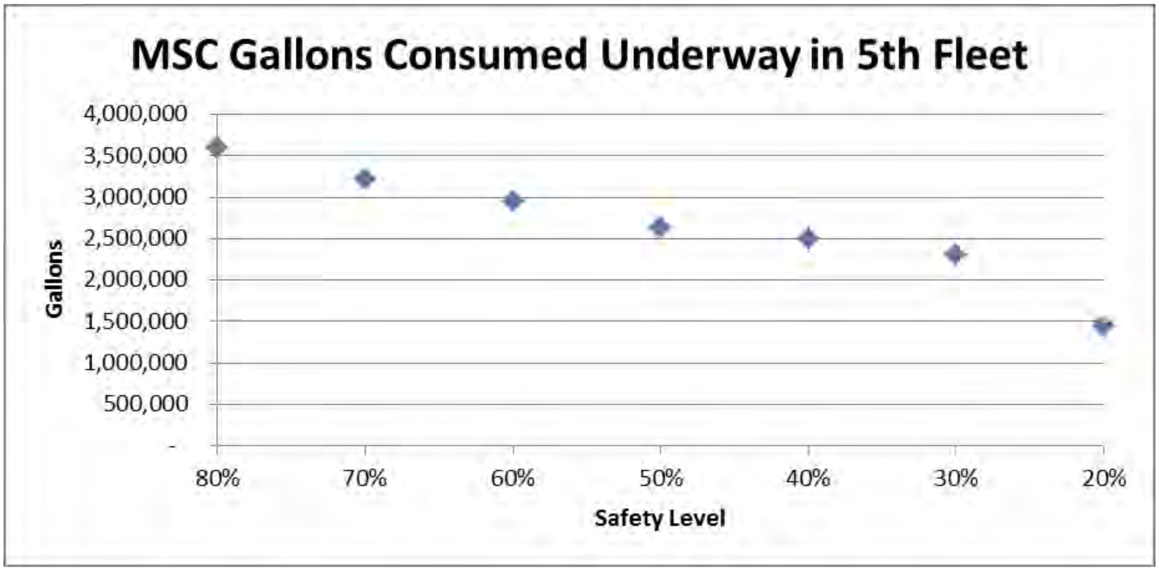

Figure 16. Varying the safety level of the U.S. Navy ships in 5th Fleet significantly affects the fuel consumed by MSC. Lowering from 60% to 50% reduces MSC fuel consumption by 10.6%.

Decreasing the safety level of U.S. Navy ships from 60% to 50% decreases the underway hours of the CLF ships by 1,140 hours to 9,964 hours, the RAS events from 80 events down to 63 events, and yields a savings of 313,099 gallons of fuel, which is a reduction of 10.6%. This fuel savings at a rate of $3.69 per gallon translates into $1,155,335 being saved simply by changing the safety levels at which the Navy ships are refueled. This is a yearly savings of approximately $6.8 million. Changes in MSC fuel consumption and dollars spent on fuel from a 60% safety level can be seen in Table 5.

Changing Minimum Fuel Safety Levels - 5th Fleet							
Fuel Safety Levels	80%	70%	60%	50%	40%	30%	20%
Gallons Consumed underway	3,590,130	3,216,585	2,947,599	2,634,500	2,505,404	2,307,342	1,439,736
Total underway hours	12,576	12,736	11,104	9,964	10,472	9,152	7,720
Assigned RAS events	143	102	80	63	57	47	43
Dollar Change vs 60%	$ (2,370,939)	$ (992,558)	$ -	$ 1,155,335	$ 1,631,700	$ 2,362,548	$ 5,564,014
Yearly Change vs 60%	$ (13,957,950)	$ (5,843,287)	$ -	$ 6,801,571	$ 9,605,973	$ 13,908,551	$ 32,755,892
% Change vs 60%	-21.8%	-9.1%	0.0%	10.6%	15.0%	21.7%	51.2%

Table 5. Altering minimum fuel safety levels can have a large impact on fuel savings for MSC. Lowering the safety level for 5th Fleet from 60% to 50% can yield almost $7 million per year in savings.

2. 7th Fleet

The 7th Fleet AOR includes ships operating in the vicinity of Southeast Asia. In this analysis covering the same 62-day period, there are 41 ships consisting of 23 DDGs, seven CGs, three LHDs, three LSDs, three LPDs, one LHA (landing helicopter assault), and one FFG (guided missile frigate). During this timeframe MSC had 15 CLF ships in the AOR consisting of six T-AOs, eight T-AKEs, and one T-AOE (fast combat support ship). At a 60% safety level, the CLF ships are scheduled to conduct 58 RAS events while underway for a total of 9,348 hours and burning 3,188,571 gallons of fuel. The effects of varying the safety level from 80% to 20% in 10% increments can be seen in Figure 17.

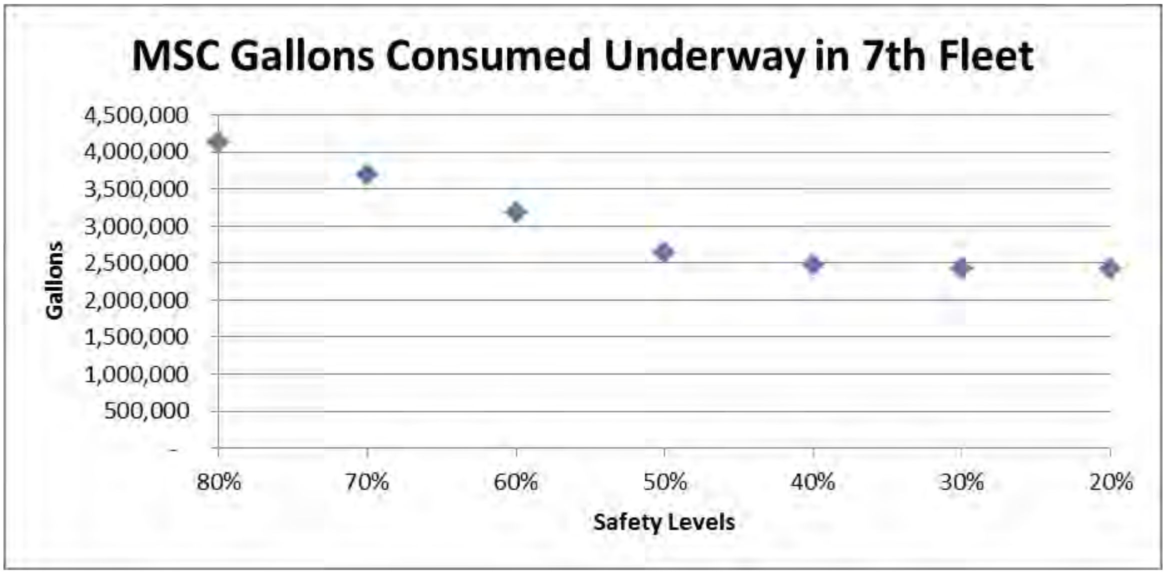

Figure 17. Varying the safety level of the U.S. Navy ships in 7th Fleet significantly affects the fuel consumed by MSC. Lowering from 60% to 50% reduces MSC fuel consumption by 16.9%.

The fuel savings has a significant downward trend between 80% and 40%, much like 5th Fleet's fuel savings in Figure 16; however, lowering from 40% to 20% does not give a significant fuel savings. This can be contributed to the distances that 7th Fleet CLF ships must travel compared to 5th Fleet CLF ships. The AOR for 7th Fleet is much larger, so refueling a Navy ship less often does not have as large of a benefit at lower levels because the quantity of fuel that the CLF ship is carrying will not refuel as many ships as if it were refueling at a higher safety level. This requires more trips over long distances depending on the location of the ships, the port at which the CLF ship obtains more fuel, and the number of ships needing to be refueled. Changes in MSC fuel consumption and dollars spent on fuel from a 60% safety level can be seen in Table 6.

Changing Minimum Fuel Safety Levels - 7th Fleet							
Fuel Safety Levels	80%	70%	60%	50%	40%	30%	20%
Gallons Consumed underway	4,133,774	3,693,822	3,188,571	2,648,512	2,466,694	2,426,470	2,416,004
Total underway hours	11,012	9,860	9,348	8,376	6,628	6,764	7,264
Assigned RAS events	104	71	58	46	39	35	33
Dollar Change vs 60%	$ (3,487,799)	$ (1,864,376)	$ -	$ 1,992,818	$ 2,663,726	$ 2,812,153	$ 2,850,772
Yearly Change vs 60%	$ (20,533,011)	$ (10,975,763)	$ -	$ 11,731,911	$ 15,681,614	$ 16,555,415	$ 16,782,772
% Change vs 60%	-29.6%	-15.8%	0.0%	16.9%	22.6%	23.9%	24.2%

Table 6. Altering minimum fuel safety levels can have a large impact on fuel savings for MSC. Lowering the safety level for 7th Fleet from 60% to 50% can yield almost $12 million per year in savings.

Decreasing the safety level of U.S. Navy ships from 60% to 50% decreases the underway hours of the CLF ships by 972 hours to 8,376 hours, the RAS events from 58 events down to 46 events, and yields a savings of 540,059 gallons of fuel, which is a reduction of 16.9%. This fuel savings at a rate of $3.69 per gallon translates into $2 million being saved simply by changing the safety levels at which the Navy ships are refueled. This is a yearly savings of approximately $11.7 million.

Not all of the CLF ships are needed to deliver the fuel to the Navy ships in this simulation, so all six TAOs and two TAKEs are placed in port in RASP and effectively removed from the calculation. When the safety level is lowered to 50% and below, the TAOE is also placed in port. At the 20% safety level, one TAO is added back in because the amount of fuel carried by the CLF ships cannot handle the large quantity of fuel needed each time fuel is delivered to a group of Navy ships. The one high-capacity TAO provides enough carrying capacity to ensure all ships are being refueled on time, but the refueling is less frequent, so this still yields a fuel savings of 10,466 gallons compared to the 30% safety level.

C. CONCLUSION

RASP is a tool that minimizes the fuel used by MSC's CLF ships to refuel Navy ships based on certain criteria such as at what fuel level the Navy ship requests to be refueled. If this level is altered, significant fuel savings can be achieved by the CLF ships. For example, lowering the minimum fuel safety level from 60% to 50% in both 5th Fleet and 7th Fleet can save a combined total of $18.5 million per year.

VII. CONCLUSIONS, RECOMMENDATIONS, AND FOLLOW-ON RESEARCH

In fiscal year 2013, the Navy spent over $4.5 billion on fossil fuel at $3.69 per gallon (Dhoran 2014). With current and likely future budget cuts, it is of paramount importance that the Navy makes every effort to reduce fuel consumption and increase fuel efficiency. This thesis explores alternative ways of operating surface ships to reduce fuel consumption and increase fuel efficiency without increasing overhead costs.

A. DRIFT OPERATIONS

A ship has the option to stop her main engines and drift when she is not transiting. Safety precautions need to be taken into account before conducting drift operations, such as visibility, sea state, weather conditions, tactical situation, contact density, and many other factors that can affect the safety of the ship. When a CG conducts six hours of drift operations in a night, she saves 3,900 gallons of fuel, which translates to approximately $14,400 in savings compared to normal steaming operations. There are 22 CGs in the Navy with an average of 113 days underway per year and 62 DDGs spending an average of 127 days underway per year (iENCON 2014). If all 22 CGs and 62 DDGs conducted six hours of drift operations per night during 10% of the nights they are underway, it would save the Navy $14.1 million per year.

B. SINGLE-GENERATOR OPERATIONS

The business practice of running two GTGs provides safety for the ship and the crew. When the tactical situation and current operations permit single-generator operations, a significant amount of fuel can be saved. If a CG or a DDG operates a full day using single-generator operations, she can save $10,600 over using two generators in parallel.

If all 22 CGs and 62 DDGs conducted single-generator operations 25% of the time underway, it would save the Navy over $27.4 million per year.

C. TRANSITS

The requirement to follow a plan of intended movement (PIM), with a moving window in which the ship must stay, is almost 70 years old. This outdated requirement is causing excessive fuel burn by ships due to their efforts to stay within this moving window. If the Navy relaxed or removed the antiquated PIM moving window requirement and relied on GPS positioning and satellite communications, a ship would have more flexibility in transits to save fuel. With four hours of drills or other stopping requirements per day, this equates to a 19% fuel reduction.

The TFP was created to improve fuel efficiency on transits by transiting at two different speeds and engine configurations for different portions of the transit. Combining the removal or modification of the moving window and using the TFP, the fuel saved on a transit can be increased to 21%.

Completing a transit in a shorter or longer period of time can have significant effects on fuel consumption due to speed requirements. Transits are typically completed between 14 and 16 kts. If a ship is required to complete a nine-day 3,300 nm transit one day early, she would burn an extra 15% in fuel. If she were allowed an extra day to complete the transit, she would reduce her fuel consumption by 9.7%.

D. MINIMUM FUEL SAFETY LEVELS

The Replenishment At Sea Planner was created to schedule MSC ships for refueling U.S. Navy ships while in 5th and 7th Fleets. The timing of refueling the ships is based on a minimum fuel safety level. If this level is changed it can significantly affect the amount of fuel burned by MSC ships.

In 5th Fleet, lowering the minimum fuel safety level from 60% to 50% reduces MSC fuel consumption by 10.6%. In 7th Fleet, lowering the minimum fuel safety level from 60% to 50% reduces MSC fuel consumption by 16.9%. This equates to a yearly combined savings between 5th Fleet and 7th Fleet of $18.5 million.

E. RECOMMENDATIONS

Lower the minimum fuel safety levels in 5th and 7th Fleet by 10% and encourage Commanding Officers to conduct drift operations and single-generator operations when the situation permits. There are safety considerations with regards to these recommendations, but these recommendations are feasible. If the CGs and DDGs in the fleet can average six hours per night of drift operations during 10% of their nights underway and conduct single-generator operations 25% of the time underway, these three recommendations alone will save $60 million per year.

Relax or remove the moving window requirement during transits and encourage the implementation and use of the Transit Fuel Planner, which can reduce fuel consumption by more than 20% during transits.

F. FOLLOW-ON RESEARCH

This thesis focuses on fuel saved and dollars saved. An important aspect of saving fuel is how much additional staying time it can provide to a ship on station. Instead of dollars or gallons saved, translating the impacts of these policies, along with other innovative techniques, into extra days that a ship can stay on station will be very valuable information for Navy leaders.

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APPENDICES

G. DATA FROM TRANSIT FUEL PLANNER

Gallons per mile	
Constant Speed	TFP
51.8	48.2
46.8	45.1
43.6	42.9
41.4	41.3
40.0	40.0
39.1	39.1
38.7	38.7
40.8	40.8
43.4	43.4
46.4	46.4
49.8	49.8
53.7	53.7
61.4	58.2
64.1	62.7
67.1	66.7
70.4	70.4
74.0	74.0
100.9	78.1
104.7	88.4
108.9	97.9
113.4	106.6
118.3	114.7
123.6	122.1
129.4	129.1
135.5	135.5
142.1	142.1

Table 7. Gallons per mile consumed by the *USS Chosin* when transiting at constant speed and when utilizing the Transit Fuel Planner (TFP).

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