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A study of alternative fuel impacts to navy fueling infrastructure

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14. ABSTRACT
Energy reform in the United States Department of the Navy is currently a leading priority. Supporting reform efforts, the Honorable Ray Mabus, Secretary of the Navy, set a goal to sail a "Green Strike Group" composed of ships powered by alternative fuels by 2016. This report details considerations for implementing an alternative fuel for the Green Strike Group. This is accomplished by developing the requirements for an alternative fuel, analyzing several potential candidates, and recommending a preferred alternative (Fischer-Tropsch S-5). Additionally, this report describes the existing infrastructure supporting fuel distribution to Navy ships and explores options for changes necessary to support the selected alternative fuel. A notional mission profile is depicted, showing the Green Strike Group's progress from Norfolk, Virginia to the Arabian Sea and back again over the course of a 180-day deployment. A deterministic fuel estimation model and the succeeding, higher fidelity stochastic model are described, leading to the prediction of alternative fuel amount requirements and necessary geographic placement. Finally, this report concludes with the assertion that while sailing the Green Strike Group is technologically possible, significant and immediate economic investments are needed in order to realize the Secretary of the Navy's goal by 2016.

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Alternative fuel, fueling infrastructure, fuel distribution, systems engineering, Green Strike Group, S-5, F-76, Navy, energy reform, Fischer-Tropsch process.

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ABSTRACT

Energy reform in the United States Department of the Navy is currently a leading priority. Supporting reform efforts, the Honorable Ray Mabus, Secretary of the Navy, set a goal to sail a “Green Strike Group” composed of ships powered by alternative fuels by 2016. This report details considerations for implementing an alternative fuel for the Green Strike Group. This is accomplished by developing the requirements for an alternative fuel, analyzing several potential candidates, and recommending a preferred alternative (Fischer-Tropsch S-5). Additionally, this report describes the existing infrastructure supporting fuel distribution to Navy ships and explores options for changes necessary to support the selected alternative fuel. A notional mission profile is depicted, showing the Green Strike Group’s progress from Norfolk, Virginia to the Arabian Sea and back again over the course of a 180-day deployment. A deterministic fuel estimation model and the succeeding, higher fidelity stochastic model are described, leading to the prediction of alternative fuel amount requirements and necessary geographic placement. Finally, this report concludes with the assertion that while sailing the Green Strike Group is technologically possible, significant and immediate economic investments are needed in order to realize the Secretary of the Navy’s goal by 2016.

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EXECUTIVE SUMMARY

There is a critical need for energy reform in the Navy from a strategic standpoint. If the Navy is to maintain a consistent, reliable, sustainable fuel source, it must look beyond the fossil fuels currently in use. The continued use of fossil fuels makes the Navy dependent on an inconsistent supply that largely exists in highly volatile regions of the world. Continued use leaves the Navy vulnerable if access is denied to those resources. Additionally, the fossil fuel supplies themselves are limited. As global supplies dwindle, competition will drive costs higher until the fuels are no longer available. An alternative fuel that can be more sustainably produced will allow the Navy to function well into the future without concerns as to the availability of fuel. In response to this problem, the Secretary of the Navy established a series of energy reform goals for the Navy. One of these goals is to sail a Green Strike Group, consisting of ships fueled by an alternative to F-76 marine diesel, by 2016. This project focuses on that goal with the intention of studying the infrastructure and logistics involved in using an alternative fuel in Green Strike Group operations.

A tailored systems engineering process was established to determine the key infrastructure modifications needed to support the Green Strike Group's use of an alternative fuel. The first phase began with a study of fuel alternatives to determine which fuel has the most potential to meet the 2016 timeframe. To begin, the project team conducted research to identify the critical criteria in selecting an alternative fuel and subsequently to determine candidate fuels. Twelve criteria were identified to evaluate the candidate fuels and ten fuels were selected. Of the ten fuels evaluated, the project team determined that Fischer-Tropsch S-5 jet fuel (FT S-5) has the most potential to meet the 2016 timeframe. Results from this study provided key inputs into the requirements for an alternative fueling infrastructure.

A description of the existing ashore and afloat fuel distribution systems is then presented. This information was used as a basis for determining key modifications required to the infrastructure with the introduction of FT S-5. Supplying fuel to the fleet involves both in-port replenishment at shore facilities and underway replenishment at sea

through afloat distribution systems. The organizations involved in these two distinct activities were documented along with their responsibilities and relationships. Using the information captured from this study along with guidance from the Universal Navy Task List (UNTL), the project team created a functional description of the existing fueling infrastructure. Five key functions were identified: transport fuel, store fuel, transfer fuel, perform fuel quality tests, and control fuel inventory and movements. These five functions were further defined for ashore and afloat infrastructure, as there are differences in the operational activities, processes, and equipment used. These functions were used as input into defining the alternative fueling infrastructure requirements.

A notional mission profile was defined for the Green Strike Group to support requirements generation for the alternative fueling infrastructure. The mission profile was used to determine how implementing FT S-5 would impact operational support requirements such as underway replenishment and storage capacity at shore-based facilities both inside and outside the continental United States. The mission defined a six-month deployment departing and returning to Norfolk, Virginia after supporting operations in and around the Arabian Sea. A fuel estimation tool was created to model fuel consumption for the mission. The model provided insight into how many refueling operations would be required during the mission and subsequently how much fuel would need to be supplied from shore-based facilities.

Requirements were derived from the existing infrastructure functions. Characteristics of FT S-5 and the mission profile were used during the solutions analysis phase to determine the extent of the modifications required to the fueling infrastructure. Several options were identified and analyzed during this phase. An object-oriented C# programming language model was developed to provide high resolution simulation data of the Green Strike Group's movement, fuel consumption, and re-fueling activities during the course of executing the mission. The model provided a means for exploring solution alternatives and examining the operational performance of the strike group over time and distance while executing the mission. Requirements-based metrics, along with a selection process that included a cost benefit analysis of the options, were developed to analyze the alternative solutions. Based on the outcome of the analysis, additional storage and fuel transfer capability will be necessary at defense fuel supply points. The number of underway replenishments will increase due to the lower energy density of FT S-5 as compared to the F-76 marine diesel fuel currently used to power non-nuclear ships in the strike groups. Additionally, based on the non-functional requirements derived from the existing infrastructure, modifications to training, fuel quality testing, and environmental and safety procedures will need to be considered. The project team concludes that it is feasible to sail the Green Strike Group by 2016. However, heavy investment is needed in the near term to make this possible.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	**Term**
AOR	Area of Responsibility
ASTM	American Society of Testing and Materials
bbls	Bulk Barrels
BTL	Biomass-to-Liquid
CBTL	Coal/Biomass-to-Liquid
CDD	Capabilities Development Document
CENTCOM	Central Command
CG	Guided Missile Cruiser
COMFISCS	Commander Fleet Industrial Supply Center
CONUS	Continental United States
CSG	Carrier Strike Group
CTL	Coal-to-Liquid
CVN	Nuclear-Powered Aircraft Carrier
DDG	Guided Missile Destroyer
DESC	Defense Energy Support Center
DFSP	Defense Fuel Supply Point
DLA	Defense Logistics Agency
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
ESOH	Environment, Safety, and Occupational Health
FISC	Fleet Industrial Supply Center

FIST	Fueling Infrastructure Study Team
FT	Fischer-Tropsch (Process)
GHG	Green-House Gas
GOCO	Government Owned, Contractor Operated
GOGO	Government Owned, Government Operated
GPH	Gallons Per Hour
GSG	Green Strike Group
HRJ	Hydro-Treated Renewable Jet
HRO	Hours of Restricted Operation
LNG	Liquified Natural Gas
MGO	Marine Gas Oil
MIRR	Material Inspection Receiving Report
MSC	Military Sealift Command
M&S	Modeling and Simulation
NALC	Naval Ammunition Logistics Center
NATO	North Atlantic Treaty Organization
NAVCENT	Naval Forces Central Command
NAVPETOFF	Naval Petroleum Office
NAVSEA	Naval Sea Systems Command
NAVSUP	Naval Supply Systems Command
NAVTRANS	Naval Transportation Support Center
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NM	Nautical Mile
NOLSC	Naval Operational Logistics Support Center

NTTP	Navy Tactics, Techniques, and Procedures
NWP	Naval Warfare Publication
OA	Operational Area
OCD	Operational Concept Description
OCONUS	Outside the Continental United States
OPCON	Operational Control
ORD	Operational Requirements Document
OSHA	Occupational Safety and Health Administration
POL	Petroleum, Oils, Lubricants
QAR	Quality Assurance Representative
SE	Systems Engineering
SECNAV	Secretary of the Navy
SME	Subject Matter Expert
SSN	Nuclear-Powered Fast Attack Submarine
STREAM	Standard Tension Replenishment Alongside Method
T-AO	Fleet Replenishment Oiler
T-AOE	Fast Combat Support Ship
TRL	Technology Readiness Level
UNREP	Underway Replenishment
UNTL	Universal Navy Task List
URC	Underway Replenishment Coordinator
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy

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I. INTRODUCTION

A. BACKGROUND

The United States has been the world’s largest energy consumer for decades, only recently surpassed by China in 2010 (International Energy Agency 2010, para. 1). It therefore comes as no surprise that the United States armed forces also consume vast amounts of energy as they operate at home and abroad. Indeed, in reference to the high level of energy consumed by the United States Navy, Deputy Assistant Secretary of the Navy (Environment) Donald R. Schregardus in his 2005 acceptance of the National Energy Security Award on behalf of the Navy stated that “The U.S. Navy is the largest diesel fuel user in the world” (NAVAIR 2005, para. 4).

Reacting to this continued massive energy use, the Honorable Ray Mabus, Secretary of the Navy (SECNAV), addressed representatives from the U.S. Navy, United States Marine Corps (USMC), academia, industry, and the media during an address to the Naval Energy Forum in McLean, Virginia on October 14, 2009. In his opening remarks to the audience, he stressed that “energy reform is a strategic imperative” and as such will be one of the areas he will focus his attention on during his tenure as SECNAV (Mabus 2009, 1).

The need for energy reform in the Navy is vital from a strategic perspective. Current Navy operations depend heavily on fossil fuels, with most of the supply coming from volatile regions of the world in which state-run oil companies control 77% of the world’s production (Jaffe 2007, 2). The current dependence upon foreign supplies is a critical vulnerability since it is conceivable that foreign suppliers may attempt to deny the United States access to critical resources in the future. Additionally, fossil fuels are ultimately a limited resource; as global supplies dwindle, competition will drive costs higher (Froggatt and Lahn 2010, 6).

During the 2009 Naval Energy Forum address, Secretary Mabus announced five specific energy targets that the Navy will meet within the next ten years. These goals address such areas as contracting practices, environmental stewardship, energy efficiency, and alternative energy supply. Yet the one goal with perhaps the greatest near-term implications for ship systems engineering and supporting infrastructure is the second one promulgated during the address:

> The Navy will demonstrate in local operations, by 2012, a Green Strike Group composed of nuclear vessels and ships powered by biofuel. And by 2016, we will sail that Strike Group as a Great Green Fleet composed of nuclear ships, surface combatants equipped with hybrid electric alternative power systems running biofuel, and aircraft flying only biofuels – and we will deploy it (Mabus 2009, 8).

The deployment of a Green Strike Group (GSG) will involve a significant and coordinated effort of research, engineering, and logistics. The authors of this report, hereafter referred to as the Fueling Infrastructure Study Team (FIST), intend to use this study to inform and advance understanding of requirements and options for deploying the GSG.

B. PROBLEM STATEMENT

The existing fueling infrastructure for Navy ships has been optimized for F-76 marine diesel. Without modification, that infrastructure may not be capable of efficiently and safely distributing alternative fuel. Thus implementation considerations must not be limited to ships and aircraft, but must also include the supporting fueling infrastructure.

The technical challenges of converting surface combatants and carrier-based aircraft to alternative fuel are expected to be numerous. In addition to physical and operational considerations, logistical issues must be considered. Any new fuel must be purchased, delivered, stored, transported, and transferred before consumption. Planning, ordering, inventory maintenance, and quality assurance constitute organizational challenges present throughout the process. These logistics activities also encompass their own extensive technical challenges. More importantly, logistics may present key drivers contributing to life-cycle cost. Key to the introduction of alternative fuel is to identify any modifications to the Navy’s existing fueling infrastructure. Knowledge of the necessary changes can then lead to practical and affordable implementation solutions.

C. PROJECT SCOPE

The SECNAV goal and associated problem statement previously outlined are vast in potential scope. Thus FIST limited the extent of the problem under investigation. FIST considered modifications to fueling infrastructure only. This did not include modifications to shipboard machinery, such as engines or fuel pumps, necessary to burn an alternative fuel. Fueling infrastructure consideration was limited to “inside the fence.” This consisted of systems used for storage, transport, and delivery of fuels to ships located pier-side at one U.S.-based port likely to host the GSG, and foreign ports or re-supply bases likely to be utilized by the GSG during a typical mission. External systems that are part of contractor delivery to the site and commercial energy infrastructure were excluded (e.g., delivery trucks, commodity transport pipelines, or other similar systems not owned and operated by the Navy). Finally, fueling infrastructure consisting of systems used for underway replenishment (UNREP) was limited to a single auxiliary ship.

D. KEY ASSUMPTIONS

There are many assumptions that were made during the course of the project. These assumptions provided FIST appropriate boundaries to the problem space. Additionally, assumptions allowed for progress where some points may currently be under debate.

FIST assumed that alternative fuels (e.g., biofuels) employed by the Navy will have fewer negative environmental impacts than the currently utilized fossil fuels and may be accurately labeled “green.”

FIST concluded that developing and utilizing alternative fuels is a productive activity consistent with addressing the strategic and tactical issues underpinning the goal of deploying a GSG by 2016. Additionally, FIST inferred that production and consumption of alternative fuels is consistent with the current United States’ national energy strategy and is likely to remain part of that strategy for years to come.

While Secretary Mabus did not precisely define the exact composition of the GSG, it is assumed to contain the same assets as a Carrier Strike Group (CSG). The composition of a modern CSG can vary. For the purposes of this study, the authors assumed that a representative strike group consists of one nuclear-powered aircraft carrier, one nuclear-powered attack submarine, two guided missile cruisers, three guided missile destroyers, and one logistics support ship (i.e., T-AO or T-AOE), consistent with strike groups currently deployed.

The relevant assets of the representative CSG are two cruisers (CGs) and three destroyers (DDGs). Frigates are not often used as an integral part of strike groups anymore and find primary use in counter-drug and maritime interception operations (NAVSEA Team Ships 2010, under Description section). As such, they have extremely limited relevance to a 2016 GSG discussion. Aircraft carriers (CVNs) are nuclear powered and carry conventional fuel only in support of other platforms and equipment. Logistics support ships service cruisers and destroyers and so can be considered strike group support rather than part of the strike group itself.

FIST determined that non-liquid fuels are undesirable F-76 alternatives since the relatively large changes required to ships, fuel storage infrastructure, and fuel delivery equipment would likely be uneconomical and impossible to achieve within the 2016 time constraint.

E. RESEARCH QUESTIONS

The following research questions shaped the direction of FIST activities during the course of the project:

Research Question 1: What alternative fuel has the most potential to support the goal of deploying a Green Strike Group by 2016?

Research Question 2: What are the necessary criteria for evaluating an alternative fuel to meet the goal of deploying a Green Strike Group by 2016?

Research Question 3: What are the current ashore and afloat fuel distribution systems used to provide fuel for selected ship classes?

Research Question 4: What key modifications to existing ashore and afloat fuel distribution systems are necessary to facilitate the identified alternative fuel?

F. PROJECT DELIVERABLES

The primary goal of this project was to investigate the changes in the Navy's fueling infrastructure necessitated by the introduction of an alternative fuel. FIST applied a tailored systems engineering (SE) process (described in the next section) to answer the research questions proposed in the previous section within the scope specified. The major outputs of this effort were:

- Operational Concept Description (OCD) for relevant Navy fueling activities, methods, and equipment.
- Specification of the high-level requirements for a proposed alternative fuel shore-based and underway fueling system.
- Description of the infrastructure of an existing shore-based fossil fuel (e.g., F-76) storage and distribution system.
- Description of the existing fossil fuel delivery system for non-nuclear surface combatants (i.e., CG 47 and DDG 51 class ships) deployed and underway.
- An alternative fuel study report including an analysis of alternative fuels for surface combatants and selection of a recommended fuel.
- A mission profile used to guide requirements exploration for the GSG.
- Development and description of proposed changes to the shore-based alternative fuel storage and delivery infrastructure supporting the GSG.
- Development and description of proposed alternative fuel delivery infrastructure supporting the GSG.

G. SYSTEMS ENGINEERING PROCESS

FIST applied a tailored SE process to develop a proposed solution to this unique problem. After consideration of multiple approaches, the team decided that this unique problem would require a unique SE process using the following phases: 1) Alternative Fuel Study, 2) Architecture Requirements Definition and Analysis, 3) Functional Analysis and Allocation, and 4) Solution Analysis. This FIST SE process resembles the old Department of Defense (DoD) SE process (Defense Acquisition University 2001, 31) but adds the initial Alternative Fuel Study which feeds activities in subsequent phases. This tailored process is represented in Figure 1.

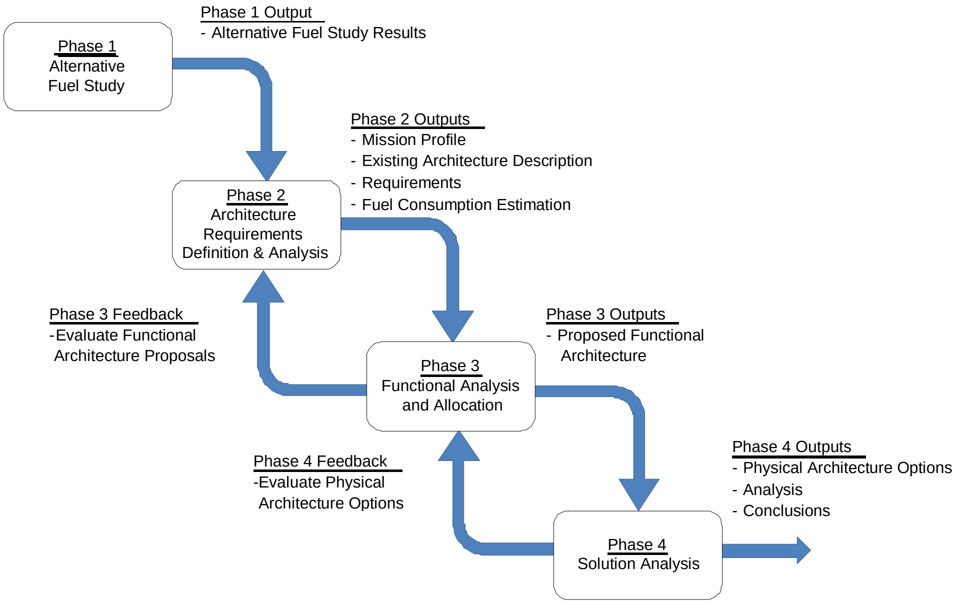

Figure 1. FIST Tailored SE Process

This figure illustrates the iterative systems engineering process adopted by FIST to enable investigation of the problem space and definition and analysis of solutions.

1. Alternative Fuel Study

During this first phase of the SE process, FIST identified relevant fuel criteria, performed a stakeholder needs assessment, and defined evaluation criteria for candidate alternative fuels. FIST compiled a set of candidate alternative fuels and then conducted a comparison and analysis. The fuel study and alternative fuel recommendation are covered in Chapter II of this report.

2. Architecture Requirements Definition and Analysis Phase

FIST captured and analyzed relevant documents and subject matter expert (SME) inputs for the ashore and afloat elements of the existing fueling infrastructure (referred to hereafter as "Existing Infrastructure"). Next, FIST identified areas that would require modification in the proposed alternative fueling infrastructure (referred to hereafter as "Proposed Infrastructure"). Additionally, FIST conducted a stakeholder needs assessment for fueling infrastructure. Finally, FIST identified assumptions and constraints, and developed a description for the existing architecture.

These activities facilitated requirements capture from Existing Infrastructure elements, and enabled requirements definition and analysis for Proposed Architecture elements. All classes of requirements (operational, functional, and non-functional) were considered. Outputs of this phase included functional and organizational description products, top-level requirements lists, and a strike group mission profile. The overall approach was to define top-level functions, refine those to lower-level functions, and where appropriate, allocate those functions to physical components.

A representative mission profile was identified, with which comparisons could be made between the existing and proposed infrastructures. The team defined its modeling and simulation (M&S) approach and developed a model for estimating fuel consumption.

3. Functional Analysis and Allocation

The team performed Existing Infrastructure functional decomposition and defined requirements for the Proposed Infrastructure during the Architecture and Requirements Definition and Analysis phase. Identifying the functional representation of the existing fuel infrastructure provided a basis to analyze the modifications necessary to support the recommended alternative fuel. In addition, the team identified and defined functional interfaces within the architectures. Since this process identified several missing and conflicting requirements, Functional Analysis and Allocation were performed iteratively with Requirements Definition. Consistent with this approach, these phases were not executed in a strictly sequential manner.

4. Solution Analysis

Using the definition of the Existing Infrastructure, FIST then defined the Proposed Infrastructure to incorporate the recommended fuel alternative from the fuel study and the captured requirements and constraints for the Proposed Infrastructure. Once the physical elements were defined, the team assessed Proposed Infrastructure options. FIST evaluated modifications to the Existing Infrastructure covering doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF) solutions that could achieve the Proposed Infrastructure needed to support the recommended alternative fuel.

II. FUEL STUDY

A. INTRODUCTION

As noted in the SE process in the opening chapter, the first phase of the project was to select an alternative fuel for the GSG to be used as an input into the Requirements Definition and Analysis phase. The selection of an alternative fuel was an important input because the authors postulated that differences between an alternative fuel and the current naval distillate fuel, F-76, would require changes to the existing fueling infrastructure.

While an Analysis of Alternatives would have been the ideal approach for selecting this fuel, it was beyond the scope of this project. Rather, a study of published literature was conducted to answer the following research question: *What fuel has the most potential to support the goal of deploying a Green Strike Group by 2016?*

Should the Navy decide to select a different alternative fuel than that which was selected for this project, the architecture and tools developed during this project could be tailored to assess the impacts of other alternative fuels.

To answer the research question above, it was necessary to understand which physical properties and other factors are important to the Navy in selecting an alternative fuel. Thus, the following additional research question was answered as a first step toward selecting an alternative fuel for this project: *What are the necessary criteria for evaluating an alternative fuel to meet the goal of deploying a Green Strike Group by 2016?*

B. U.S. NAVY GAS TURBINE ENGINES AND FUELS

The Navy first used General Electric’s LM2500 gas turbine for ship propulsion in 1969, onboard the cargo ship Adm. Callaghan (General Electric Marine Task Force 2006, 1). Over the subsequent forty years of Navy service, 175 vessels powered by LM2500 gas turbines have achieved and logged over 13 million hours of total service (Maritime Executive 2009, para. 4). Worldwide, LM2500’s have powered over 500 naval surface combatants, numerous commercial vessels, and over 1,000 shore-based power installations (General Electric Marine Task Force 2006, 1).

Reasons for the popularity of the LM2500 in a naval propulsion role include its simplicity as a simple-cycle gas turbine as well as its unique packaging concept, which facilities simple integration into ship systems as well as relative ease of replacement and overhaul. Specifically, the LM2500 gas generator, power turbine, shock mounts, vibration isolators, lubrication systems, and so forth all fit within an intermodal shipping container which is delivered for integration pre-wired and pre-plumbed (General Electric LM2500 2006, 1). The LM2500 is termed an ‘aeroderivative’ gas turbine, since its hot core is derived from aircraft engines – specifically the TF39 and CF6-6 high-bypass turbofans (General Electric LM2500 2006, 1). Together these turbofans have propelled aircraft such as the C-5A Galaxy, KC-10A Extender, Boeing 747, Boeing 767, and Airbus A300, accumulating over 325 million operating hours (General Electric CF6 2008, para. 1).

Gas turbine engines are inherently capable of flexible fuel operation. In power generation operations (for which the LM2500 is used extensively), the combustion flexibility of gas turbines permits use of fuels as diverse as heavy fuel oils, industrial process gasses, low heating value waste gasses, and biodiesel (Rahm, et al. 2009, 5). Operational experience suggests that the lower limit of fuel energy density compatible for LM2500 consumption is 15.12MJ/kg, which is approximately one-third that of the F-76 fuel used by the U.S. Navy to power its engines (Badeer 2000, 13); this places a lower bound on the energy density of candidate alternative fuels. The actual limitation appears to be reduction of compressor surge margin due to the relatively large mass flow required to achieve a given specific energy output (Palmer, Erbes and Pecthl 1993, 5). Given the ubiquitous use of the LM2500 in U.S. Naval service, as well as its inherent fuel flexibility, it is likely that any new naval fuels introduced into service would be a drop-in replacement for its existing fuel.

The Navy’s standard fuel for shipboard propulsion is called ‘Diesel Fuel Marine’ and identified by its North Atlantic Treaty Organization (NATO) supply symbol F-76. F-76 is similar to commercially available marine gas oil (MGO) fuel in many respects, but has some military-unique properties which are defined in its detail specification MIL-DTL-16884L (Naval Sea System Command 2006, 5). Since DoD must stockpile fuel for wartime reserve purposes, degradation in storage is unacceptable. To ensure storage stability, the F-76 specification requires that naval fuels be straight distillate, incorporate a specific additive for metal deactivation, and meet specific storage stability requirements. Another aspect of F-76 which differs from commercial fuels is that the specification requires that the fuel have a minimum flash point of 60^{o}C, which is required to ensure safety in storage and handling.

C. FUEL CRITERIA

The criteria for selecting a fuel can be divided into two categories: factors that are derived from Secretary Mabus’ energy goals and those that are critical physical properties.

Two criteria are derived from the energy goals. First, the alternative fuel must reduce dependence on foreign sources. This would improve the nation’s security posture, in accordance with Secretary Mabus’ goals. Second, the alternative fuel must be available through the Defense Energy Supply Center (DESC) by 2016. DESC is the procurement activity for all DoD fuels, and has the mission to “provide the Department of Defense and other government agencies with comprehensive energy solutions in the most effective and economical manner possible” (Defense Energy Support Center 2009, 3).

When one considers domestic availability through DESC, several issues must be addressed to meet the 2016 timeline. In a telephone interview held on July 26, 2010 the Navy Fuels Lead on the Tri-Service Fuels IPT, Mr. Richard Kamin, asserted that meeting the Navy’s goal of satisfying 50% of its energy needs through alternative fuels by 2020 will require production of at least 8 million barrels of alternative fuel per year. However, in FY 2009, DESC contracts for alternative liquid gas turbine fuels totaled only 7,500 barrels (Defense Energy Support Center 2009, 77). For the GSG specifically, it will be shown later in this report that its propulsion needs will require on the order of 620,000 barrels of fuel. This quantity represents a significant departure from the status quo for alternative fuel supply, which Mr. Kamin characterized as “pilot production only.” From an availability perspective, the challenge is to increase current availability by two orders of magnitude to support the 2016 GSG deployment, and by three orders of magnitude to meet the Navy’s 2020 goals.

Safety is a consistent theme in the necessary fuel properties. A fuel’s flash point (the temperature at which vapors will ignite when an ignition source is present) is of major concern to the Navy (Sermarini 2000, 19).

To facilitate the evaluation of alternative fuels for other safety factors besides flash point, the National Fire Protection Association’s (NFPA) standard risk codes were adopted to compare health, flammability and instability of the alternative fuels. Specifically, NFPA 704 *Standard System for the Identification of the Hazards of Materials for Emergency Response*, defines the internationally recognized NFPA fire diamond, an example of which is shown in Figure 2 (National Fire Protection Association 2007, 11).

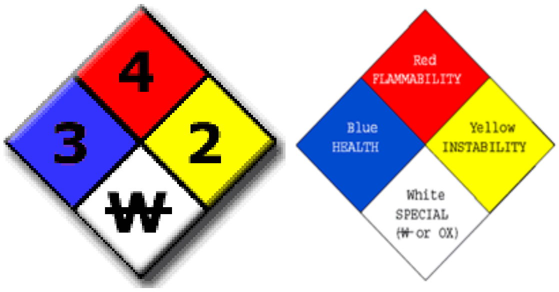

Figure 2. NFPA Fire Diamond.

The NFPA Fire Diamond is a widely adopted format from which to quickly identify the hazard to exposure to a material and appropriate fire-fighting responses. From (National Fire Protection Association 2010, under How is the Rating Displayed section).

The NFPA fire diamond is used by fire protection and hazardous materials first responders to gauge the hazards inherent in a spill or other incident, and NFPA risk codes are generally defined on a fuel's Material Safety Data Sheet. The fire diamond is broken into four categories: health hazards (blue), flammability (red), instability (yellow), and special fire-fighting instructions (white). The colored sections contain a number, from zero to four, denoting the specific level of hazard from harmless (zero) through high risk (four) (National Fire Protection Association 2007, 9-13). For example, the fire diamond for F-76 fuel has NFPA health and instability risks of zero, a flammability rating of 2, and no special fire fighting measures defined (Citgo Petroleum 2007, 1). If an alternative fuel has increased levels of risk in any area, use of such fuel may require changes in infrastructure, handling, and training, or perhaps even affect mission capability and platform survivability.

Another property unique to the Navy is storage stability. Due to the Navy's large strategic petroleum reserve, a fuel may be stored for 1 to 3 years (Willauer, et al. 2008, 5). There is evidence that indicates some alternative fuels cannot be stored for this length of time, therefore storage stability was selected as a criteria. As an example, available data indicates that the "B20 in vehicles or storage tanks should be used within six months of manufacture" (U.S. Army Tank-automotive and Armaments Command 2004, 5). B20 is a blend of 20% biodiesel with 80% diesel.

Since fuel tanks onboard ships have limited capacity, energy density can be a critical attribute because use of a low energy density fuel will limit operational range without refueling. Furthermore, use of low energy density fuels results in higher mass flow through turbines, which can compromise compressor surge limits (Palmer, Erbes and Pechtl 1993, 2). Alternative fuels typically have a lower energy density than the fossil fuels that they substitute (DeWilde and Londo 2009, 19), as indicated in Figure 3.

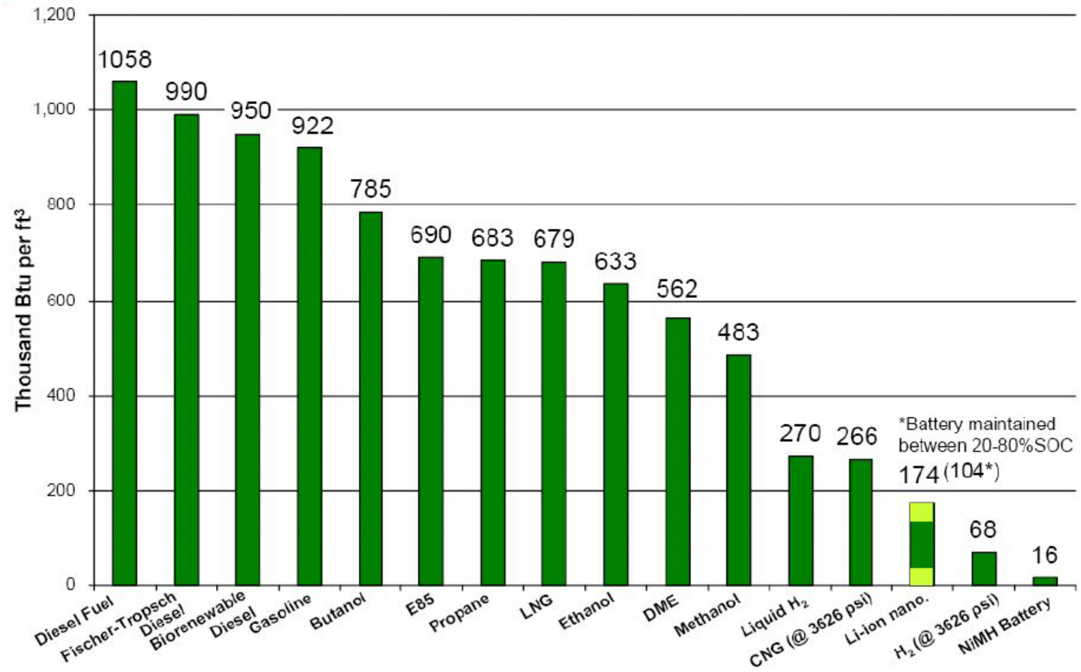

Figure 3. Energy Density of Alternative and Fossil Fuels

Typical alternative fuels have less energy density than diesel fuel. From (DeWilde and Londo 2009, 19).

While the project focused on fueling infrastructure, the compatibility of alternative fuel with the LM2500 gas turbine was also a necessary consideration. Selecting a fuel to evaluate infrastructure changes that would have severe implications to the ship's engines would not support the goal of the project.

The factors that are important to the engine performance are also important to the infrastructure, namely, viscosity, corrosiveness, and lubricity. These attributes are noted in the Navy's F-76 specification (Naval Sea Systems Command 2006, 5) and are governed by standards issued by the American Society of Testing and Materials (ASTM), which can serve as a convenient comparison method.

Since naval vessels generally use seawater compensation in fuel tanks – a process in which seawater is used to replace fuel as it is consumed, ensuring proper trim – it follows that any naval fuel must not be miscible in water. Therefore solubility in water is a significant concern and was also selected as an evaluation criterion.

Finally, fuel density was considered. While perhaps not as critical as the other factors, density could impact ship ballasting procedures or other aspects of the infrastructure.

A list of the alternative fuel selection criteria is summarized in Table 1. An explanation of how these criteria were used to evaluate the alternative fuels is provided after the following description of the alternative fuels.

Table 1. Alternative Fuel Evaluation Criteria

This table lists the criteria for selecting an alternative fuel as well as how to determine how each fuel can be evaluated for each criteria.

Criterion	**Comparison Factor**
Reduce Dependence on Foreign Sources	Domestic Availability
Available through DESC by 2016	Production Maturity
Flash Point	Greater than 60°C
Overall Safety	NFPA Safety Codes
Storage Stability	Time or ASTM D5304 if available
Energy Density	Mega Joules per Liter
Compatibility with Shipboard Equipment	Compatibility with LM2500 Engines
Viscosity	mm^2/second; ASTM D445 if appropriate
Corrosiveness	ASTM D130
Lubricity	Compared to F-76; Multiple ASTM Tests
Solubility in Water	Water-in-Water Emulsion (percentage)
Density	Expressed in kg / m^3

D. ALTERNATIVE FUELS

After research and consideration of many potential alternative fuels, 10 were considered for further review; the first three due to their wide commercial availability:

1. Ethyl alcohol (ethanol) – Ethanol is a widely used fuel that has been produced biologically and purified for human consumption for millennia. Ethanol has a very low energy density (24 MJ/L), extremely low flash point (13° C), and is highly miscible in water (Iowa State University (Ethanol) 2001).

2. Methyl alcohol (methanol) – Methanol is a popular alternative fuel used extensively in mixtures with gasoline for ground transportation. Methanol has an even lower energy density (16 MJ/L) and flash point (11° C) than ethanol (Iowa State University (Methanol) 2001). In addition, methanol has additional drawbacks: high biological toxicity, and characteristic of burning with a colorless flame, making fire suppression efforts difficult (Iowa State University (Methanol) 2001).

3. Liquefied Natural Gas (LNG) – Natural gas, delivered in gaseous form, is a widely used heating fuel. However, in order to achieve reasonable energy density for use as a ship fuel, natural gas must be liquefied. In this form it has an energy density equal to ethanol (24 MJ/L), but exhibits an extraordinarily low flash point of -188° C at atmospheric pressure. (Conoco Phillips 2009). While the flash point increases when gas is stored under pressure, storage of pressurized flammable gasses onboard surface combatants can introduce catastrophic failure mechanisms when the vessel sustains damage in combat.

Two versions of biodiesel were researched as well:

4. Biodiesel, 100% (B100) – The specification of B100 is governed by ASTM D6751-09 (National Biodiesel Board 2008). B100 can be derived from a number of different feed stocks such as vegetable oil and animal fats, which impart varying chemical properties. Pure biodiesel, however, has limited storage stability (Willauer, et al. 2008, 5), limiting its utility in naval applications.

5. Biodiesel, 20% (B20) – B20 is a blend of 20% biodiesel with 80% diesel fuel, and is currently available for purchase through the DESC (Defense Energy Support Center 2009, 87). Since the majority of this fuel is diesel – which typically is not manufactured from domestic crude – B20 cannot achieve Secretary Mabus’ energy independence goals.

Three of the fuels considered were manufactured by the Fischer-Tropsch (FT) process. The original FT process was developed in the 1920's by German researchers Franz Fischer and Hans Tropsch at the Kaiser Wilhelm Institute with the purpose of producing liquid fuel from coal. Both Germany and Japan used the FT process during World War II to produce fuel from coal to mitigate the effects of Allied strikes on oil shipments and infrastructure. In the postwar years, advances have been made to the FT process – particularly in South Africa where international sanctions restricting oil shipments during the Apartheid era encouraged development of a South African FT industry. The FT process can be used to convert any hydrocarbon fuel stock such as natural gas or coal to liquid fuel. Recently, conversion of biomass to liquid fuel has also been accomplished (Bowen and Irwin 2006, 10).

In the FT process, described schematically in Figure 4, the feedstock is gasified to produce a synthetic gas, which is a mixture of carbon monoxide and hydrogen. This gas is generally referred to as "syn-gas." The syn-gas then goes through a FT conversion, which upgrades it into a waxy long-chain hydrocarbon (Benedetto 2007, 81-82). The next step in the process is to produce the final liquid form, in this case, gas turbine fuel.

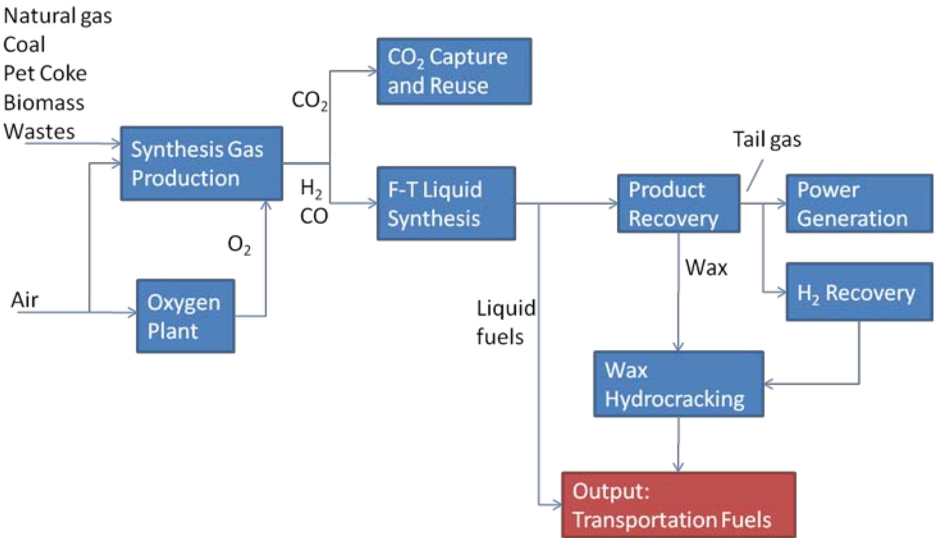

Figure 4. Fischer-Tropsch Process

The Fischer-Tropsch process converts hydrocarbons into liquid fuels. After (Harrison 2009, 10).

The three FT process fuels that were considered are:

6. FT S-8 – A synthetic version of the JP-8 jet fuel qualified for use by the Air Force in a 50/50 blend for the B-52 and C-17 aircraft (Harrison 2009, 12). Since the B-52 engines are GE CF6-6, with an identical hot core to the Navy's LM2500 gas turbine engine systems, FIST concluded that this test is promising from a perspective of using alkane rich FT-derived fuels in naval engines.

7. FT S-5 – A synthetic version of the surface Navy's JP-5 jet fuel which has been domestically produced by Syntroleum Corporation (Lamprecht 2007, 1449). One interesting opportunity which may accrue should FT S-5 prove adequate for ship propulsion use is the fact that JP-5 is used in the Navy's aircraft. Should the infrastructure support FT S-5, the Navy can streamline many of its systems by using a common fuel for all naval uses.

8. FT F-76 – In the Autumn of 2009, DESC awarded a contract for up to 20,000 gallons of an FT F-76 derived from natural gas for engine testing (Iden 2010, 6).

Two additional fuels were selected because they were also initiatives of DESC with recent contract awards (Iden 2010, 7).

9. Algae-Derived F-76 – Up to 20,055 gallons to support Navy certification efforts (Iden 2010, 7). However, it is important to note that the contract specified the first delivery as a quantity of only five gallons which may be indicative of the maturity of this product.

10. Hydro-Treated Renewable Jet Fuel, HRJ5 – 1,500 gallons of an algae-derived fuel and 190,000 gallons of a camelina derived fuel to support Navy certification efforts (Iden 2010, 7).

During a telephone interview on July 26, 2010, Mr. Benet Curtis, of the Air Force Petroleum Agency, stated that the Hydro-Treated Renewable Jet (HRJ) process results in a similar crude product as the FT process. In HRJ, a biomass feedstock is used to produce an alkane wax similar to that produced during FT product recovery, and conventional refining can then be used to generate any cut of distillate, from diesel-like fuels through light kerosene. According to Mr. Curtis, the advantage of HRJ is its greenhouse gas emissions: if a fuel is produced using a fossil fuel feedstock such as coal and the FT process, all of the carbon atoms sequestered in the fossil fuels are ultimately released to the environment. For HRJ, however, all of the carbon atoms in the finished product are from plant or animal origin, and HRJ is therefore referred to as a "carbon neutral" fuel. According to Mr. Curtis, Congress has directed the United States Air Force (USAF) to concentrate on HRJ technology to reduce the carbon footprint of synthetic fuel production. During a July 25, 2010 telephone interview with Mr. Jeff Bigger, Chief Technical Officer of Syntroleum Corporation, Mr. Bigger stated that there is only one domestic pilot production plant for HRJ – the Dynamic Fuels LLC facility, which achieved an initial operational capability in 2010 with a capacity of 5,000 barrels per day.

One significant disadvantage to both FT and HRJ fuels is a materials compatibility issue. In gas turbine fuel systems, elastomers such as neoprene are used to seal fittings. According to Mr. Richard Kamin, the aromatic molecules of conventional petroleum products are absorbed into materials such as neoprene, causing them to swell up and seal leaks. Since both the FT and HRJ processes produce pure alkanes (straight chain hydrocarbons), pure FT or HRJ products completely lack the aromatic content needed to achieve adequate seal swell. Mr. Curtis of the Air Force Petroleum Agency asserts that in current USAF and Navy programs this compatibility issue is mitigated by blending fuels in a 50/50 ratio with petroleum-based fuel, which guarantees an adequate concentration of aromatic hydrocarbons. According to Mr. Curtis, the USAF Petroleum Agency is sponsoring research to determine the absolute minimum concentration of aromatics required for seal swelling; at present the best estimate is 8%. According to Mr. Bigger of Syntroleum Corporation, synthetic aromatic hydrocarbon additives can be manufactured, but their use will depend on whether their manufacture can be achieved economically.

The data for these ten fuels were compiled to support the fuel selection along with the Navy's current F-76 diesel fuel for comparison purposes.

E. FUEL SELECTION

The process of selecting a fuel began after reviewing the attributes of the ten fuels against the established criteria. First, fuels were discarded that did not meet a minimum standard of a criterion. Thus, ethanol, methanol, S-8 synthetic jet fuel, and LNG were eliminated because they did not meet the surface Navy's long established minimum flash point of 60° C.

Additionally, LNG presents some significant challenges for shipboard use. LNG must be stored at cryogenic temperatures as well as under pressure. LNG has an extremely high flammability risk with both a low flash point and also a wide flammability range (Conoco Phillips 2009, 4). Since existing fuel systems do not use cryogenic, pressurized storage, use of LNG would require reengineering of a significant portion of a ship. In addition, the high flammability risk of LNG is not conducive to survival under battle conditions or collisions at sea.

B20 was eliminated because it is 80% fossil fuel-based diesel and therefore does not meet the intent of Secretary Mabus' goal to reduce dependence on foreign oil.

B100 was eliminated because of the documented concern over storage stability (National Renewable Energy Laboratory 2009, 10).

With the above fuels eliminated, the next step was to compare the maturity of the remaining fuels to determine which fuel has the most potential for availability for the Green Strike Group in 2016.

Two of the four remaining fuels, algae-based F-76 and HRJ5, are still relatively immature in that their production processes have not yet been demonstrated on a commercial scale. Insufficient data are available to determine whether these will be available in sufficient quantities or qualified in time to power the Green Strike Group.

The final two fuels, FT F-76 and FT S-5, both use a relatively mature FT process. Of these two FT fuel types, the FT S-5 jet fuel represents the best opportunity for an economically viable fuel for the GSG due to efforts underway by the USAF and commercial aviation for commercialization of FT jet fuels. It is expected that maturity and economic viability in the jet fuels sector should provide the production capacity needed to produce FT S-5 in bulk quantities. Recent studies indicate that a production potential of 75,000 barrels per day of an FT jet fuel could be produced domestically (Hileman, et al. 2009, 41). As noted later in this report, a notional GSG deployment would require approximately two percent of this annual domestic production to complete its missions.

F. SELECTED FUEL

Based on criteria important to the Navy and the literature review of the alternative fuels, the FT S-5 fuel was determined to have the most potential to support the goal of sailing the GSG by 2016.

G. ENVIRONMENTAL CONSEQUENCES OF SELECTED FUEL

During a telephone interview on July 26, 2010, Mr. Benet Curtis, Chief of the Science and Technology Division of the Air Force Petroleum Agency, asserted that the most likely means of fully achieving the 2016 GSG requirements for both achieving energy independence and reducing environmental impact would be through use of HRJ or a combined coal-to-liquid (CTL) and biomass-to-liquid (BTL) input to a FT synthesis process. From an environmental perspective, use of coal feedstock combined with carbon capture and sequestration during FT production would result in life cycle greenhouse gas (GHG) emissions comparable to conventional jet fuel (Hileman, et al. 2009, 8).

However, in order for a FT fuel to reduce life cycle GHG emissions and accurately be labeled “green,” it would need to be produced from biomass or from a combination of coal and biomass with carbon capture and sequestration (Hileman, et al. 2009, 43). However, as noted above, the BTL and combination coal/biomass to liquid

(CBTL) production processes are not projected to be at the scale required to meet the fuel demand of the strike group in 2016 and carry significant cost increase compared to fossil fuels. For example, it is projected that a CBTL process with only 15% biomass is projected to have a 15-35% increase in fuel cost in 2017 compared to conventional jet fuel (Hileman, et al. 2009, 11).

Further, fundamental uncertainty exists in predicting the economic production potential of a 100% BTL FT fuel in the 2016 time frame. In a recent report, the cost of 100% BTL FT fuel at a 5,000 barrel per day production rate is estimated to be 300% higher than conventional gas turbine fuel, and the authors question whether this production rate would be achieved by 2017 (Hileman, et al. 2009, 46). According to Mr. Jeff Bigger of Syntroleum, however, the new Dynamic Fuels LLC facility achieving IOC in the fall of 2010 has a projected capacity of 5,000 barrels per day using animal waste fats to drive the FT process; a more realistic estimate of the actual costs of BTL FT should be available in the near future.

In short, to meet the 2016 goal, the Navy must rely on the CTL FT process and phase in BTL FT as it becomes available and affordable. Environmental benefits of this approach are minimal in the near-term, but become increasingly significant as the BTL processes mature.

H. DIFFERENCES BETWEEN EXISTING AND SELECTED FUEL

Key differences in the physical properties between FT S-5 and the existing F-76 diesel fuel are noted in Table 2.

Table 2. Key Differences Between FT S-5 and F-76

This table lists several key differences between traditional F-76 fuel and the selected alternative, FT S-5 fuel.(Naval Sea Systems Command 2006, 5; Willauer, et al.2008, 5; Frame and Alvarez 2003, 2; Syntroleum 2004, 1).

Criterion	FT S-5	F-76
NFPA Health Hazard	1 (irritant, minor injury if untreated)	0
Storage Stability	Unknown, Low Risk	Up to 3 Years
Energy Density (MJ/L)	33.0	38.6
Viscosity (mm^2/s)	1.2 – 1.8 @ 40°C 6.2 @ -20°C	1.7 - 4.3 @ 40°C
Lubricity	Poor as Neat Fuel Satisfactory with Additive	n/a
Density (kg/m^3 @ 15°C)	765	876

Materials compatibility can be an issue with neat FT S-5. Since the FT process produces pure alkanes, there is no aromatic content in FT fuels. Per telephone interviews with Mr. Jeff Bigger of Syntroleum, and Mr. Benet Curtis of the Air Force Petroleum Agency, aromatic hydrocarbons are useful in fuel systems because they cause swelling in nitrile and similar seal materials – permitting the seals to achieve a tight fit. Both experts consulted agree that FT S-5 must be mixed with some aromatic additives to ensure materials compatibility, and doing so is achievable at relatively minimal risk.

The lubricity of FT S-5 is considered poor as a pure fuel, but may be enhanced through use of standard lubricity enhancing additives. Preliminary research has demonstrated that additives allow for adequate performance in rotary pumps, but the resulting lubricity is still considered "low" when tested against ASTM standards (Frame and Alvarez 2003, 4). Further research in this area may be warranted to assess the operational suitability of FT S-5 using existing additives, or develop requirements for additional additives.

Per the July 25, 2010 telephone interview with Mr. Jeff Bigger of Syntroleum, FT S-5 is essentially a 'drop-in' replacement for petroleum-derived JP-5 jet fuel. The LM2500 gas turbines used for naval propulsion can burn JP-5 without modification. In fact, the Naval Supply Service authorizes use of JP-5 when F-76 is unavailable (U.S.

Navy Petroleum Office 1999, 1). Therefore it is expected that LM2500’s should be compatible with FT S-5 without modification to their control or fuel systems.

Per its Materials Safety Data Sheets, FT S-5 has a slightly increased health risk relative to F-76; exposure could cause irritation but only minor residual injury even if no treatment is given (National Fire Protection Association 2007, 9-13). The research provided no indication that the FT S-5 could not be stored for the same duration as F-76, but variability in storage time will be considered during the infrastructure evaluation since this is not confirmed with FT S-5.

As with all alternative fuels, the energy density of FT S-5 is lower than the existing F-76. This implies reduced vessel range for a given fuel volume, and also the need to transport relatively larger volumes of fuel to support a given operation. Both of these implications may have significant operational implications, and are addressed later in this report.

In short, transitioning from F-76 to FT S-5 poses the following potential challenges for the existing fuel infrastructure: slightly increased occupational safety risks, potential storage time differences, possibly reduced lubricity, and decreased energy density.

III. EXISTING FUELING INFRASTRUCTURE

A. INTRODUCTION

The Navy has established a multifaceted supply system in order to support fleet operations. The goal of the supply infrastructure is to deliver needed resources from the Navy's supply system to the war fighter. For example, this infrastructure allows the Navy to re-supply and refuel ships in port or at sea. Ships are supplied in-port via stores loads and standard fueling procedures. At sea, underway replenishment (UNREP) is the primary method of transferring fuel, ammunition, and other supplies from one ship to another. The goal of the resupply, specifically UNREP, is to safely transfer a required amount of material to a receiving ship in a minimum amount of time. In addition, the UNREP should not interfere with the primary mission of the war fighter (Naval Doctrine Command 2001, 1-1).

Understanding the fueling part of the existing supply infrastructure will aid in understanding the "pieces and parts" available to leverage for a proposed alternative fuel infrastructure supporting the GSG. Also, an examination of the existing infrastructure will enable determination of the changes necessary to implement an alternative fuel and deploy the GSG. This chapter discusses the "as-is" system of providing fuel to a deployed CSG. It reviews the organizations that support the refueling of CG 47 and DDG 51 class ships in-port and at-sea. Additionally, the top-level functions and equipment required to conduct naval fuel management are surveyed.

A high-level operational concept, shown in Figure 5, was developed to help describe the fueling infrastructure under investigation. Bulk fuel is transported from the commercial refinery to the fuel facility storage tanks. From there is it transferred to pier-side refueling terminals where the CG 47 and DDG 51 class ships, as well as fuel supply tankers, are replenished. The fuel supply tankers transport fuel to fuel storage and refueling facilities outside the continental United States (OCONUS). Fuel is transferred at sea to deployed ships from the tankers through UNREP. It should be noted that external systems that are part of contractor delivery to a Navy site or free market energy infrastructure are out of scope for this study.

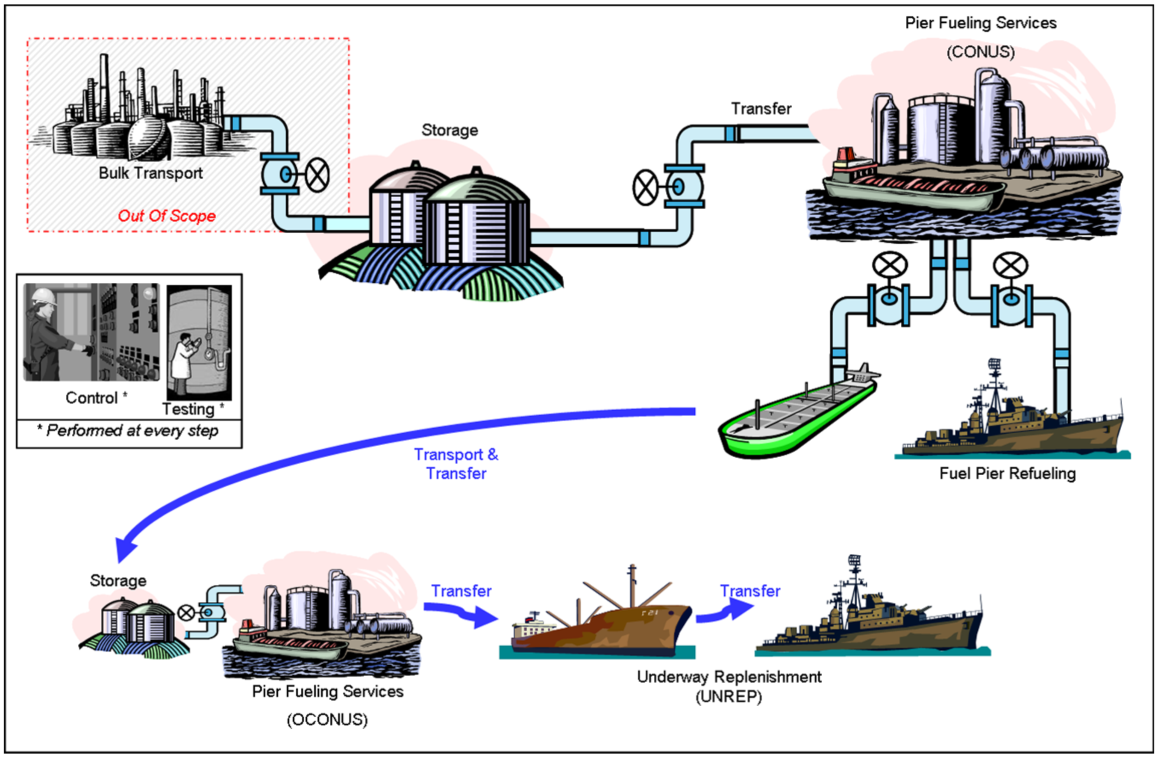

Figure 5. Existing Navy Fueling Infrastructure High-level Operational Concept

This figure represents a view of the existing Navy fueling infrastructure which includes production, storage, transport, and delivery by various means.

B. ORGANIZATIONS

A key to understanding refueling operations is appreciating the roles of, and relationships between, the various agencies and organizations involved in the procurement, transport, storage, quality assurance, delivery and documentation of bulk fuels for the Navy.

1. Ashore Organizations

The organizational relationship diagram shown in Figure 6 depicts the organizational components of the ashore fuel activities. This includes the chain of command and operational control (OPCON) relationships of the agencies.

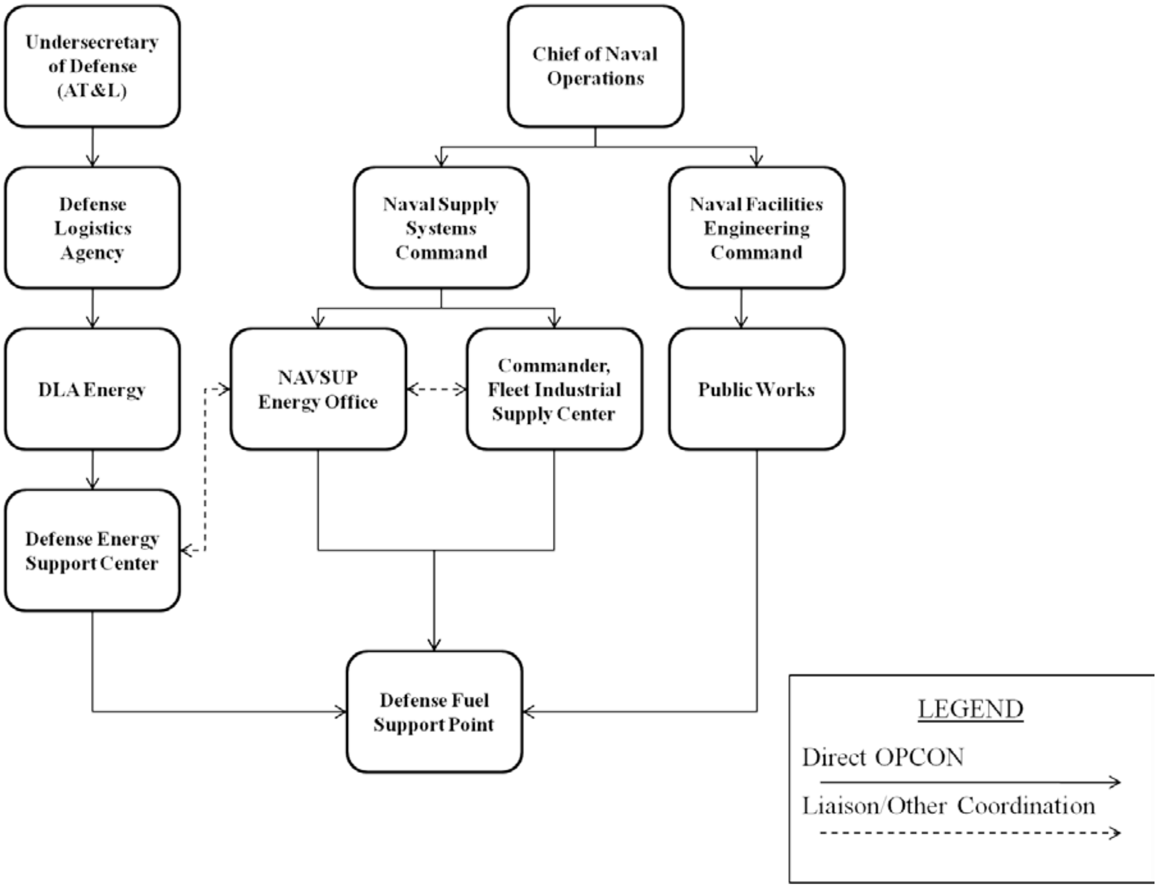

Figure 6. Organizational Relationship for Petroleum, Oils, and Lubricants (POL) / Fuel Logistics

This figure shows the relationship between the major Navy stakeholders involved in procuring, providing, assessing, specifying, and supporting the infrastructure for petroleum, oil, and lubricants (POL).

Defense Logistics Agency and Defense Energy Support Center – All bulk fuels for the DoD are purchased by DESC, a branch of the Defense Logistics Agency (DLA). In 2004, the Secretary of Defense designated the DLA as the Executive Agent for bulk petroleum. DESC is the DoD Integrated Material Manager and DoD Executive Agent for bulk petroleum products purchased through the Defense Working Capital Fund (Defense Energy Support Center DESC-P-2 2010, 1).

DESC has operation centers located worldwide. As of September, 2009, DESC operated 625 Defense Fuel Support Points (DFSP), 135 of which support the Navy.

DFSPs support the receipt, storage, and distribution of fuel for military forces in their assigned area. Most DFSPs are owned by the U.S. Government, but may be operated by either government or contractor personnel. Among the Navy-support DFSPs, 42 are Government Owned, Government Operated (GOGO); 32 are Government Owned, Contractor Operated (GOCO); and 61 are floating storage facilities. Floating storage facilities are contractor owned and operated with only the cargo being government owned (Department of Defense 2004, 9-1 – 9-6). These DFSPs provide a robust network of Navy refueling points which are strategically placed to support missions world-wide (Defense Energy Support Center Fact Book 2010, 26).

One example is the DFSP in Djibouti. DFSP Djibouti opened in 2006 at the Port of Doraleh. The Navy leased several fuel storage tanks from DFSP Djibouti for exclusive use by ships supporting maritime security operations (Thompson 2006, 1). The facility currently has two 400,000-barrel storage tanks dedicated to F-76 fuel storage. The DFSP operates a fuel jetty with two fuel berths. Berth 1 measures 800 feet in length and can support tankers and fleet oilers. Berth 2 measures 492 feet in length and therefore, is not long enough to support tankers or oilers. DFSP Djibouti also has a state-of-the-art laboratory for fuel quality testing (Bell 2006, 14). Figure 7 shows the locations of the DFSP Djibouti and a similar facility at Souda Bay, Crete.

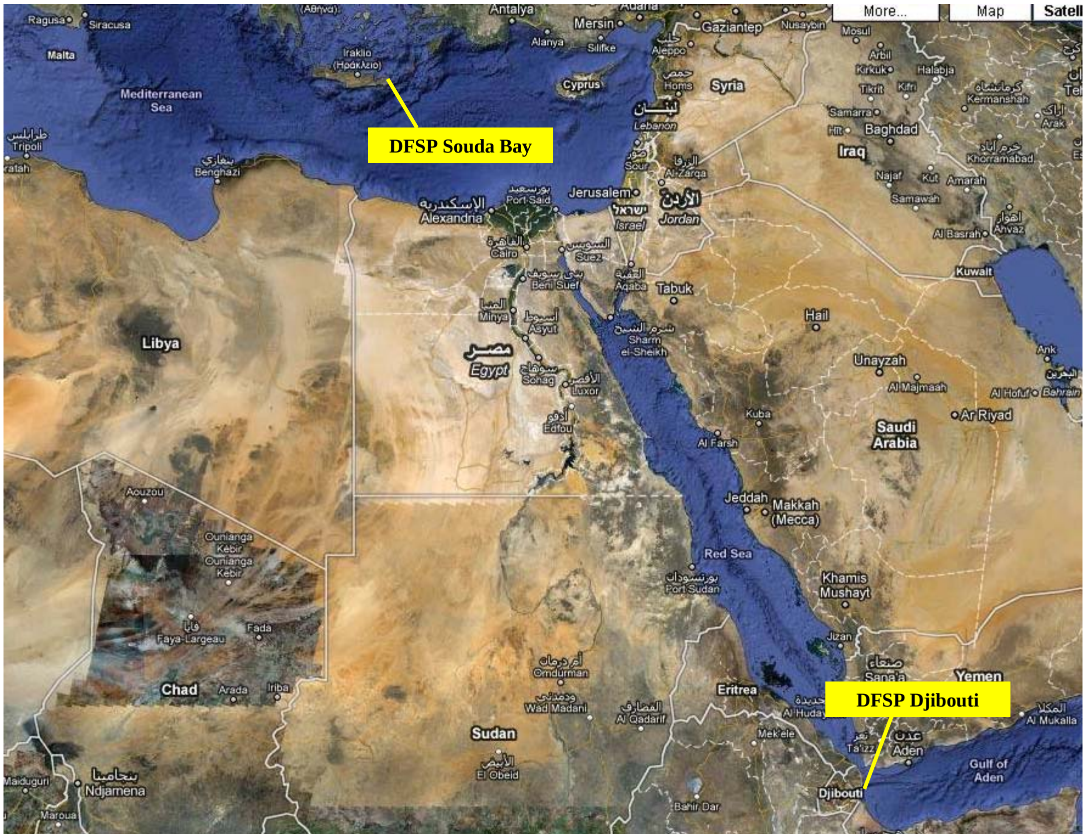

Figure 7. Satellite View of Souda Bay and Djibouti DFSP Facilities

This figure presents a satellite view of the Mediterranean and Red Seas showing the locations of the DFSP facilities at Souda Bay, Crete and Djibouti. After (Google Earth, Red Sea, 2010).

Naval Supply Systems Command – The Naval Supply Systems Command (NAVSUP) is the Navy's agent responsible for ashore marine and aviation fuel services. NAVSUP liaisons with DESC to receive, store, issue, maintain quality, and account for bulk liquid fuel and lubricating oils supplied to Navy ships. NAVSUP is also responsible for the planning, implementation, and performance of a facilities maintenance system. Additionally, NAVSUP performs quality assurance by offering testing services to include blending, sampling, and environmental testing (Naval Supply Systems Command Products and Services 2010, under Services, Bulk Petroleum, Oil, and Lubricants (POL) Support-Fuel Services). NAVSUP is divided into five components, with two components critical to fuel logistics and storage. They are the NAVSUP Energy Office and

Commander, Fleet Industrial Supply Centers (COMFISCS) (Naval Supply Systems Command Our Team 2010, under Supporting the Warfighter).

On Oct 10, 2010, NAVSUP consolidated fuel management task functions. COMFISCS now execute the consolidated management functions through the seven Fleet and Industrial Supply Centers (FISC), which are the theater leads for fuel logistics capabilities (Naval Supply Systems Command-News Releases 2010, under NAVSUP Consolidates Petroleum Management). The NAVSUP Energy Office's core competencies include:

- Serving as the Navy's Service Control Point for all POL
- Developing and promulgating Navy and USMC Petroleum Policy
- Ensuring petroleum quality standards for Naval Forces
- Serving as Navy and USMC advocate for POL facility construction, maintenance, sustainment and modernization
- Interfacing with other Services, Combatant Commanders and industry relating to POL issues
- Maintaining a liaison with DESC for POL
- Coordinating Naval Fuel Requirements (Naval Supply Systems Command-Our Team 2010, under NOLSC: Petroleum)

COMFISCS is NAVSUP's global provider of integrated supply and support services. COMFISCS operates seven FISCs worldwide. Among their many services, COMFSICS provide "stewardship, assistance and expertise to ensure that bulk petroleum distribution systems, operations, requirements and quality meet war fighter needs" (Commander, Fleet Industrial Supply Center (COMFISCS) 2008, 7). FISCs maintain and operate the deep water bulk fuel terminals providing regional fuel support for the Navy, joint and multinational forces. They also perform receipt, storage, issue, transfer and accounting of all bulk liquid fuel and lubricating oil. This includes all labor and equipment used to complete pier-side, truck rack, pipeline and reclamation operations (Commander, Fleet Industrial Supply Center (COMFSICS) 2008, 1-7).

An example of a FISC which supports fuel operations and logistics is FISC Norfolk. FISC Norfolk oversees five GOCO fuel terminals, including the largest DFSP in the United States at Craney Island in Portsmouth, Virginia. Craney Island Fueling

Depot is comprised of 27 storage tanks (18 tanks used for F-76 and 9 tanks for JP-5), 2087 feet of pier, and 7 fuel barges (Roddy Regional Fuel Operations 2009, 26-28).

Tankers, barges, and ships can be refueled at Craney Island's fuel pier. Government and commercial barges are used to transport fuel to and from Navy ships berthed at Sewell's Point, Norfolk Naval Shipyard, Little Creek Naval Amphibious Base, local private shipyards, Naval Air Station Patuxent River and other locations (Roddy Regional Fuel Operations, 26-28). An aerial view of the area covered by the barges is shown in Figure 8 with a detail of the Norfolk area shown in Figure 9.

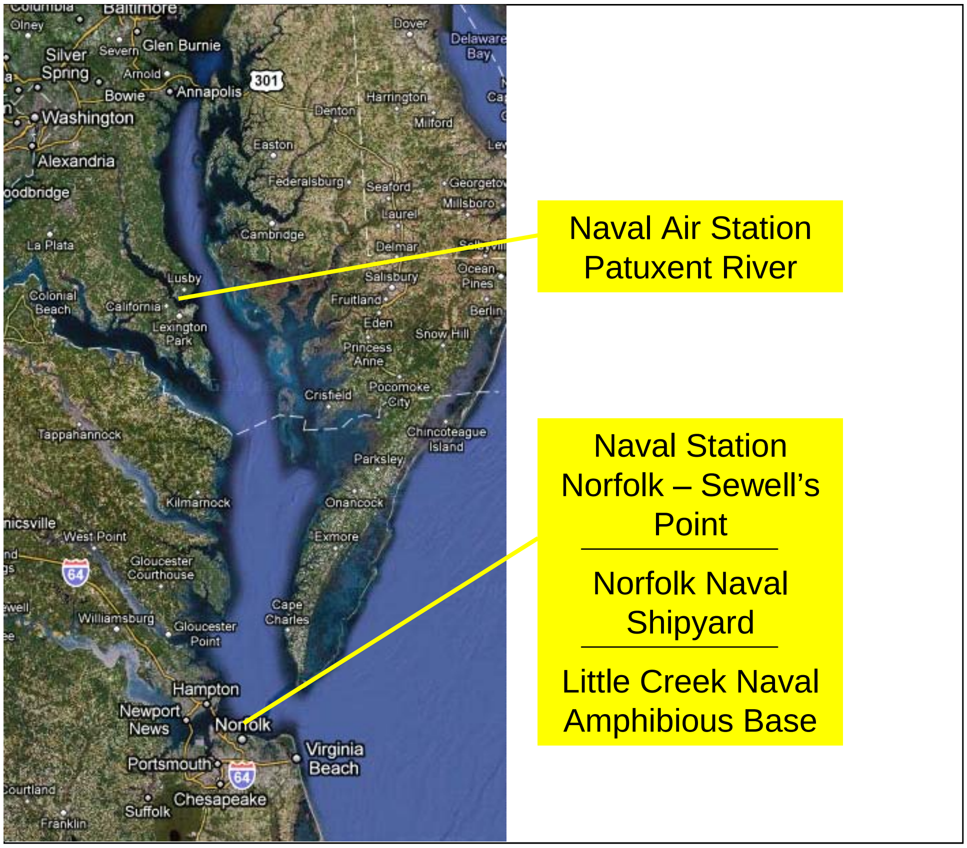

Figure 8. Satellite View of the Area Covered by Craney Island Fuel Barges

This figure presents a satellite view of the portion of the eastern coast of the United States serviced by fuel barges from DFSP Craney Island. After (Google Earth, Chesapeake Bay, Virginia, 2010).

Figure 9. Satellite View of Naval Facilities in the Norfolk, VA Area.

This figure presents a satellite view of the facilities in the Norfolk, VA area serviced by barges from DFSP Craney Island. After (Google Earth, Norfolk, Virginia, 2010).

Naval Facilities Engineering Command – The Naval Facilities Engineering Command (NAVFAC) provides facilities engineering and management, utilities engineering and acquisition, technical support for service contracts, and transportation equipment management. NAVFAC employees will be primarily responsible for the maintenance of all fuel storage facilities and associated equipment (Naval Facilities Engineering Command (NAVFAC) 2010, under Public Works Business Line).

2. Afloat Organizations

As with the ashore infrastructure, a knowledge of the various agencies, units and organizations involved in the transport, storage, quality assurance and delivery of fuels to a CSG is important to understanding the fueling process. FIST created an organizational relationship diagram, shown in Figure 10, to depict the organizations involved in fuel transfer afloat and associated activities along with their relationships. The organization shown is specific to a CSG operating in the Central Command (CENTCOM) area of responsibility (AOR), but would be similar for a CSG assigned to any numbered fleet.

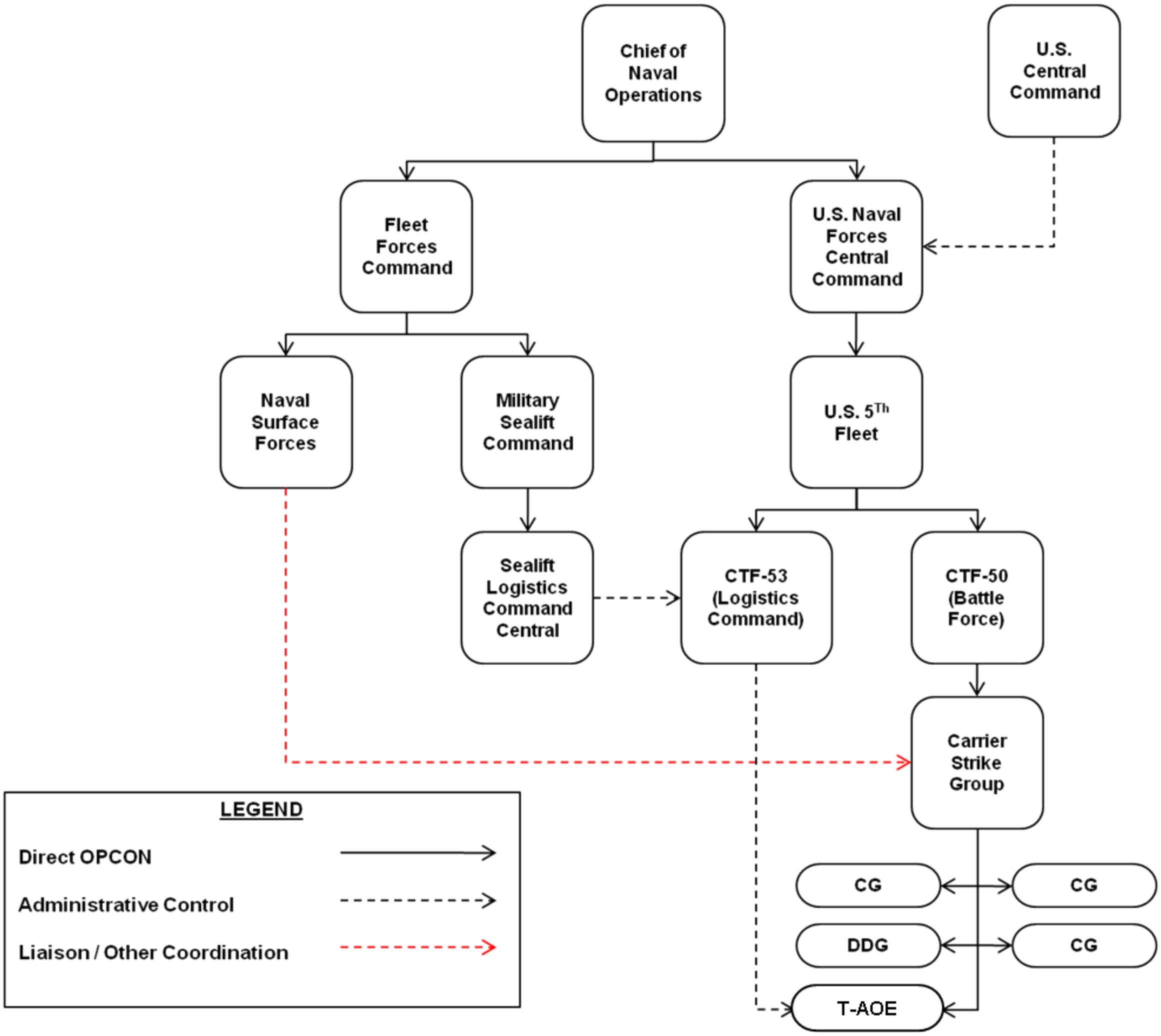

Figure 10. Organizational Relationships for Sea-Based Forces

An organizational diagram depicting the organizations involved in fuel transfer afloat and associated activities along with their relationships.

Numbered Navy Fleets – The Navy has six active numbered fleets: the 2nd, 3rd, 4th, 5th, 6th and 7th. The numbered fleets have operational and tactical control of the naval units in their AOR (U.S. 5th Fleet Missions 2010, under Area of Operations). The numbered fleet component tasked with providing logistics and supply coordination is Task Force X3, where X is the fleet number. (For example, Task Force 53 is a component of the 5th Fleet.) The numbered fleets and associated AORs are shown in Figure 11.

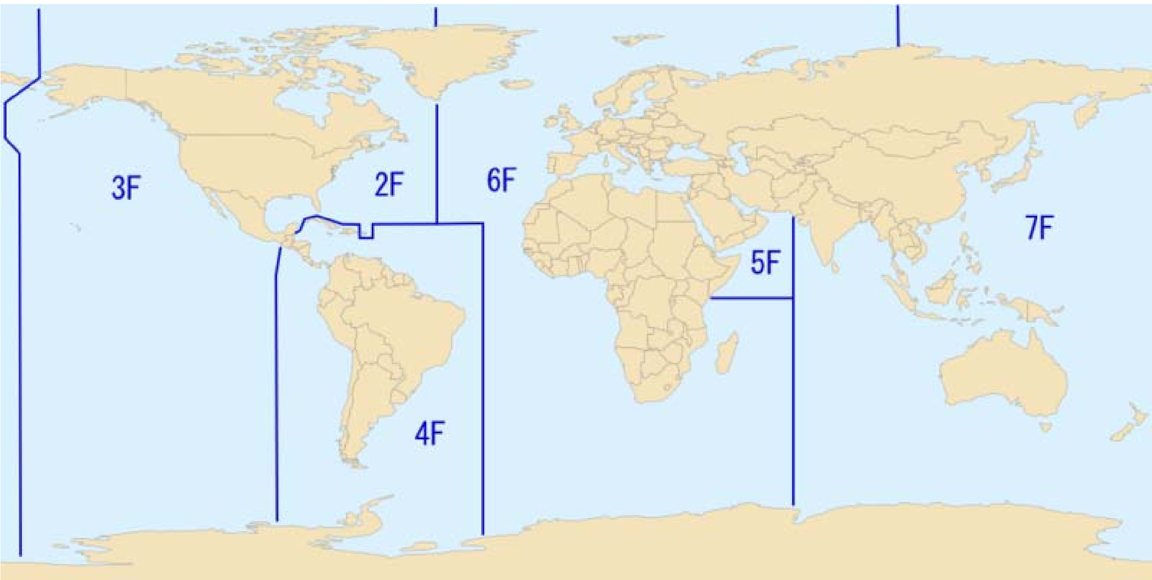

Figure 11. Navy Numbered Fleet AORs

World map detailing the areas of operations of the six active Navy numbered fleets. From (Wikimedia Commons, 2009, under File: Navy Fleets).

Commander, Task Force X3 (CTF X3) is the single focal point for operational logistics in support of naval forces operating within the AOR of their associated numbered fleet. CTF X3 receives all logistics inputs and requirements for the region. CTF X3 functions include requirement identification, confirmation of on-hand assets, transfer, shipment and receipt reports and policy guidance (Naval Doctrine Command 2001, 4-4 – 4-5).

Military Sealift Command – Military Sealift Command (MSC) provides ocean transportation of supplies for DoD and other federal agencies. According to their website, MSC operates a mix of government-owned and commercial, long-term-charter vessels. Approximately 90% of military supplies (including 95% of military fuel) are transported by the MSC. MSC transports fuel from refineries to DFSPs (Military Sealift Command Sealift Command 2010).

The two ship types primarily used to transport fuel from DFSPs to warships are Fast Combat Support Ships (T-AOE) and Fleet Replenishment Oilers (T-AO). The four T-AOEs of the MSC are designed to have the speed to keep up with a CSG. They can carry 177,000 barrels of fuel, as well as ammunition, dry goods and refrigerated goods. The T-AOE receives supplies from shuttle ships and redistributes them to CSG ships (Military Sealift Command T-AOE Factsheet 2010). The MSC operates fifteen T-AOs. Each T-AO carries between 159,000 and 180,000 barrels of fuel depending on the specific ship (Military Sealift Command T-AO Factsheet 2010).

Sealift Logistics Command - Sealift Logistics Command provides at-sea logistics and strategic sealift services to U.S. war fighters. Five Sealift Logistics Commands are operated by the MSC. The five commands support operations in the Atlantic, Pacific, European, Central Asian and Far East commands (Military Sealift Command Organization 2010). Sealift Logistics Commands operate closely with (and sometimes under the same commander as) CTF X3s (Military Sealift Command Sealift Logistics Command Central 2010).

Each of the organizations discussed above plays a key role in the activities that supply fuel to combat forces. Each of them performs numerous functions. The next step in the analysis process of existing infrastructure is to determine what specific functions are executed in the fuel management process.

C. FUNCTIONAL AND PHYSICAL DESCRIPTIONS

This section describes the existing Navy fueling functions as they pertain to F-76 marine diesel fuel. Understanding these existing functions is intended to facilitate the determination of potential modifications for a proposed Navy fueling infrastructure accommodating an appropriate alternative fuel. This section will discuss systems used for storage, transport, and delivery of fuels to CSG ships including UNREP and ship’s fuel transfer systems. The discussion will not include external systems that are part of contractor delivery to the site or free market energy infrastructure (e.g., delivery trucks, commodity transport pipelines, or other similar systems not owned and operated by the Navy).

As a starting point, FIST leveraged existing logistical activities identified in OPNAVINST 3500.38B Universal Navy Task List (UNTL) to ensure proper alignment with existing naval capabilities. Therefore, the UNTL was solely used as a guide to assist in identifying existing functions performed by the fueling infrastructure. The top-level UNTL activities for logistics and its subsets are shown in Table 3.

Table 3. UNTL Activities for Fuel Logistics

List of relevant tasks associated with the Navy's fueling and supply operations. Table created with information from (Department of the Navy 2008, 3-B-53, 3-B-65).

NTA 4	**Perform Logistics and Combat Service Support**
4.2	**Fuel**
4.2.1	Conduct Fuel Management
4.2.2	Move Bulk Fuel
4.6	**Supply the Force**
4.6.3	Provide Underway Replenishment (UNREP)
4.6.4	Provide in-port Replenishment

Based on these activities and those required to support them, FIST determined that there are five key functions involved in supplying fuel to ships underway. Those five functions are:

- Transport fuel
- Store fuel
- Transfer fuel
- Perform fuel quality tests
- Control fuel inventory and movements

Figure 12 shows that the processes of ensuring that fuel is available to ships in a CSG are broken down into ashore and afloat functions. The five functions apply to both at-sea and ashore fueling activities. However, there are significant differences in operational activities, processes and equipment involved for ashore activities verses afloat activities. For example, ashore replenishment done at pier-side includes containment barriers that afloat replenishment does not. Conversely, UNREP requires equipment specifically tailored for ship-to-ship transfer of fuel. Figure 13 and Figure 14 detail how the five functions are applied to the ashore and afloat activities, respectively.

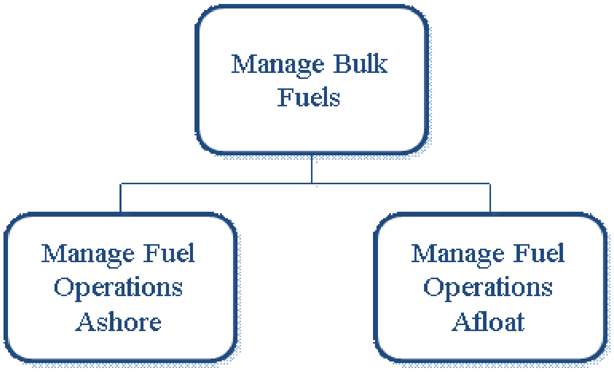

Figure 12. Existing Fueling Infrastructure Functions

Diagram showing a functional description of the top-level existing fueling infrastructure.

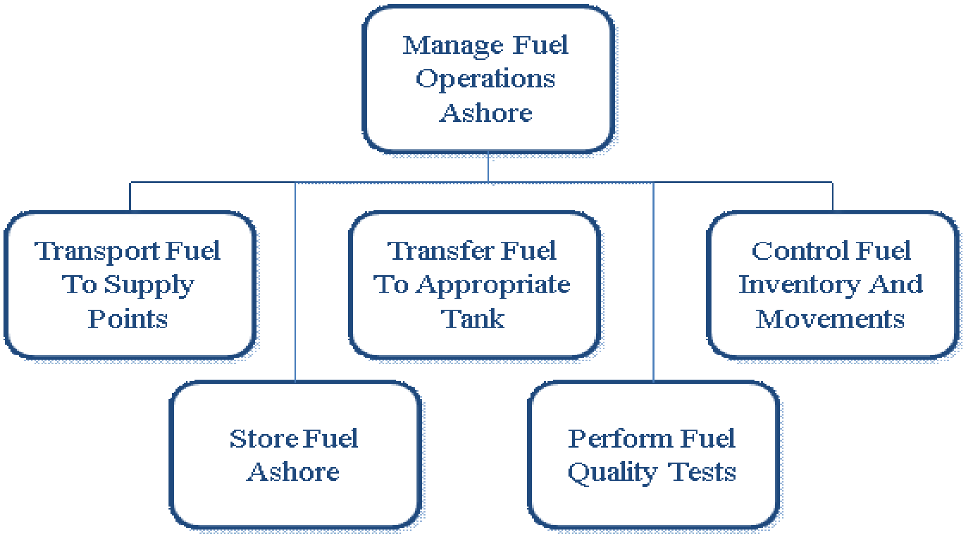

Figure 13. Ashore Infrastructure High-Level Functions

Diagram showing a functional description of the ashore existing fueling infrastructure.

1. Transport Fuel – Ashore

Transport of fuel ashore involves the movement fuels via tankers, hoses, pipes or bulk transporters from suppliers to bulk fuel storage facilities. Bulk fuel is purchased from refineries by the DLA through its DESC organization (Defense Energy Support Center Fact Book 2010, 1). NAVSUP coordinates with DESC to arrange for a shipment of fuel to be delivered to a fuel depot. Fuel is received by the depot and directed to the appropriate storage tanks (Navy Warfare Development Command 2002, 2-18 – 2-20). Due to shipping and logistics costs, fuel is normally purchased from a refinery located as close to the destination DFSP as possible. Therefore, OCONUS DFSPs are normally supplied by foreign refineries (Andrews 2009, 14).

2. Transfer Fuel – Ashore

The fuel transfer ashore function involves the movement of fuel from the initial bulk storage location to the appropriate storage tanks, barges, tankers or oilers in support of replenishment. Fuel shipments are coordinated to ensure required peacetime and pre-positioned wartime reserve levels are maintained at all facilities (Department of Defense 2004, 11-1 – 11-11).

3. Store Fuel - Ashore

The fuel storage function entails the stockpiling of petroleum in sufficient quantities to ensure mission success. Bulk fuel is stored in both above and below ground tanks. Storage tanks are required to be constructed of material that is compatible with the fuel product being stored. The agency controlling the storage facility is required to maintain a spill response plan. The plan must reflect every type of petroleum product stored at the facility (Environmental Protection Agency 2002, 32-44). The two DoD defined storage terms are short-term (less than six months) and long-term (more than six months). Each storage term has different testing requirements (Department of Defense 2008, 46).

Storage tanks are used for a single fuel product whenever possible. When tanks are changed from one product type to another, they are inspected, cleaned and then, once used, periodically re-inspected for excess sludge and rust (Department of Defense 2008, 47).

4. Perform Fuel Quality Tests – Ashore

Fuel quality is typically verified prior to acceptance by the government to determine if the fuel meets the product specifications. The government quality surveillance program begins upon receipt at the fuel depot to ensure the fuel maintains its quality and is suitable for use. Quality tests are performed by NAVSUP technicians according to the product being received. For instance, tests are performed on diesel fuel to verify density, flash point, viscosity, particulate levels, and storage stability (Department of Defense 2008, 96).

5. Control Fuel Inventory and Movements – Ashore

The control function involves monitoring, tracking and documenting the movement of petroleum products. The Material Inspection and Receiving Report (MIRR) also known as DD Form 250 or DD250 records quantity and quality of fuel received. The DD250 must be completed under the cognizance of a government Quality Assurance Representative (QAR) or military equivalent (Department of Defense 2008, 11-12). Along with the DD250, the government also maintains the bill of lading, transfer meter receipt and all shipping documents (Defense Energy Support Center DESC P-2 2010, 2).

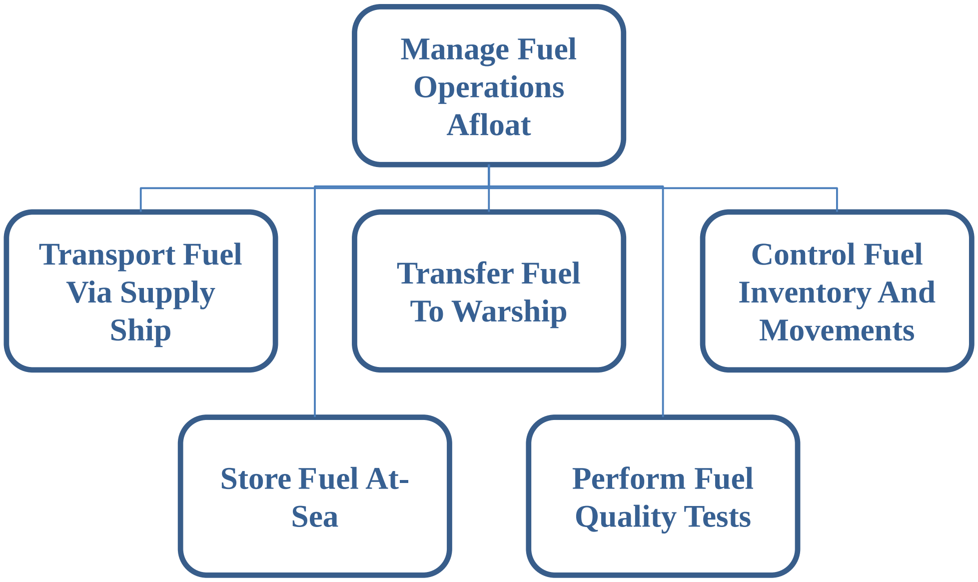

Figure 14. Afloat Infrastructure High Level Functions

Diagram showing functional description of the afloat existing fueling infrastructure.

6. Transport Fuel – Afloat

The transport fuel afloat function involves the movement of petroleum by support ships in support of the replenishment. In preparation for a fuel UNREP, fuel is transported from DFSPs to ships at sea by T-AOs or T-AOEs. Ships in a CSG can also be refueled from the CVN, but this operation is not in the scope of this study.

7. Store Fuel – Afloat

A primary purpose of the storage afloat function is to contain the fuel for future use while preserving its quality and integrity. For example, storage Tanks on T-AOs and CG/DDGs are typically constructed of either stainless or carbon steel to limit tank corrosion from affecting fuel condition. The function also entails keeping the fuel at the best possible condition for use. To this end, service tanks normally contain internal heaters to ensure that the fuel is at the optimum temperature for use (Bureau of Naval Personnel 1970, 222).

8. Transfer Fuel – Afloat

The transfer fuel afloat function allows for the movement of petroleum from a support ship to a warship as part of replenishment. Before a transfer of fuel occurs, a fuel transfer plan is developed that includes the order that ships will be refueled, the refueling time schedule order, number of rigs to be used, and the transfer rate for each ship class to be fueled. Expected weather conditions are discussed and all procedures, including emergency breakaway, are agreed upon (Naval Doctrine Command 2001, 1-4).

The standard equipment utilized for UNREP is documented in NAVSEA S9570-AD-CAT-010, Underway Replenishment Hardware and Equipment Manual. Fuel is transferred to the CG and DDG using the Standard Tension Replenishment Alongside Method (STREAM) rig shown in Figure 15. The rig uses a series of winches to maintain tension on a span wire. The span wire supports saddles which, in turn, support the fuel transfer hose. The fuel transfer hose's couplings are constructed of aluminum, anodized aluminum, bronze or aluminum bronze, and the fuel probe is constructed of the same material. O-rings are made from synthetic rubber, compound Buna-N (i.e., nitrile). Transfer hoses can be either neoprene or "synthetic rubber compounds utilizing copolymer product of butadiene and acrylic nitrile" (Naval Sea Systems Command 2001, 2-42). The primary fueling hose is a seven-inch neoprene hose, fabric reinforced with nylon or polyethylene glycol terephthalate (Naval Sea Systems Command 2001, 2-5 – 2-53).

Fuel travels from the T-AO storage tanks via a transfer pump and fuel header to the transfer hose. The hose terminates with a fuel probe which is inserted into a probe receiver on the CG or DDG. The fuel flow rate is controlled by the T-AO based on the requirements of the receiving ship. Once fueling commences, the fuel is tested by engineers on the CG or DDG. Fuel flow is directed to the CG or DDG's storage and settling tank. When the storage tanks have reached their maximum allowed levels, the T-AO secures fuel transfer and the STREAM rig is disconnected (NSWC Port Hueneme 2009, 3-33 – 3-39; Navy Warfare Development Command 2002, 2-18 – 2-20).

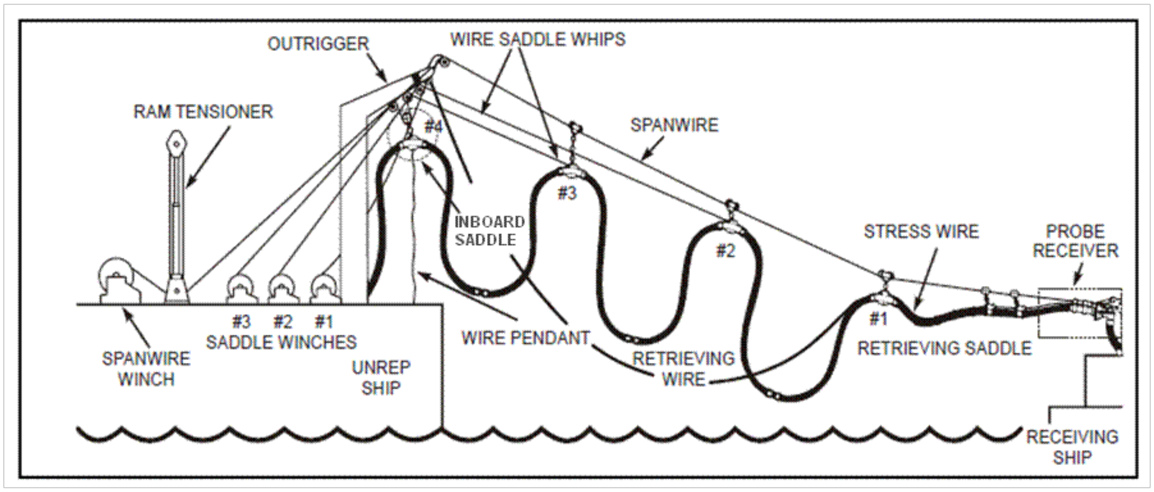

Figure 15. STREAM Rig for UNREP

This figure shows the rather intricate mechanical setup and equipment currently required to perform UNREP operations. From (Naval Surface Warfare Center Port Hueneme 2009, 3-1).

9. Perform Fuel Quality Tests – Afloat

Fuel quality standards are verified by the transferring ship prior to receipt by the government. The transferring ship is responsible for ensuring fuel is filtered to the level required by the standards of the product being transferred. For F-76 the limit is 10 mg/L of sediment. The receiving ship's engineering department performs quality surveillance during and after transfer. Quality tests are performed by NAVSUP technicians according to the product and the situation (Department of Defense 2008, 25-30, 96).

10. Control Fuel Inventory and Movements – Afloat

As with the ashore control function, this involves monitoring, tracking and documenting the fuel movements. The afloat function begins with UNREP planning and concludes following the transfer function. The required frequency of UNREPs is calculated in advance by the CSG's Underway Replenishment Coordinator (URC). The URC, with guidance from the CSG Logistics Coordinator recommends a refueling schedule to CTF X3. CTF X3 has tactical control of the CSG’s T-AO and schedules the fuel transfer from the fuel depot to the T-AO. The T-AO then deploys to rendezvous with a CG or DDG in the operating area (Navy Warfare Development Command 2007, 4-1 – 4-10). The supply ship records the amount of fuel in storage prior to the transfer, known as On-Board Quantity, and the amount of fuel in storage after the transfer, designated Remaining On-Board. The difference in these amounts allows both ships to compute amount transferred for accounting, management and ship’s trim and ballast calculations (Defense Energy Support Center Fact Book 2010, 3). The amount calculated by the transferring ship may be transmitted to the receiving ship by Naval message (Naval Doctrine Command 2001, 2-45).

This chapter has provided the reader with a brief explanation of the functions and the organizations which support CSG fueling activities. The following chapter describes the GSG mission profile and deployment scenario. Analysis of the functions and operations introduced in this chapter, when applied to the scenario detailed in the mission profile will provide the basis of the determination of necessary changes.

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IV. MISSION PROFILE

A. INTRODUCTION

The mission profile was created to define a notional mission for the GSG to support architecture and requirements development, and to serve as a framework scenario for analyzing and discussing fueling implications. The mission profile was used to determine how implementing FT S-5 fuel would impact the operational support requirements. In deriving the scenario and many of the values presented, several of the authors drew on their own experiences as uniformed members of the Navy. Additionally, they checked their assumptions and conclusions regarding plausible ship operating speeds and fuel consumption rates from published Navy sources (Navy Warfare Development Command 2007, Appendix D; Lovins et al. 2001, 88-89; I-ENCON 2010, under Reference Data Fuel Curves). The mission profile defines the composition of the GSG and identifies a homeport, transit route, and operational scenario information.

B. GREEN STRIKE GROUP COMPOSITION

The composition of a typical CSG can vary. However, they normally include guided missile cruisers, guided missile destroyers, attack submarines, and logistics support ships (T-AOE or T-AO equivalent) (Navy Warfare Development Command 2007, 4-1). The GSG is assumed to be a carrier strike group with the following composition as specified in Chapter I:

- One Nuclear-Powered Aircraft Carrier (CVN)
- Two Guided Missile Cruisers (CG) powered by the alternative fuel
- Three Guided Missile Destroyers (DDG) powered by the alternative fuel
- One Nuclear-Powered Fast Attack Submarine (SSN)
- One Logistics Support Ship (i.e., T-AO or T-AOE), powered by F-76

C. MISSION OVERVIEW

The mission is a 180-day deployment with a total of 155 days underway and 25 days in port. The mission is broken into eight segments based on operational performance characteristics and objectives of the segment. A speed profile is created for each segment, consisting of a table of anticipated operational speeds and durations normalized to a 24-hour day. The objective of a segment can be either to transit a distance or patrol an area. The combination of speed profile and segment objective is used to calculate fuel consumption of the GSG for each mission segment.

The ships depart their homeport of Norfolk, Virginia en route to supporting operations in and around the Arabian Sea. Two operational areas (OA) are defined for patrol by the GSG. The first OA is a 160,800 square nautical miles (NM^2) area off the coast of Somalia used to support operations in the vicinity of the Horn of Africa. The GSG patrols this OA for 69 days, including 10 days in port. The second OA is an 81,000 NM^2 area off the coast of Oman used to support strike operations around Iran, Afghanistan and Pakistan. The GSG patrols this OA for 60 days, including 8 days in port.

The deployment's eight segments are presented in detail in the following section. Individual segment fueling infrastructure requirements for the GSG are analyzed and aggregated for the entire mission. During the six month deployment, the GSG ships travel a total distance of approximately 43,860 NM.

D. DETAILED MISSION INFORMATION

The six month mission is broken into the following eight segments (each addressed in the subsequent sections):

- Transit from Norfolk to the Suez Canal
- Transit through the Suez Canal
- Transit through the Red Sea to Operational Area 1
- Patrol of Operational Area 1
- Patrol of Operational Area 2
- Return Transit from Operational Area 2 through the Red Sea
- Return Transit through the Suez Canal
- Return Transit from the Suez Canal to Norfolk

1. Transit from Norfolk to the Suez Canal

The first segment of the mission is the transit from Norfolk to the Mediterranean entrance of the Suez Canal, as shown in Figure 16.

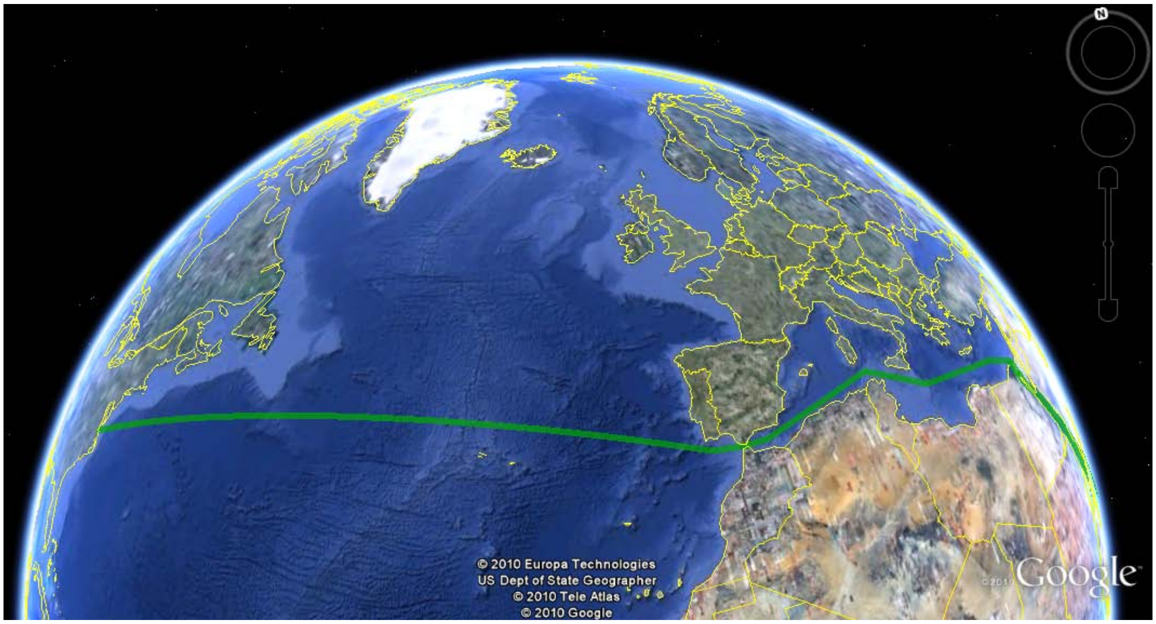


Figure 16. Transit Path - Norfolk to Suez Canal. After (Google Earth, Atlantic Ocean, 2010).

The first segment of the mission starts at Norfolk and ends at the Mediterranean entrance of the Suez Canal, a transit of 5,310 NM.

The objective of this segment is a timely and fuel-efficient transit of the 5,310 NM distance. A speed profile was developed for this segment with the GSG operating for 16 hours per day at the most fuel efficient cruising speed of 13 knots (Lovins et al. 2001, 88-89; I-ENCON 2010, under Reference Data Fuel Curves) with brief periods of operations at faster and slower speeds giving an average speed of 14.1 knots. The speed profile is provided in Table 4. The speeds for all segments were chosen to represent realistic activities and parameters. Later in this chapter a spreadsheet-based fuel consumption estimation model is presented. The model's fuel consumption profiles, following the given times, speeds, and activities, align with expected fuel consumption as measured by a model from the Navy Warfare Development Command (Navy Warfare Development Command 2007, Appendix D).

Table 4. Nominal Speed Profile Norfolk to Suez Canal

This table lists the activities and parameters that specify the first segment and the corresponding speeds.

Time (hours / day)	**Speed (knots)**	**Activity**
2	5	Drills
16	13	Transit
2	15	Drills
2	20	Flight Operations/Drills
2	25	Flight Operations/Drills

Thirteen knots was selected as the optimal fuel-efficient cruising speed based on gallons per NM versus speed curves (Lovins et al. 2001, 88-89; I-ENCON 2010, under Reference Data Fuel Curves). The optimal fuel-efficient speed can be found by plotting ship speed on the X-axis with gallons per nautical mile on the Y-axis. The point with the highest speed and lowest fuel consumption represents the optimal fuel efficient cruising speed as shown in Figure 17 for DDGs and Figure 18 for CGs. Note that cruisers and destroyers are powered by four LM2500 gas turbine engines driving two shafts (United States Navy Fact File Cruisers-CG 2010, para. 6; United States Navy Fact File Destroyers-DDG 2010, para. 6). There are three propulsion plant configurations: Split, Trail, and Full. Trail plant propulsion uses a single gas turbine driving only one shaft; the other shaft is not powered. Split plant propulsion means that each shaft is powered by a single gas turbine and with Full plant propulsion each shaft is powered by two gas turbines. The most fuel efficient speed occurs while using Trail plant propulsion (Clifton 2010, 1-2).

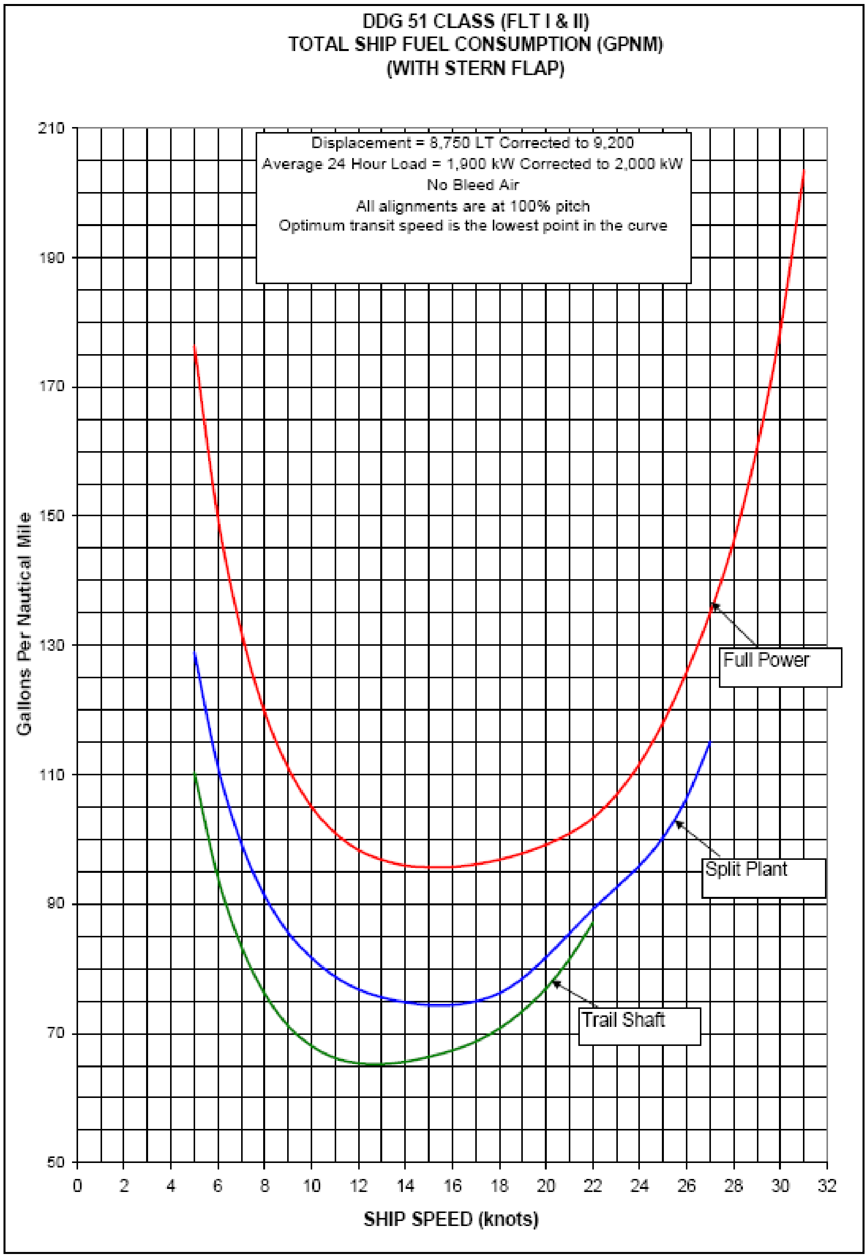


Figure 17. DDG 51 Class Fuel Consumption vs. Speed

This figure depicts the DDG 51 class fuel consumption in gallons per nautical mile for three propeller configurations. From (I-ENCON 2010, under Reference Data Fuel Curves).

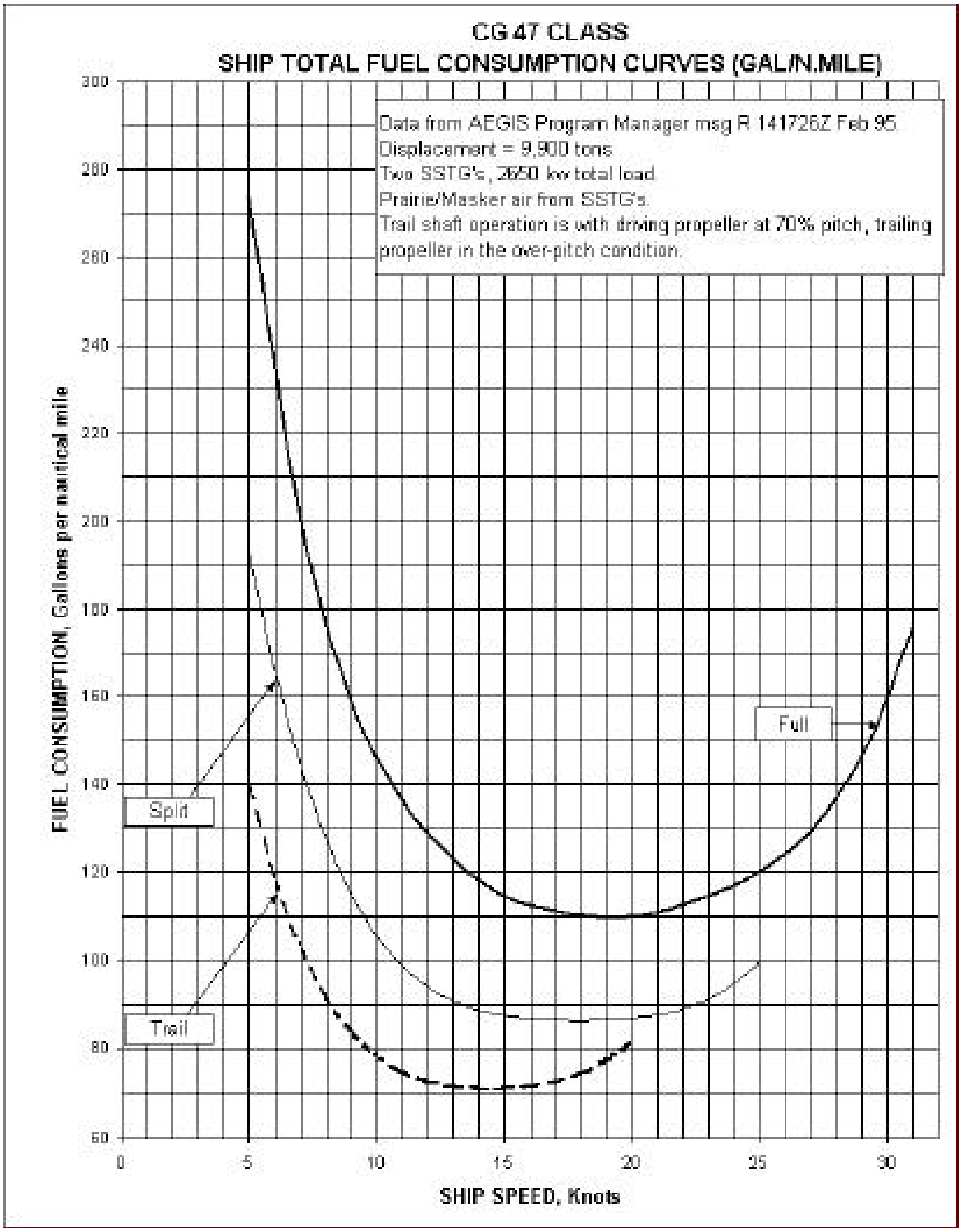


Figure 18. CG 47 Class Fuel Consumption vs. Speed

This figure depicts the CG 47 class fuel consumption in gallons per nautical mile for three propeller configurations. From (Lovins et al. 2001, 88-89).

2. Transit through the Suez Canal

The second segment of the mission covers the short transit through the Suez Canal. This is defined as a 9.5 hour trip at an average speed of 9.2 knots covering the 86.8 NM distance. These numbers are based on assumed realistic activities and parameters derived from expected daily fuel consumption found in NWP 4-01.2 (Navy Warfare Development Command 2007, Appendix D).

3. Transit through the Red Sea to Operational Area 1

The next defined segment for the mission is the transit from the exit of the Suez Canal through the Red Sea and the Gulf of Aden to Operational Area 1, shown in Figure 19. Similar to the first segment, the objective of this segment is a timely and fuel-efficient transit. The same speed profile as shown in Table 4 is used and results in a six-day trip covering the 1,982 NM distance.

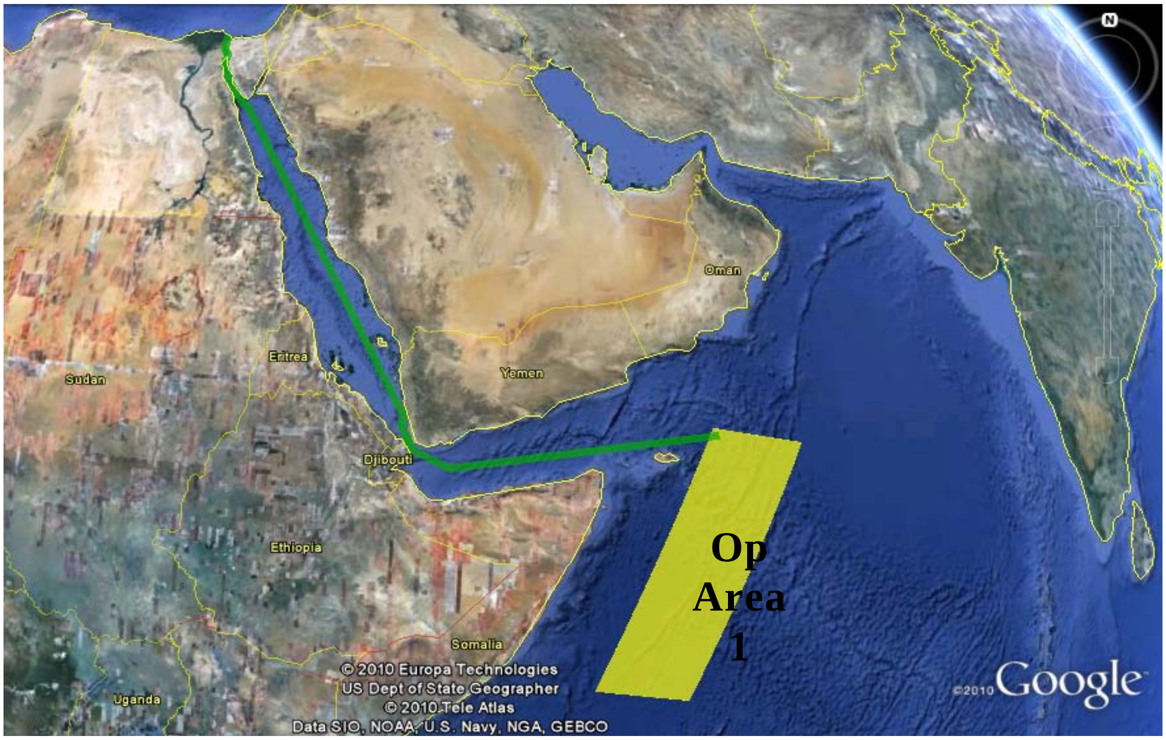


Figure 19. Transit to Operational Area 1. After (Google Earth, Arabian Sea off Coast of Somalia, 2010).

This figure diagrams the third segment, the transit from exit of Suez Canal through the Red Sea and Gulf of Aden to Operational Area 1.

4. Patrol of Operational Area 1

Operational Area 1, shown in Figure 20, is a 160,820 NM^2 area with a perimeter of 1,883 NM. The objective of this segment consists primarily of loitering in OA 1, launching and recovering aircraft, and routine drills.

A speed profile for this segment is shown in Table 5 where fuel consumption is minimized by operating the GSG at minimal propulsion speeds with brief bursts of speed necessary for drills and flight operations. OA 1 is patrolled for a period of 69 days, of which 59 days are spent at sea, covering a combined distance of approximately 14,750 NM.

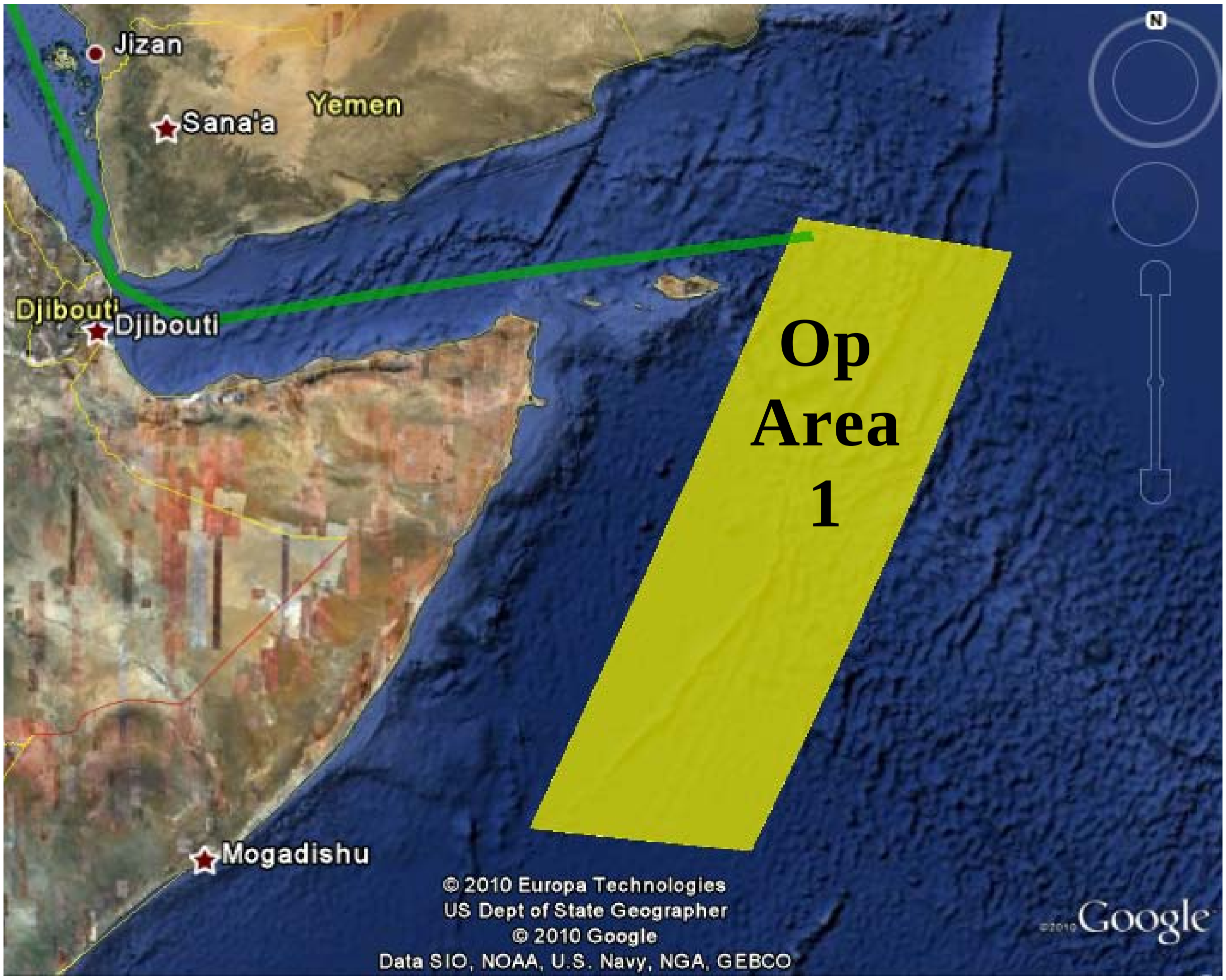


Figure 20. Operational Area 1. After (Google Earth, Arabian Sea off Coast of Somalia, 2010).

Segment 4, 160,820 NM^2 area with a perimeter of 1,883 NM.

Table 5. Nominal Speed Profile Operations Area 1

This table lists the activities and parameters that specify the fourth segment and the corresponding speeds.

Time (hours/day)	Speed (knots)	Activity
18	5	Loitering
3	18	Flight Ops/Drills
2	25	Flight Ops/Drills
2	28	Flight Ops/Drills

5. Patrol of Operational Area 2

Similar to the previous segment, this mission segment is concerned with patrolling Operational Area 2 as shown in Figure 21. OA 2 is an area in the Arabian Sea off the coast of Oman covering 81,083 NM^2 with a perimeter of 1,249 NM.

Figure 21. Operational Area 2. After (Google Earth, Arabian Sea off the Coast of Oman, 2010).

Area off the coast of Oman covering 81,083 NM^2 with a perimeter of 1,249 NM.

A nominal speed profile for this area is shown in Table 6. This speed profile includes slightly more hours spent at flight operations speeds due to the anticipated increased tempo expected in this geographic region. The patrol duration of this area is defined as 60 days, of which 52 days are at sea covering a total distance of 14,144 NM.

Table 6. Nominal Speed Profile Operations Area 2

This table lists the activities and parameters that specify the operations in Operations Area 2 and the corresponding speeds.

Time (hours/day)	Speed (knots)	Activity
16	5	Loitering
2	18	Flight Ops/Drills
4	25	Flight Ops/Drills
2	28	Flight Ops/Drills

6. Return Transit from Operational Area 2 through Red Sea

After patrolling the operational areas, the return trip to Norfolk begins with a return to the Suez Canal through the Red Sea, a distance of 2,191 NM. Similar to the previous transit segments, the fuel-efficient speed profile (shown in Table 4) is used, resulting in an average speed of 14.1 knots and a transit of six days.

7. Return Transit through the Suez Canal

The return trip through the Suez Canal is identical to the segment defined in Section 2 (above). It consists of a 9.5 hour trip at 9.2 knots covering 86.8 NM.

8. Return Transit from the Suez Canal to Norfolk

The final segment of the mission is the return trip from the Suez Canal to Norfolk – the reverse of the path shown in Figure 16. A slightly faster speed profile is used to include "liberty turns," which consists of increasing the average speed to 15 knots to arrive in port early for liberty, thus shaving one day off the transit time (see Table 7).

Table 7. Nominal Speed Profile Return to Norfolk

This table lists the activities and parameters that specify the return to Norfolk segment and the corresponding speeds.

Time (hours/day)	Speed (knots)	Activity
2	5	Drills
2	13	Transit
16	15	Transit
3	20	Flight Operations
1	25	Flight Operations

E. REFERENCE MISSION FUEL ESTIMATION

The reference mission provides a context for exploring the fuel requirements to support a GSG for a six-month deployment. The amount of fuel consumed by the GSG drives the requirement for how much must be available in the mission time period as well as how much must be stored.

During transit segments, fuel consumption is optimized by selecting the speed that minimizes gallons per nautical mile in order to determine how far ships can travel before needing to refuel. In contrast, minimizing fuel consumption while patrolling a confined area requires operating the ships from a different perspective because the distance traveled will vary as the ships patrol an operational area. In this case, how much time can pass before needing to refuel is of interest. Therefore fuel consumption is measured in gallons per hour (GPH). Figure 22 graphs DDG 51 class ships GPH vs. speed – minimizing GPH requires operating the ships at speeds of 5 knots or less. Figure 23 shows the fuel consumption rate (GPH) vs. speed for CG 47 class ships.

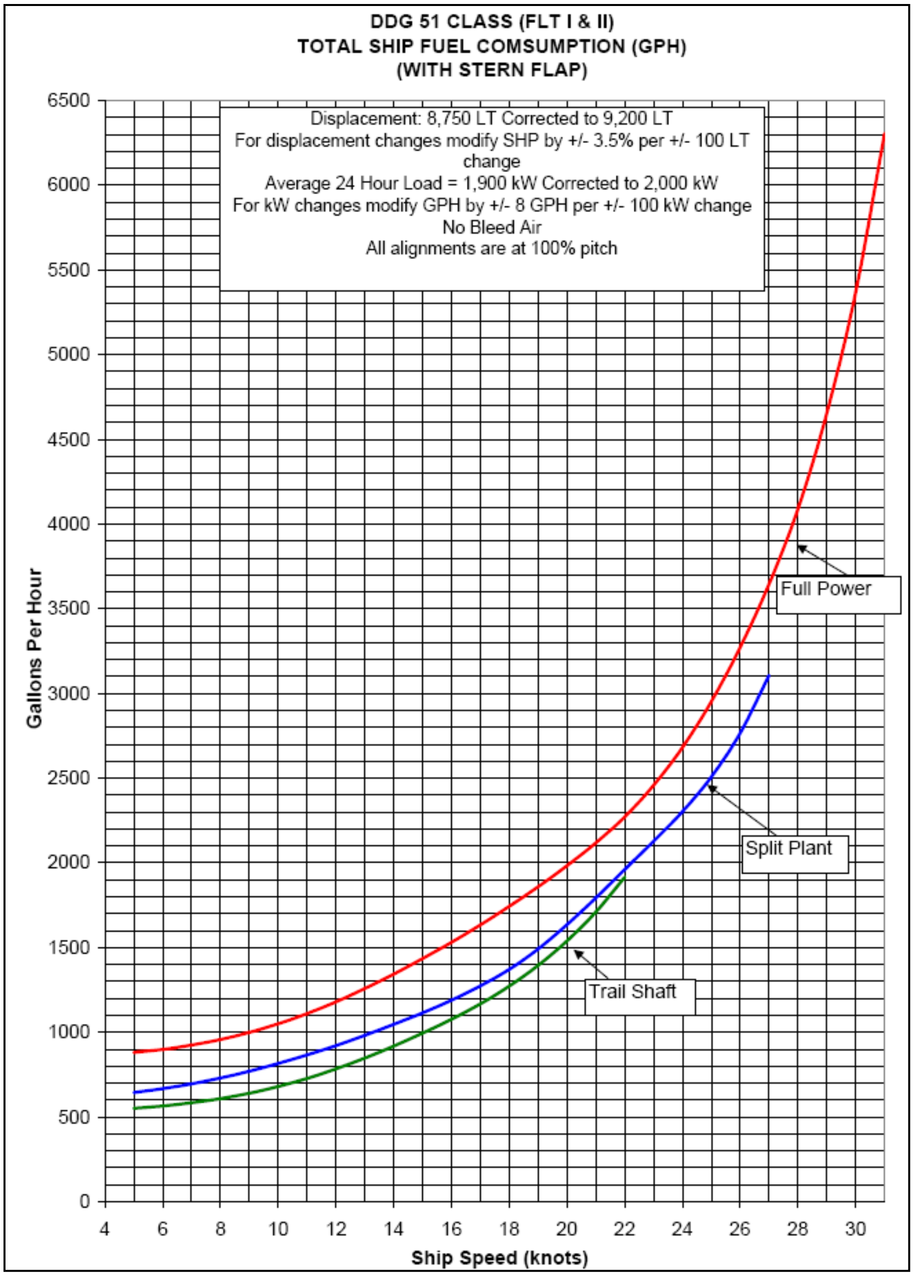


Figure 22. DDG 51 Class Fuel Consumption Rates (GPH) vs. Speed.

This figure depicts the DDG 51 class fuel consumption in gallons per hour (GPH) for three propeller configurations. From (I-ENCON (n.d.), Reference Data Fuel Curves).

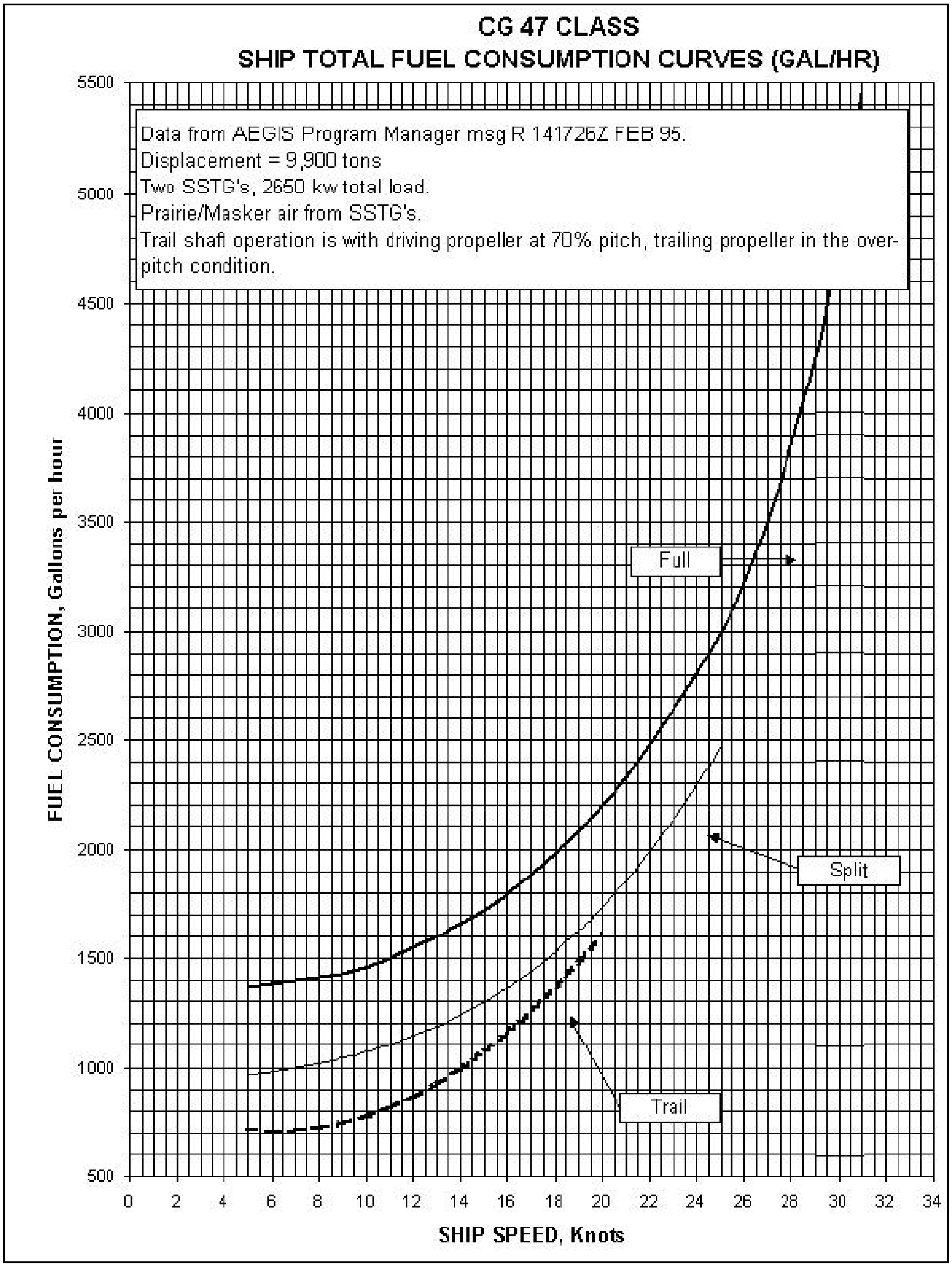


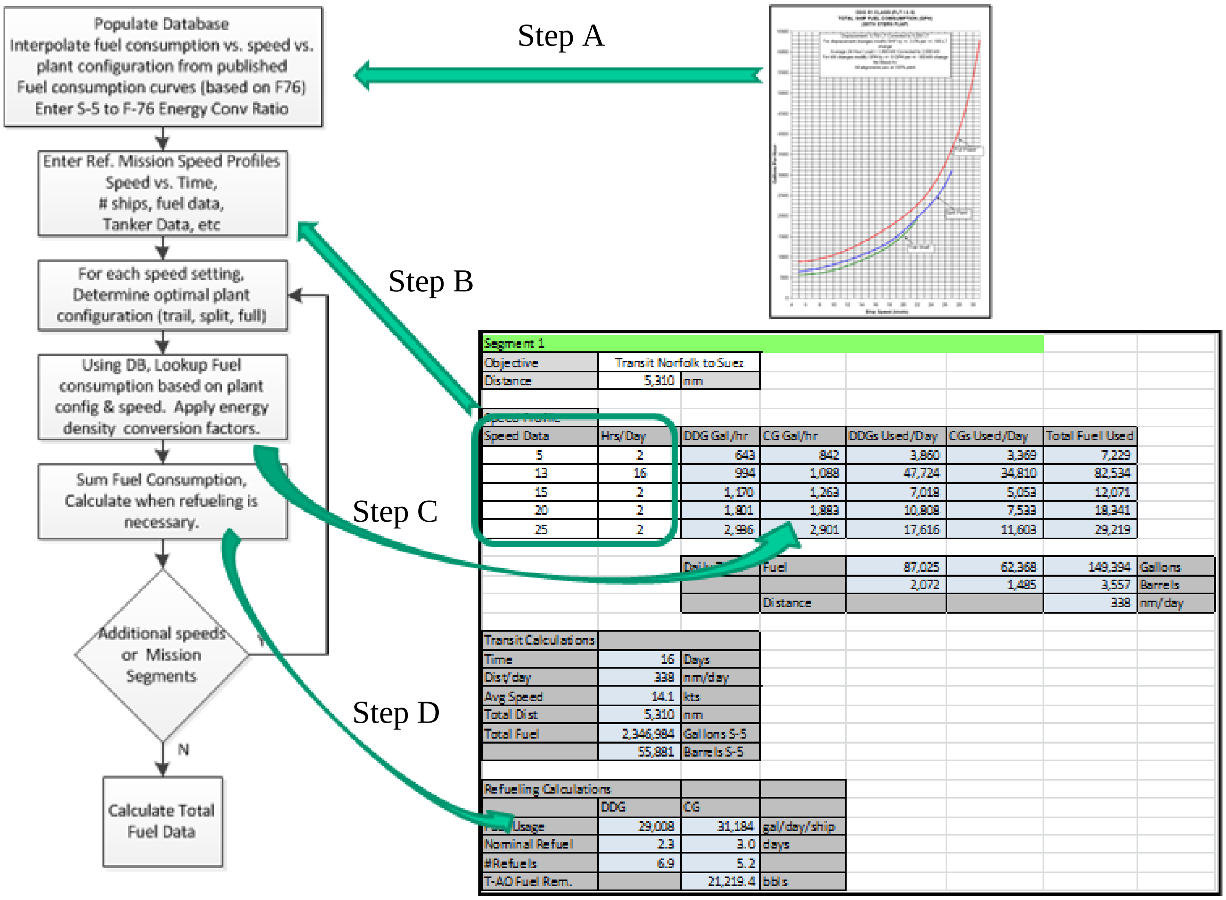
Figure 23. CG 47 Class Fuel Consumption Rates (GPH) vs. Speed.

This figure depicts the CG 47 class fuel consumption in gallons per hour (GPH) for three propeller configurations From (Lovins et al. 2001, 88-89).

1. Fuel Estimation Model

A fuel estimation tool was created using a Microsoft Excel spreadsheet. The estimation tool allows for entering speed profiles for the GSG over a 24 hour period for each segment of the reference mission. Based on the fuel consumption rate curves for DDG 51 (Figure 22) and CG 47 (Figure 23) class ships, the model determines the most fuel efficient propulsion plant configuration (i.e., split plant, trail shaft, or full power) for the desired speed and calculates the fuel consumption. Knowledge of fuel consumption for segments and the entire mission led to insight as to how much fuel would be needed to store at shore-based facilities.

The basic flow of the model is shown in Figure 24. To begin, fuel consumption databases were established for cruisers and destroyers based on interpolation of Figures 22 and 23 (Step A). Next, the speed profile information was entered for each segment in the mission (Step B). Subsequently, the speed profiles were used to look up fuel consumption values in the databases, taking into consideration the most optimal propulsion plant configuration (Step C). Finally, the model uses time parameters such as speed profile hours per day and segment number of days to calculate fuel consumption for the entire segment (Step D). Ultimately, the segment fuel estimates were summed to arrive at an aggregate fuel consumption estimate for the entire mission. Combined with knowledge of logistics support ships’ tank capacity, the fuel estimation model led to insight as to how many refueling operations would be necessary to support the GSG.



Segment 1							
Objective	Transit Norfolk to Suez						
Distance	5,310	nm					
[illegible]							
Speed Data	Hrs/Day	DDG Gal/hr	CG Gal/hr	DDGs Used/Day	CGs Used/Day	Total Fuel Used	
5	2	643	842	3,860	3,369	7,229	
13	16	994	1,088	47,724	34,810	82,534	
15	2	1,170	1,263	7,018	5,053	12,071	
20	2	1,801	1,883	10,808	7,533	18,341	
25	2	2,986	2,901	17,616	11,603	29,219	
		Daily T	Fuel	87,025	62,368	149,394	Gallons
				2,072	1,485	3,557	Barrels
			Distance			338	nm/day

Transit Calculations		
Time	16	Days
Dist/day	338	nm/day
Avg Speed	14.1	kts
Total Dist	5,310	nm
Total Fuel	2,346,984	Gallons S-5
	55,881	Barrels S-5

Refueling Calculations			
	DDG	CG	
Usage	29,008	31,184	gal/day/ship
Nominal Refuel	2.3	3.0	days
#Refuels	6.9	5.2	
T-AO Fuel Rem.		21,219.4	bbls

Figure 24. Fuel Estimation Model with Inputs/Outputs

Instantiated the model in a Microsoft Excel spreadsheet to obtain flexible tool for performing simulation and analysis.

2. Alternative Fuel Consumption Calculations

The fuel estimation model can calculate fuel consumption rates for conventional F-76 fuel or alternative fuels based on relative volumetric energy densities. For example FT S-5 energy density is 33.0 MJ/L compared to F-76's 38.6 MJ/L; this equates to FT S-5 having 85% the energy per unit volume compared to F-76. For this study, it is assumed the gas turbines are equally efficient at burning FT S-5 and F-76 for a given speed. In that case, the fuel consumption rate (gallons per hour) increases by 15% when burning FT S-5 as compared to F-76. The fuel estimation model allows for entering a relative energy density value and the associated burn rates and related fuel calculations are automatically adjusted accordingly.

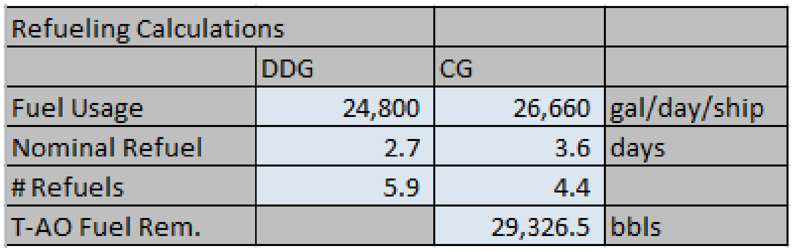
3. Refueling Interval Calculations

The fuel estimation model calculates how frequently the CGs and DDGs will require refueling. Typically combatants try to maintain significant fuel reserves – requiring frequent refueling. The model allows for entering minimum and maximum fuel tank levels. The minimum level sets the low level, at which point a refueling operation is requested, allowing sufficient time for the T-AO to arrive before the ship's fuel level drops to unacceptable levels. If an oiler is not available for refueling tank levels may drop as low as 50%, however, ships try to refuel when their tank level drops to 80%. For the purposes of our calculations, the minimum level for requesting refueling was set to 85% to allow time for the oiler to respond the request. Lower tank levels are explored in later analysis. The maximum level is the maximum level the tanks will be filled to – typically tanks are only filled to 95% capacity to prevent inadvertent spilling of fuel.

Using the known ship's fuel tank capacity, entered minimum and maximum levels, and calculated fuel consumptions, the model predicts how frequently each ship will require refueling. Table 8 shows the calculated results for the GSG transit from Norfolk to the Suez Canal. In this case, the DDGs will require refueling every 2.7 days, the CGs every 3.6 days. To make the entire 5,310 NM transit, the DDGs need to be refueled 5.9 times and the CGs 4.4 times during this single transit. Practically, these estimates must be rounded up to six and five refueling operations for destroyers and cruisers respectively. Additionally the model keeps track of the amount of fuel remaining in the escort oiler's fuel storage tanks. In this case, the T-AO departs Norfolk with 77,100 bulk barrels (bbls) of fuel and arrives at the Suez Canal with 29,326 bbls remaining.

Table 8. Refueling Calculations for Segment 1 (F-76 Fuel)

The table details the amount of fuel used per day for each ship as well as the time period between refueling and the number of expected refuels for the Norfolk to the Suez Canal leg of the mission profile.



Refueling Calculations			
	DDG	CG	
Fuel Usage	24,800	26,660	gal/day/ship
Nominal Refuel	2.7	3.6	days
# Refuels	5.9	4.4	
T-AO Fuel Rem.		29,326.5	bbls

4. Fuel Estimation Summary Calculations

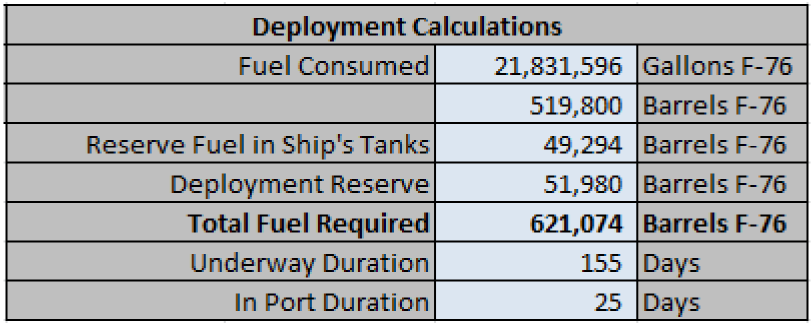
The fuel estimation model performs mission summary calculations to determine the total amount of fuel required to support the CGs and DDGs during the entire six month deployment. The summary calculations include the amount of fuel burned, as well as the amount of fuel remaining in ships' tanks as they pull into port (for this analysis the model assumes the minimum refueling request level of 85% remains in each ship). Additionally the model allows for including a mission excess reserve. This is a fixed percentage of the total fuel consumed to allow for mission variations ensuring sufficient fuel exists for an actual mission.

These calculations are based on the assumption that an additional 10% of the burned fuel will be purchased as reserve fuel. Table 9 shows the summary for the GSG burning conventional F-76 fuel (alternative fuels will be analyzed later in the report).

The model predicts a total of 519,800 barrels of F-76 will be burned over the six month period. An additional 49,294 barrels of fuel will remain in the ship's tanks as they pull into home port. An additional 51,980 barrels of fuel will be purchased (before the mission commences) to have in reserve in the event additional fuel is required. A total of 621,074 barrels of fuel (F-76 in this case) will be required to perform the six month mission. As presented later in Chapter V, this information, coupled with the FT S-5 fuel energy density, was used to support requirements development.

Table 9. Deployment Summary Fuel Calculations (F-76)

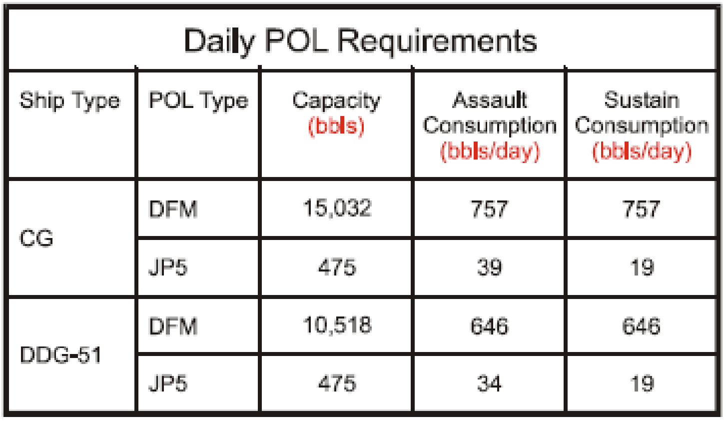
This table contains details of GSG fuel usage for the entire mission.



Deployment Calculations		
Fuel Consumed	21,831,596	Gallons F-76
	519,800	Barrels F-76
Reserve Fuel in Ship's Tanks	49,294	Barrels F-76
Deployment Reserve	51,980	Barrels F-76
Total Fuel Required	**621,074**	**Barrels F-76**
Underway Duration	155	Days
In Port Duration	25	Days

5. Fuel Estimation Model Verification

Naval Warfare Publication (NWP) "Sustainment at Sea" (NWP 4-01.2) Appendix A provides planning factors for supporting ships – including fuel consumption for CG 47 and DDG 51 class ships (see Figure 25). As stated in the NWP, the values provided are only for planning purposes and will need be adjusted based on actual mission factors.



Daily POL Requirements				
Ship Type	POL Type	Capacity (bbls)	Assault Consumption (bbls/day)	Sustain Consumption (bbls/day)
CG	DFM	15,032	757	757
	JP5	475	39	19
DDG-51	DFM	10,518	646	646
	JP5	475	34	19

Figure 25. NWP 4-01.2 Table A-2.3 SSG/LCS Planning Factors

Cruisers and Destroyers have specified capacities for F-76 diesel fuel and JP5 jet fuel (for air operations). They also have nominal fuel consumption rates based on combat operations or sustainment. From (Naval Warfare Development Command 2007, 4-01.2).

Using the daily POL requirement values provided in Figure 25 multiplied by the number of days underway and the number of ships in the GSG, the NWP model estimates 533,524 bbls of F-76 will be consumed during the reference mission. The fuel estimation model predicts a total of 519,800 barrels will be consumed, a value within 2.6% of the

NWP's estimation. The high degree of agreement between NWP's estimate and the FIST fuel estimation provides a high level of confidence in the reference mission speed profile selection and fuel calculation method.

F. SUMMARY

This chapter presented a nominal mission profile from which understanding of GSG operations and fuel consumption was enabled. The mission profile therefore drove considerations for requirements. These requirements and the process by which they were derived are presented in the next chapter.

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V. REQUIREMENTS ANALYSIS

A. INTRODUCTION

In order to propose an infrastructure to support an alternative fuel, analysis was performed to capture relevant requirements for the infrastructure. Research of existing documentation was conducted to define the existing ashore and afloat infrastructure to understand current capabilities. The information was used to perform a functional decomposition of the existing infrastructure, which was in turn used to define requirements for the proposed infrastructure. In addition to reviewing existing documentation, the FIST team conducted the fuel study and developed a mission profile discussed in the previous sections to determine how the attributes of alternative fuels would shape the infrastructure requirements.

B. REQUIREMENTS ANALYSIS PROCESS

The basic tactic utilized to derive the infrastructure requirements was to leverage the information captured in the previous chapters, specifically:

- The existing infrastructure currently required to support the storage and movement of fuel.
- The fuel study to determine the chemical and physical fuel attributes of the selected alternative fuel, FT S-5, which impact the functional and non-functional infrastructure requirements.
- Modeling and analysis of the reference mission profile to determine fuel demand during CSG deployment (discussed at length in Chapter VI). This analysis was then refined to determine infrastructure capacities and timing which would impact the CSG operational mission.

The methodology for requirements discovery and evaluation was a five-step process. The steps were as follows:

1. *Perform Research*—researched existing documentation, publications and DoD websites in order to define the existing fueling infrastructure discussed in Chapter III.
2. *Evaluate Existing Infrastructure*—used existing documentation, such as the UNTL, MIL-STD-3004.B, NTTP 4-01.4 and Joint Publication 4-01.2,

to identify areas where FT S-5 fuel would impact the existing logistics infrastructure.

3. *Determine Operational and Support Constraints*—implementation of FT S-5 fuel to power CG and DDG platforms may require changes to the supporting infrastructure. Areas where modifications needed to be made were identified through the fuel study and the mission profile research.

4. *Identify and Evaluate New/Modified Requirements*—new and/or modified requirements were identified and evaluated based on the functions and constraints identified for the logistical infrastructure.

5. *Categorize Requirements*—upon completion of requirements definition, each one was sorted into the appropriate top-level requirement category.

Figure 26 illustrates this process, including the logic behind categorizing requirements, as a flowchart.

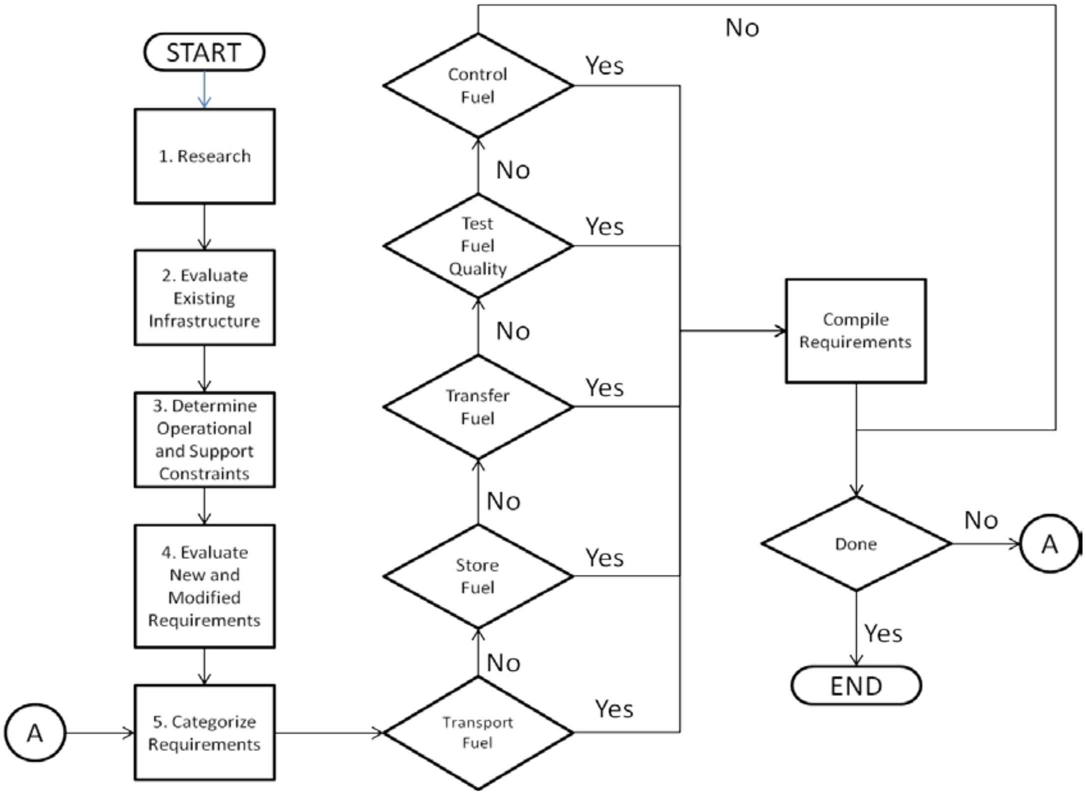


Figure 26. Requirements Evaluation Flow Chart

Illustration of the methodology used to step through the requirements evaluation process.

It is worth taking a closer look at some elements of this requirements discovery and evaluation process. The following sections give more insight into how FIST used the process to arrive at a top-level requirements list.

1. Perform Research

In order to begin deriving requirements for the infrastructure necessary to support FT S-5, it was useful to first understand the functions of the existing infrastructure. Research of existing documentation was conducted to understand the current logistical movement of fuel from storage to refueling operations both ashore and afloat for the purpose of defining the top-level functions and requirements for the infrastructure.

As discussed in Chapter III (Existing Fueling Infrastructure), the UNTL from OPNAVINST 3500.38B was used to assist with identifying the top-level functions provided by the existing infrastructure. The top-level UNTL activities addressing fuel-related logistics are represented in Figure 27.

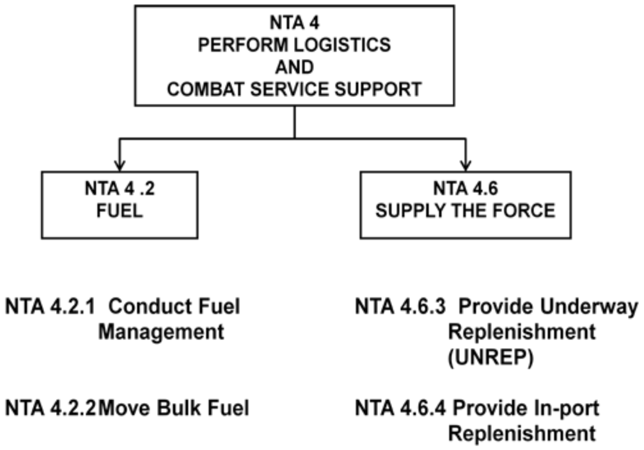


Figure 27. UNTL Top Level Logistics Activities (Department of the Navy 2008, 3-B-53 to 3-B-65)

This figure depicts the top level logistics activities from Universal Naval Task List provided in OPNAVINST 3500.B which provides Navy standardized activities

In addition to leveraging the UNTL activities, other naval publications were analyzed to help guide development of requirements for the infrastructure. These publications are listed below:

- *Department of the Navy Office of Chief of Naval Operations, Underway Replenishment NTTP 4-01.4*. This Navy publication provided an understanding of the Navy's procedures for UNREP.
- *Sealift Support to Joint Operations, Joint Publication 4-01.2, 31 August 2005*. This document provided an understanding of how the Military Sealift Command is tasked to support joint operations. Information gained was used to determine ship capacities in liquid volume, types of liquid cargo carriers, and approximate number of fuel barrels they carry.
- *Department of Defense Standard Practice Quality Assurance/Surveillance for Fuel, Lubricants and Related Products MIL-STD-3004.B*. This document provided insight into fuel control testing and methods.

A published presentation from the Fuel Department Deputy Director of NAVSUP FISC Norfolk Virginia was reviewed. This presentation included the following mission statement that provided a basis for the top-level infrastructure requirements: "Safely and efficiently receive, store and issue on-specification petroleum products for our customers" (Roddy, "Regional Fuel Operations", 2). The information obtained from this presentation was valuable in assisting the authors with defining the existing infrastructure provided in Chapter III.

2. Evaluate Existing Infrastructure

Based on the research, FIST elected to divide the infrastructure to support the GSG into two categories, ashore and afloat. The ashore category addresses pier-side materiel, activities, and organizations, while the afloat category addresses the same elements at sea. As defined in Chapter III (Existing Fueling Infrastructure, section C) the five key functions involved in supplying fuel to ships are as follows:

- Transport fuel
- Store fuel
- Transfer fuel
- Perform fuel quality tests
- Control fuel inventory and movements

These five key functions were used to establish the categories applicable to GSG top-level requirements. The top-level requirements were then decomposed further to establish requirements for the ashore functions and the afloat functions.

3. Identify Constraints and Requirements—Fuel Study

As discussed in Chapter II, the authors conducted a fuel study to determine an appropriate candidate fuel for use in the GSG by 2016. It was necessary to conduct this study early as it provided information on fuel attributes that could impact the infrastructure and would therefore drive any needed modifications.

From the fuel study, FIST was able to determine that the energy density attribute would affect fuel consumption rates during transit and operations. It would therefore impact both storage capacity and the number of replenishments required during operation.

The attributes associated with the NFPA health hazard category could impact the safe handling of the fuel, requiring additional training and safety documentation.

In addition, the attributes associated with viscosity, corrosiveness and lubricity could affect compatibility with existing hardware (e.g., valve and seals).

4. Identify Constraints and Requirements—Mission Profile

A mission profile was developed to assist with determining how the attributes of the alternative fuel, FT S-5, would influence the operational support requirements. These operational support requirements could impact storage capacity and frequency of underway replenishments. The mission profile provided a basis to logically follow the physical movement and transfer of the fuel from storage ashore to the GSG and subsequently through a plausible mission. In this case, the mission, as described in Chapter IV, involved transiting from the homeport in Norfolk, Virginia to the operational areas around the Arabian Sea and back. Once the mission profile was defined, development of a fuel estimation model commenced to determine fuel consumption rates for CGs and DDGs during transit and operations. The energy density for FT S-5 was provided as input to the model to calculate the total number of barrels of FT S-5 fuel required to support the described mission as well as the number of barrels required to maintain a 10% reserve to ensure mission success in the face of unforeseen events. These calculations provided data to determine the impact of the alternative fuel to locations and associated existing storage capacities. Based on the FT S-5 energy density of 33.0 MJ/L, 608,008 barrels will be required to complete the mission, and 60,801 barrels required for reserve.

C. TOP-LEVEL REQUIREMENTS

As a result of the research and analysis conducted, the top-level requirements were grouped by the following categories:

- Infrastructure functional requirements encompassing the need to move the fuel from the supply point, whether that is pier-side or underway, to the end consumer, the GSG.
- Non-functional requirements which encompass the activities that support the fuel handling operations necessary to maintain control as well as quality of the fuel.

In addition to the requirements, constraints were identified that could impact the implementation of infrastructure changes. These constraints and requirements are identified in Table 10. The next chapter, Solution Analysis, utilizes the requirements listed. It explores solution options in light of DOTMLPF considerations.

Table 10. Infrastructure Requirements

This table lists the top level functional and non-functional requirements for the infrastructure further decomposed to include the ashore infrastructure requirements and the afloat infrastructure requirements.

ID	**Functional Requirements**	**Requirement Description**
1.0	Transport Fuel	The infrastructure shall support the movement of alternative fuels via tankers, hoses, pipes or bulk transporters (barges) to end users or intermediary refueling units. FT S-5 fuel shall be transported via T-AOs or T-AOE's to provide UNREP to DDGs and CGs during GSG transit and operations.
2.0	Store Fuel	The infrastructure shall store sufficient FT S-5 fuel to adequately support the mission operations and the reserve quantities necessary to ensure mission success. Based on the mission profile described in Chapter IV, 668,809 barrels of FT S-5 fuel will be required to support the GSG.
2.1	Store fuel ashore	Fuel storage facilities shall provide for bulk storage of FT S-5 fuel.
2.2	Store fuel afloat	The ships utilized for UNREP shall store sufficient quantities of fuel to support the GSG during transit and operations. The minimum draw down level for ships fuel tanks is 50%, at which point a refueling operation is required. (Naval Sea Systems Command 2007, 541-9.6.2.2)
3.0	Transfer fuel	The infrastructure shall enable the transfer of FT S-5 fuel from one entity to another.
3.1	Transfer fuel ashore	The infrastructure shall enable transfer of FT S-5 fuel to the appropriate storage tanks, barges, tankers or oilers to support in-port replenishment of GSG DDGs and CGs.
3.2	Receive fuel ashore	The shore facility shall be able to receive and control the flow of FT S-5 fuel delivered from commercial sources into the appropriate storage tank(s).
3.3	Transfer fuel afloat	The infrastructure shall enable the transfer of FT S-5 fuel from the TAO to the GSG as part of underway replenishment (UNREP) of fuel in support of operating forces. Using 1 Hose, the average transfer rates (Per Hour) for CG is 2,238 barrels and for a DDG is 2,070 barrels (Assumption made for values based on data contained within NTTP 4-01.4, Underway Replenishment, March 2009, figure 1-2)
3.4	Receive fuel afloat	The CG and DDG ships shall be able to receive and control the flow of FT S-5 fuel delivered from the TAO during UNREP.
4.0	Test fuel quality	Fuel quality tests shall be performed on FT S-5 fuel. MIL-STD-3004B may be used as a guide for types of tests to be

		performed to ensure the fuel complies with quality assurance standards.
4.1	Test fuel quality ashore	Fuel quality tests shall be performed upon receipt of the FT S-5 fuel from the commercial vendor.
4.2	Test fuel quality afloat	Fuel quality tests shall be performed on FT S-5 fuel received from the T-AO or T-AOE to verify the fuel is within specification. CG and DDG Platforms shall be provided fuel-testing equipment and instruction manuals to test received fuel. (Assumption made based on data contained within NTTP 4-01.4, Underway Replenishment, March 2009, Para E.4.4.3(2))
5.0	Control fuel inventory and movements	The infrastructure shall monitor, track, and control the movement of FT S-5 fuel from receipt, storage, transport and UNREP by the appropriate NAVSUP agency.
ID	**Non-Functional Requirements**	**Requirement Description**
6.0	Quality Assurance	The infrastructure shall support a quality assurance program, which is designed to ensure that raw materials, products and services related to production, distribution, management and testing processes conform to the standards established by the end user. The quality assurance program shall include documentation, procedures and databases for FT S-5 fuel.
7.0	Training	Training shall be provided for all aspects of handling FT S-5 fuel. Support personnel at the shore installations shall receive training on safety, handling and testing the fuel. Navy personnel aboard the ships shall receive training on handling fuel during UNREP and on testing for quality assurance.
8.0	Environmental Assurance	The infrastructure shall comply with all environmental requirements from environmental impact studies to National Environmental Policy Act (NEPA) requirements. Infrastructure located OCONUS shall comply with DoD 4715.05-G, Overseas Environmental Baseline Guidance Document, Chapter 9.
9.0	Occupational Safety and Health Administration (OSHA) Compliance	The infrastructure for the FT S-5 fuel shall be compliant with all applicable OSHA regulations.
ID	**Constraints**	
1	Changes to infrastructure shall be accomplished by 2016 in order to support a Green Strike Group deployment.	
2	Operations Tempo impacts to Navy UNREP and Defense Fuel Support Points shall be minimized such that the Navy's operational commitments are not degraded.	

VI. SOLUTION ANALYSIS

A. INTRODUCTION

The final step in the SE process defined in Figure 1 is Solution Analysis. The purpose of this phase was to identify and analyze options that are capable of meeting the requirements defined in Table 10 to answer the final research question: *What key modifications to existing ashore and afloat fuel distribution systems are necessary to facilitate the identified alternative fuel?*

The full solution space of DOTMLPF (Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities) was considered during this process.

B. INFRASTRUCTURE ASSESSMENT

FIST approached solution analysis by first examining the results of the Fuel Study in Chapter II and then examining candidate solutions from the individual perspectives of DOTMLPF. Using the DOTMLPF construct, FIST developed notional solution sets which were aligned with the identified requirements, functions, and constraints. As solution analysis proceeded, it became evident that many aspects of the non-functional requirements solution space would remain consistent; that is to say, a given solution for a non-functional requirement would be applicable for all solution sets. For example, with respect to training, all the solutions fulfilling the training requirements would need to incorporate modifications to the respective instructional curriculum to accommodate the selected alternative fuel. However, in the case of operational requirements, there were several that had multiple possible solutions and therefore some trade space for different candidate solutions to be assessed. A summary of only those areas identified as needing a change or where more study is required is provided below and is organized by DOTMLPF category.

1. Doctrine

The introduction of an FT S-5 fuel will require changes to Navy doctrine with respect to the top-level functions of Transport, Transfer, Store, and Control Inventory movement.

Due to differences in the energy density between FT S-5 and F-76, the CG and DDG ships will need to be refueled more frequently to support the Transport Fuel requirement. This will lead to an increase in OPTEMPO for the T-AO assigned to GSG refueling. This conclusion is analyzed and discussed in detail in the Operational Solutions Development section later in this chapter.

No changes should be necessary in support of the GSG operational objectives to meet the Store Fuel requirement. However, due to potentially accelerated degradation of the storage infrastructure and the potentially limited storage life of FT S-5, doctrinal changes may need to be promulgated to limit the storage time of FT S-5. Current research is inconclusive as to whether this is a valid concern.

Changes in the OPTEMPO of fuel transfers, both from DFSP to T-AO and from T-AO to CG/DDG would be necessary to meet the Transfer Fuel requirement. This conclusion is analyzed and discussed in detail in the Operational Solutions Development section below.

Regulations and guidance will need to be promulgated in order to establish reporting instructions in order to support the requirement for Control Fuel Inventory and Movements requirement.

2. Organization

No organizational changes would be needed to the existing fuel infrastructure based on the introduction of FT S-5.

3. Training

Since JP-5 is already transported by T-AOs and received by CGs and DDGs for their aviation assets, and given the similarities of FT S-5 and JP-5 (as noted in Chapter

II), supplemental quality assurance training would be necessary but minimal across the architecture to meet the defined Quality Assurance requirement.

To meet the Training requirement, training will be needed to augment DLA Energy seminars to include FT S-5. Updates would be needed to include DLA Energy training for Navy E-1 to E-4 to work in the field of FT S-5 fuel. Updates would also be needed to training for E-4 to E-9 to operate and maintain FT S-5 fuel systems ashore and afloat. There would also be a need to update the DLA Energy course on Engineering Bulk Fuel Systems for officers, enlisted, and DoD civilians that will work at shore facilities with bulk FT S-5 storage. Training would need to cover operations and maintenance of FT S-5 at terminal and skills needed for fuel testing (DoD 4140.25-M Vol II, Chapter 18, June 2002). See Appendix C for a more detailed discussion on the potential impacts to fuel quality testing.

Personnel designated to handle FT S-5 will require training on any new standard operating procedures put in place as a result of the environmental impact assessment required by the Environmental Quality Improvement Act of 1970 to meet the Environmental Assurance requirement.

To meet the OSHA Compliance requirement defined by FIST, training will be required due to FT S-5's NFPA health hazard rating of 1 as compared to F-76's rating of 0 (as noted in Table 2). A hazard of 1 identifies a slightly hazardous material requiring minimal protection such as eye protection and gloves.

To meet the Transport Fuel and Store Fuel requirements, no significant changes should be needed other than awareness of potential FT S-5 impacts on the infrastructure and additional safety precautions that FT S-5 requires compared to F-76. Basic transport and storage procedures should remain the same.

Since FT S-5 would be a new commodity, training would consist of awareness training that a new product is available for use and for awareness of the new regulations and guidance referenced under Doctrine in order to meet the Control Fuel Inventory and Movements requirement.

4. Materiel

Current fuel handling equipment for JP-5 and F-76 should be sufficient for FT S-5 in the short-term (2016) to meet the Transport Fuel requirement. However, long-term exposure of this equipment to the chemical attributes of FT S-5 may cause accelerated degradation of the transport infrastructure. For instance, long term exposure may cause accelerated degradation in nitrile gaskets due to the lack of aromatics in the fuel. Additionally, neoprene hoses used for UNREP and pier-side replenishment may encounter similar issues (Muzzell et al. 2005, 15-16). However current research is insufficient to provide a definitive answer at this time.

Current guidance stipulates that hoses used for one type of fuel may not be used to transfer a different type of fuel. As a result, T-AOs will need to carry duplicate sets of hoses for each type of fuel to be transferred.

5. Leadership

Within the existing organizational structure an office for synthetic fuel management that includes SMEs familiar with FT S-5 acquisition, storage, transport, and transfer requirements would be needed.

6. Personnel

Crewmen qualified to assess the quality of JP-5 for aviation use or F-76 for surface fleet use would additionally need to be fully qualified to assess FT S-5 for surface fleet use to meet the Quality Assurance requirement. Additionally, in order to meet the Transfer Fuel requirement, crewmen and personnel who are currently qualified to transfer JP-5 fuel should be fully qualified to transfer FT S-5. Also, any crewman qualified to test JP-5 should be qualified to test FT S-5 with minor training modification to meet the Test Fuel Quality requirement. Personnel levels should remain at the levels currently needed with no additional or fewer personnel required.

To meet the defined Environmental Assurance requirement, FT S-5 subject matter experts (SMEs) will be needed who are cognizant of hazardous environmental attributes specific to the fuel. Furthermore, FIST recommends designating FT S-5 SMEs from ship crews or DFSPs who are cognizant of hazardous environmental attributes specific to the fuel to meet the OSHA Compliance requirement. This would also mean that minor changes would be needed to certify that the ship's crew or DFSP workers designated are cognizant of the hazardous material attributes specific to FT S-5. Doing this would meet the Transport Fuel requirement.

To meet the Store Fuel requirement, there would be some impact to the DFSP(s) supporting the GSG due to an increased number of refuelings pier-side which could increase the number of personnel needed to sustain DFSP OPTEMPO. The increased number of UNREPs could also drive an increase in the number of personnel qualified to perform STREAM on the receiving ship.

7. Facilities

Meeting the Transport Fuel requirement is potentially significant in the long-term. Due to the reduced energy density of FT S-5 as compared to F-76, T-AO apportionment, scheduling, and DFSP OPTEMPO could be impacted. This conclusion is analyzed and discussed in detail in the Operational Solutions Development section below.

Since different types of fuels cannot be stored together, increase in the overall storage capacity at every location used will be significant in order to meet the Store Fuel requirement defined by FIST. Even if existing F-76 storage is adequately cleaned and purged, volumetric storage needs will increase due to FT S-5's comparatively lower energy density.

Expansion of fuel transfer capabilities ashore may be needed in order to accommodate increased OPTEMPO in order to meet the Transfer Fuel requirement.

C. OPERATIONAL SOLUTIONS DEVELOPMENT

1. Operational Planning Considerations

One of the overriding goals of this project was to ensure that the GSG will be operationally relevant and effective using an alternative fuel. To this end, FIST developed a model, termed FISTSIM, and used it to explore fuel supply/resupply alternatives within normal fleet operating procedures and guidelines. This tool provided a means to evaluate the trade space for FIST requirements of transport, store, and transfer fuel. Furthermore, this allowed evaluation of the use of FT S-5 while assessing its feasibility within the defined constraints of:

- Changes to infrastructure shall be accomplished by 2016 in order to support a Green Strike Group deployment
- Operations Tempo impacts to Navy UNREP and Defense Fuel Support Points shall be minimized such that the Navy's operational commitments are not degraded.

2. FISTSIM Background

Early in the analysis phase, FIST determined that the fuel estimation tool as presented in Chapter IV was sufficient to provide a rough order of magnitude of fuel consumption estimation. However, FIST noted that the fuel estimation tool lacked the fidelity to analyze real-life operational considerations facing a deployed GSG operating with minimal fuel infrastructure support. A more sophisticated model was then required that could account for considerations such as:

- Geospatial locations of possible DFSPs, locations of the GSG, and the transit times required by the oiler when refueling from DFSPs
- Geospatial considerations of moving the GSG through oceans as well as restricted waterways
- Geospatial limitations on refueling opportunities
- Operational limitations imposed by the oiler's maximum speed being significantly less than that of the rest of the GSG
- Calculation of time and space-based performance metrics required for solution analysis

A variety of modeling techniques were considered including more advanced Excel-based models, discrete event models using purpose-build simulation software, and developing a high-fidelity computer model in an object-oriented programming language. Given the complicated nature of moving ships across the elliptical surface of the Earth and the desire to develop sophisticated data analysis tools, FIST decided to develop a simulation program using an object-oriented language called C#.

a. Objectives

FISTSIM was designed to study the performance characteristics of the GSG supported solely by a single escort oiler and one or more shore-based DFSPs. A single oiler was selected due to the desire to minimize impact to the current F-76 infrastructure supporting conventionally fueled ships. Using two or more oilers was deemed a relatively trivial solution with regard to transporting fuel in support of the GSG; however, the associated costs with reserving two of the USN's limited supply of existing oilers in support of a single GSG deployment was deemed an undesirable solution.

During the simulation, the escort oiler remains with the GSG and refuels ships when necessary. Once the oiler's fuel level becomes low, the oiler travels to the nearest available DFSP (as configured by the model's input parameters), refuels, and returns to the fleet. FISTSIM models the interactions of the various system components on an hour-by-hour basis for the entire mission profile, a six month deployment.

FIST analyzed the operational performance of the GSG by varying the number and location of available shore-based DFSPs with the goal of:

- Identifying viable solutions to support a GSG deployment per the proposed mission profile
- Minimizing shore infrastructure requirements to sustain the GSG
- Minimizing operational impacts to the GSG due to limitations of the refueling infrastructure

b. Parameters

FISTSIM supports a wide variety of simulation input parameters defined in a configuration file. These parameters include simulation settings such as the number of runs per simulation and the type of statistical distribution to use for randomizing the ships' speed profiles. Additionally, FISTSIM includes a host of parameters related to operational aspects of the GSG, such as number of each type of ship, maximum speed, tank capacities, refueling level, and refueling rate. FIST identified suitable values for all parameters and performed analysis using 1000-run Monte Carlo simulations while holding all the input parameters constant with the exception of the available DFSPs.

The fuel consumption rates for the DDG and CG ships are provided as parameters in the FISTSIM configuration file. The fuel burn rates are referenced to F-76. Fuel burn rates for the alternative fuel are calculated by dividing the F-76 burn rate by the relative energy density of the alternative fuel as compared to F-76. This results in an identical energy flow rate into the gas turbine engines yielding identical shaft horsepower and ship cruising speeds.

FISTSIM has the ability to apply randomizations to the speed profile data based on a normal distribution. A normal distribution was chosen over other distributions given the assumption that a ship's commander was equally likely to choose a speed that was one or two knots lower or higher than the stated speed profile. The use of normal distributions for both the selected ship speed and duration values based on the mission segment speed profile improves the quality of the stochastic simulation. The end goal was to generate statistical data that more closely resembles the performance of the GSG due to the uncertainties in the actual operation of the GSG ships.

c. **Validation**

To validate the FISTSIM model, the fuel calculations generated were verified against the Microsoft Excel fuel estimation tool developed for the mission profile, as discussed in Chapter IV. Common metric values of FISTSIM were within 0.6% of the Microsoft Excel fuel estimation tool. In addition, the FISTSIM model fuel consumption calculations were also within 5.2% of the fuel estimation process described in the Navy Warfare Publication Sustainment at Sea NWP 4-01.2. Therefore, FIST determined that FISTSIM accurately models GSG fuel consumption and operational performance parameters. For a more detailed discussion of the FISTSIM model, including its input parameters and execution, see Appendix B.

3. Potential DFSP Location Options

With a model developed, FIST identified three DFSP locations in the vicinity of the mission profile's operational areas. The DFSP locations considered were Djibouti, Souda Bay, and Fujairah (as shown in Figure 28). Based on these three locations, it was determined that there are six feasible alternatives for forward-basing FT S-5 fuel. These six operationally plausible options are:

- Djibouti
- Fujairah
- Fujairah & Souda Bay
- Djibouti & Souda Bay
- Djibouti & Fujairah
- Fujairah, Souda Bay, & Djibouti

The option of using only the Souda Bay DFSP, located in the Mediterranean Sea, was not considered as it is not operationally practical to utilize solely in sustaining the GSG operations in the Arabian Sea area since the Suez Canal would have to be traversed for each and every oiler refuel.

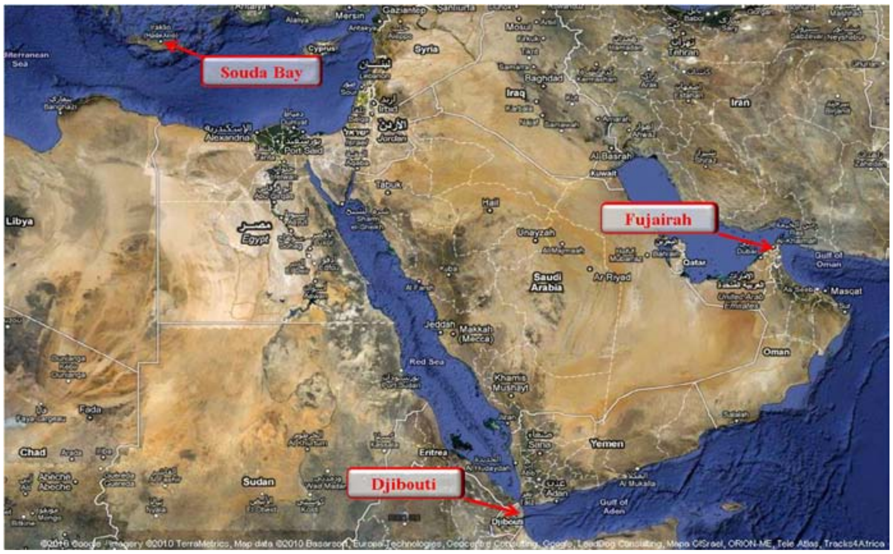


Figure 28. DFSP Locations. After (Google Earth, Mediterranean, Middle East)

Locations of Djibouti, Fujairah and Souda Bay DFSPs.

4. FISTSIM Simulation Data as OPTEMPO Metrics

FISTSIM data include several parameters that can be used to compare the options, including: hours of operation with a restricted speed (to conserve fuel while waiting for refuel), mission time underway, distance T-AO traveled, number of T-AO refuels, and quantities of fuel dispensed at each forward operating DFSP location.

These FISTSIM-generated parameters are mapped against the functional requirements for the purpose of indicating their impact to operational tempo, as shown in Table 11.

Table 11. FISTSIM Results Mapped to Requirements

Mapping of the FISTSIM simulation data to the functional requirements to establish traceability to operational tempo measurements.

Functional Requirements	Hours of operation with restricted speed	Time underway	Lowest fuel tank level	Fuel burned	Number of UNREPS	Oiler distance traveled	Number of Oiler refuels	Storage volume at DFSP
Transport Fuel	N/A	N/A	N/A	N/A	Less is better	Less is better	Less is better	N/A
Store Fuel	Less is better	N/A	MORE is better	N/A	N/A	Less is better	N/A	Less is better
Transfer fuel	N/A	Less is better	N/A	Less is better	Less is better	N/A	Less is better	N/A
Control fuel inventory and movements	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Less is better

Data was generated by the FISTSIM model for the six options. In Table 12, the Djibouti option is presented as an example of the data generated by the model.

Analysis of the FISTSIM data of the six options was conducted to determine which measures would be useful in discriminating OPTEMPO performance between the respective DFSP options. For this purpose, the Djibouti scenario was chosen as a baseline. All of the FISTSIM DFSP options data varied from 98% to 116% of the Djibouti-only option, with the exception of Hours of Restricted Operation (HRO). This metric accounts for the time the GSG is either being refueled or has reduced speed to preserve fuel while waiting for the oiler to return from a DFSP with fuel. The HRO varied from a minimum of 572 hours (Souda Bay & Fujairah Scenario) to 1500 hours

(Fujairah Scenario), yielding a variation from 68% to 179% of the baseline scenario. Therefore, the HRO was determined to be the most significant factor in deriving an OPTEMPO metric for the GSG.

Table 12. Baseline OPTEMPO Scenario

FISTSIM model data for Djibouti scenario.

Djibouti Scenario	**Average (1000 runs)**
Mission Time Underway (Days)	173.2
Fuel Burned (bbls)	629,967.7
Restricted Ops (hrs)	836.9
DDG0 Lowest Lvl %	52.1
DDG1 Lowest Lvl %	54.1
DDG2 Lowest Lvl %	49.7
CG0 Lowest Lvl %	59.1
CG1 Lowest Lvl %	56.6
DDG Avg Num. of Refuelings per ship	50.0
CG Avg Num. of Refuelings per ship	43.4
Oiler Distance Traveled (nm)	48,697.9
Oiler Num of Refuels	9.6
DFSP Djibouti Fuel Used (bbls)	545,668.3
DFSP Souda Bay Fuel Used (bbls)	0
DFSP Fujairah Fuel Used (bbls)	0
Total Scenario DFSP Fuel (bbls)	545,668.3

Given that OPTEMPO is the pace of performance in military operations, the assumption was made that if operational speeds are restricted due to lack of fuel, the GSG operational capabilities will suffer as the number of HRO increases. Therefore, the ratio of HRO to Mission Time Underway (in hours) is a suitable derived metric for estimating OPTEMPO. This derived metric is defined as OPTEMPO Efficiency = 1 – (HRO/Mission Time Underway).

5. Results

With an appropriate metric defined for comparing the options, the OPTEMPO Efficiency was calculated for each option. Table 13 shows a summary of these scores. The option to use only the DFSP at Djibouti scored second to last; however, all options except for Fujairah were closely clustered in score.

Table 13. Scenario OPTEMPO Efficiency Scores

Rank order of scenarios based on OPTEMPO Efficiency using Djibouti-only option as baseline.

Scenario	OPTEMPO Efficiency (Higher is Better)	OPTEMPO RANK
Souda Bay & Fujairah	86.0%	1
3 DFSP	85.5%	2
Fujairah & Djibouti	83.6%	3
Souda Bay & Djibouti	82.8%	4
Djibouti	79.9%	5
Fujairah	68.3%	6

In the worst case (Fujairah-only option), all five of the GSG surface combatants' average lowest fuel tank levels ranged from 28.6% to 47.9 %. This is reflected by the OPTEMPO Efficiency which is well below that of the other DFSP options. Because the average lowest fuel tank level was below the 50% requirement, the option where Fujairah is the single overseas DFSP supporting the GSG with FT S-5 is considered to be an infeasible solution.

6. Cost Analysis

The next step was to evaluate the projected cost of the six options in terms of "start-up" costs. The major cost drivers for getting a GSG deployed in the short-term were assumed to be military construction and fuel. These also were assumed to be viable discriminators between the DFSP options. Archive and recent data from Federal Business Opportunities was researched to determine potential construction costs of the OCONUS infrastructure needed to support the GSG. Eight contract awards were found that were subjectively similar in description to what would be needed for the FIST DFSP options. As shown in Figure 29, non-linear regression analysis was performed in order to derive an equation for storage tank size versus cost of construction. It must be noted that due to the small sample size and large variation in source data, the predicted cost curve is subject to uncertainty of +/- 30%. This indicates that further research will be necessary but that this analysis is sufficient for obtaining a rough order of magnitude cost for storage tanks.

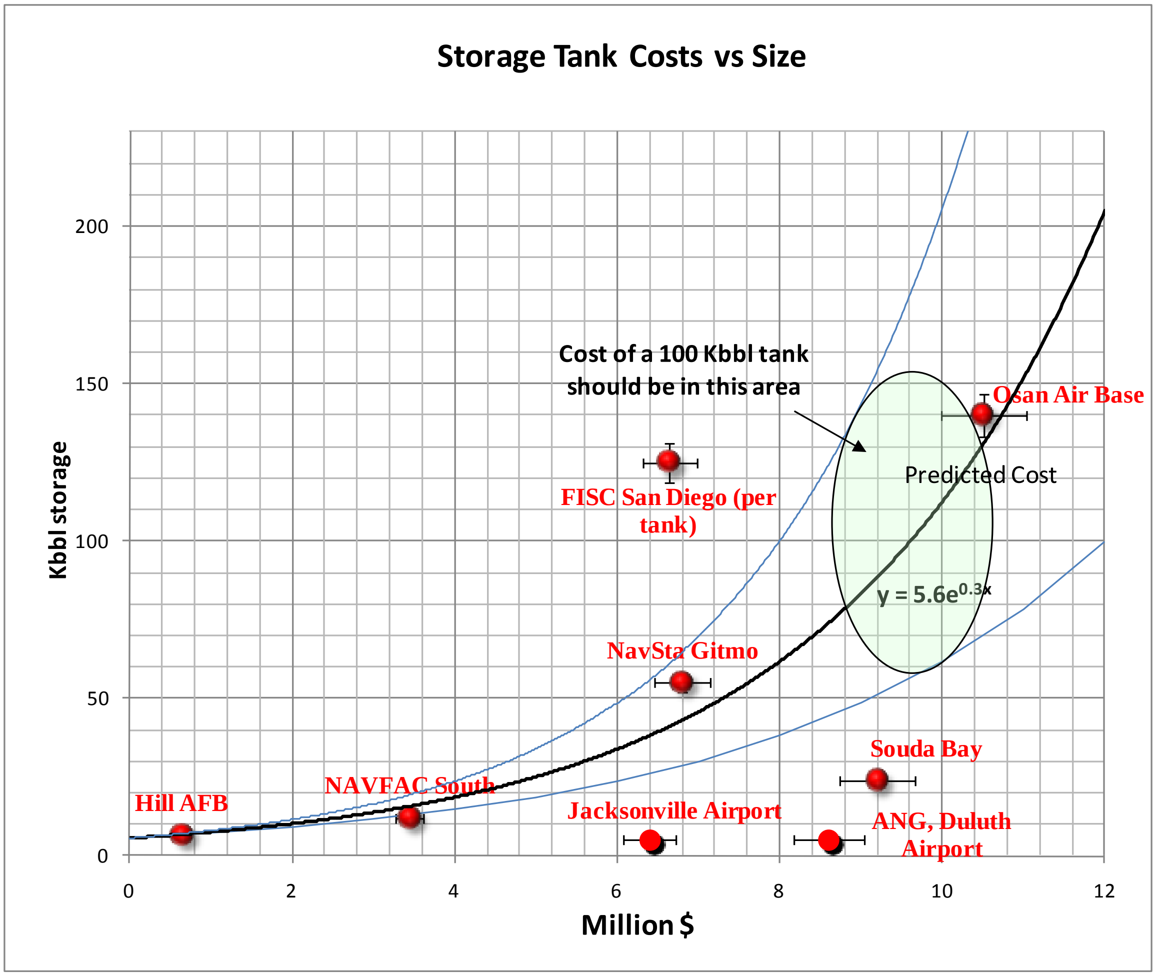


Figure 29. Storage Tank Size vs. Cost

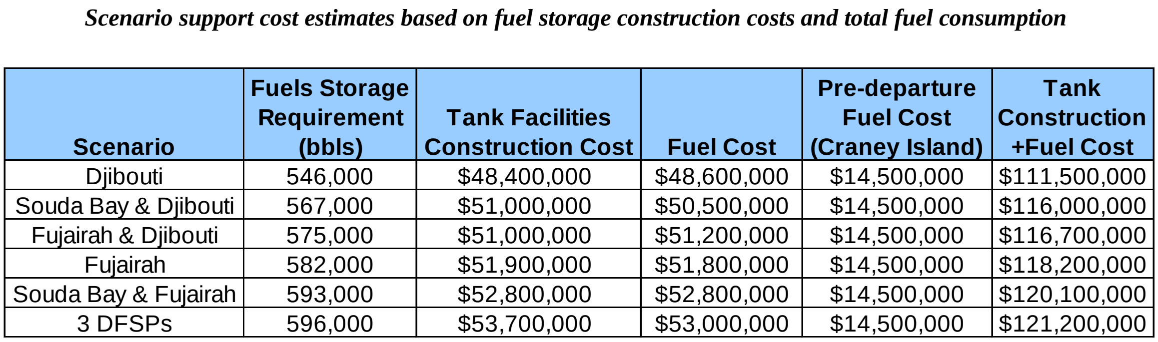
This figure depicts potential cost of construction of a fuel distribution system based on the size needed (Defense Logistics Agency 2009; U.S. Department of Homeland Security 2005; U.S. Air Force 2003; United States Navy 2003; United States Navy 2010).

FISTSIM data indicated that the minimum required storage at any one location across the six options was approximately 76,000 bbls. Therefore a 100,000 bbl fuel tank was selected as a conveniently-sized tank large enough to provide significant storage.

Using this analysis, FIST estimated that construction of a suitable, 100,000 bbl fuel tank would cost approximately $8.8 million (FY10 dollars).

FIST used existing research to estimate the FT S-5 fuel costs in the 2016. Based on the production potential of FT S-5 using the coal-to-liquid (CTL) process in 2017, only 1 year after the planned sailing of the GSG, the maximum projected cost of FT S-5 is $2.12 per gallon (Hileman et al. 2009, 42). This is expressed in FY10 dollars to be consistent with the fuel tank costs. This figure was used as a point estimate for the fuel cost of each of the scenarios. The total fuel burned in each scenario (the mean plus two standard deviations from the FISTSIM model) was then used to obtain the overall fuel cost of the scenario. The results of this analysis are shown in Table 14.

Table 14. DFSP Option Construction and Fuel Cost Comparison



Scenario support cost estimates based on fuel storage construction costs and total fuel consumption

Scenario	Fuels Storage Requirement (bbls)	Tank Facilities Construction Cost	Fuel Cost	Pre-departure Fuel Cost (Craney Island)	Tank Construction +Fuel Cost
Djibouti	546,000	$48,400,000	$48,600,000	$14,500,000	$111,500,000
Souda Bay & Djibouti	567,000	$51,000,000	$50,500,000	$14,500,000	$116,000,000
Fujairah & Djibouti	575,000	$51,000,000	$51,200,000	$14,500,000	$116,700,000
Fujairah	582,000	$51,900,000	$51,800,000	$14,500,000	$118,200,000
Souda Bay & Fujairah	593,000	$52,800,000	$52,800,000	$14,500,000	$120,100,000
3 DFSPs	596,000	$53,700,000	$53,000,000	$14,500,000	$121,200,000

The pre-departure cost of fueling the GSG ships at Craney Island is constant across the six options. As such, it is separated from the cost of fuel stored overseas.

7. Cost Benefit Analysis

Evaluations of the OPTEMPO and Cost estimates for each of the scenarios provide divergent answers in terms of "best" potential DFSP option. Given this discrepancy, FIST elected to do a cost-benefit, or "Bang for the Buck" evaluation of each option. In Figure 30, the previously presented OPTEMPO Efficiency values for each option are plotted versus the option costs.

As discussed previously, the Fujairah-only option is a poor performer. This is shown more clearly in Figure 30 as its "bang" is much lower than the other options for a similar cost. The other options are much more similar in cost and performance. Figure 31 is a closer view of the relevant performance and cost region from Figure 30.

It is logical to expect that the cost of maintaining multiple DFSP FT S-5 storage facilities will increase over that for a single DFSP. Personnel, maintenance, training and other costs will also be multiplied as the number of DFSPs increase. As a result, it is evident that the preferred option is to use the DFSP at Djibouti as the sole refueling point for the GSG with a single T-AO based on the mission profile.

It is important to note that the maximum projected price of CTL FT S-5 was used for this analysis ($89/bbl). The order of the six options, in terms of cost, does not change across the range of the projected price for the CTL FT S-5 fuel. In other words, Djibouti as the preferred option is not sensitive to the projected price range of CTL FT S-5.

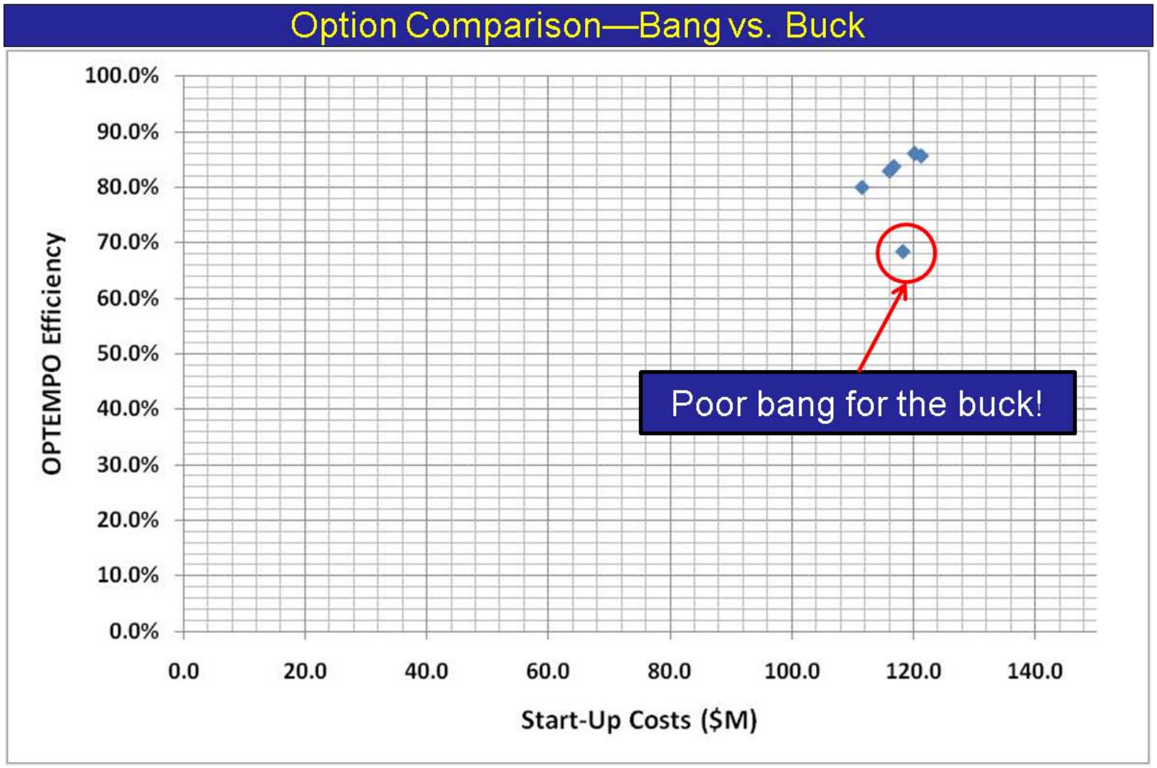


Figure 30. OPTEMPO Efficiency vs. Cost

This figure illustrates the relationship between scenario cost and OPTEMPO Efficiency. As the number of supporting DFSPs increase, the OPTEMPO Efficiency increases, but with diminishing returns.

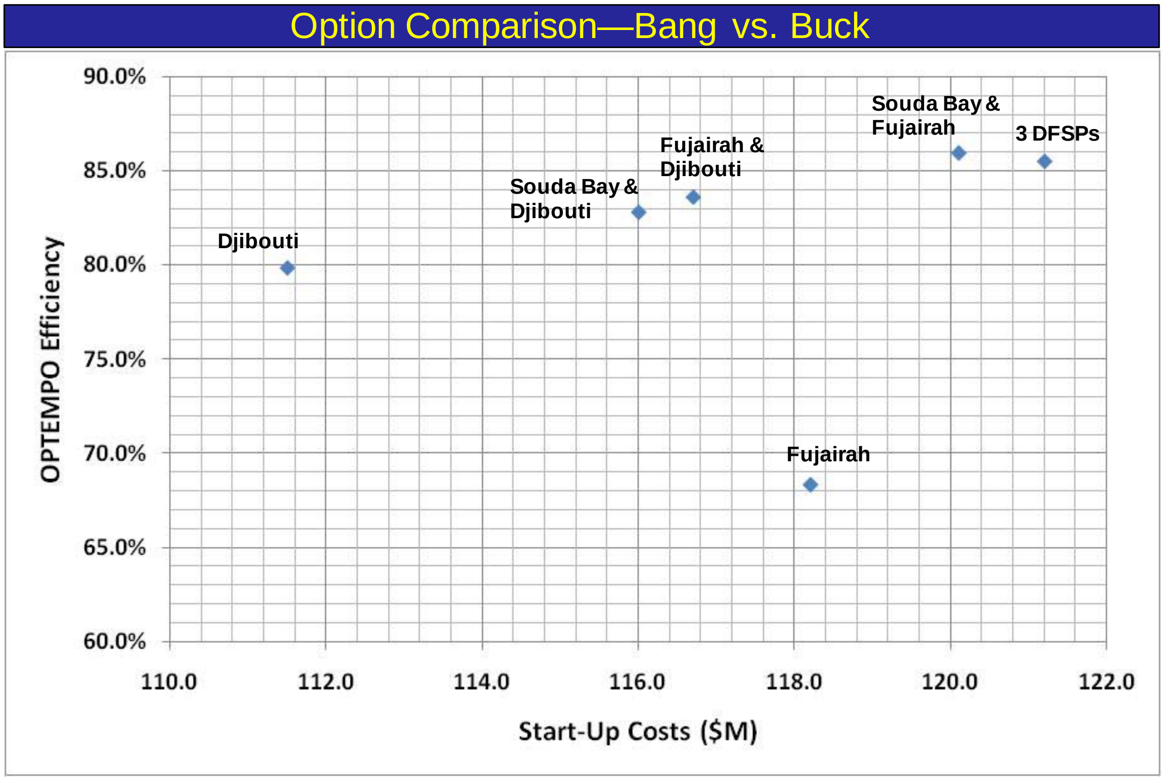


Figure 31. Close-up of Relevant Bang vs. Buck Region

This figure looks at a zoomed in region of the performance vs. cost graph for the DFSP options.

D. CONCLUSION

In summary, addressing Research Question 4, “What key modifications to existing ashore and afloat fuel distribution systems are necessary to facilitate the identified alternative fuel?” the following recommendations are made:

Based on the options discussed in this chapter, it is recommended that the DFSP at Djibouti be used to stage FT S-5 fuel to support the GSG during its mission. This recommendation is based on the mission profile documented in Chapter IV and the analysis of this and other options earlier in this chapter. The key modifications required based on this mission profile are:

- Storage will be needed for a minimum of 546,000 barrels of FT S-5 fuel at the Djibouti DFSP.
- The number of UNREPS to support the mission will increase by 5% as compared to the same operations conducted with F-76.
- The number of times the oiler will need to be refueled will increase by 11% as compared to the same operations conducted with F-76.

While these recommendations are based on the identified mission profile, similar modifications will be necessary for any mission selected. This is due to the increased amount of fuel required because of the lower energy density of FT S-5 and the need to store this fuel separate from F-76, thus requiring additional storage capacity.

Additionally, a summary of DOTMLPF changes were identified that require more study to meet the identified non-functional requirements.

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VII. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

FIST established and executed a systems engineering process to determine the key modifications to the Navy's existing fueling infrastructure that will be required with the introduction of an alternative fuel to power the GSG.

To scope the problem, FIST assumed a representative GSG composition and focused its efforts on the Navy's infrastructure systems used to store, transfer, and deliver fuel to the specified three destroyers and two cruisers of the GSG. FIST focused on the systems controlled by the Navy and excluded the systems used by the commercial energy industry to deliver the fuel to the Navy.

With the problem scoped, FIST developed four research questions to support and focus progression through the SE process.

> *Research Question 1*: What alternative fuel has the *most potential* to support the goal of deploying a Green Strike Group by 2016?

FIST determined that S-5 jet fuel manufactured by the Fischer Tropsch (FT) process has the most potential to support the sailing of the GSG by 2016. The FT process is mature. However, recent studies indicate a domestic production potential of only 75,000 barrels per day of an FT-derived jet fuel by 2017 using the CTL process (Hileman, et al. 2009, 41). The GSG would require approximately 2% of this annual production just to complete the single mission defined for this study. While the use of a CTL FT S-5 would reduce dependence on foreign sources, to be considered green, the fuel would need to be produced with biomass-to-liquid (BTL) FT process. However, while fundamental uncertainty exists in predicting the economic production potential of a BTL FT fuel in the 2016 time frame, a recent study indicates an estimated production price of $6.00 per gallon equivalent to $252/bbl (Hileman, et al. 2009, 45). Therefore, to meet the 2016 goal, the Navy would have to rely on the non-green (but energy independence fostering) CTL FT process and phase-in BTL FT as it becomes commercially available and affordable.

To amplify, the fuel costs of the recommended option of Djibouti using CTL FT S-5 and BTL FT S-5 were compared to the current use of F-76. The cost of a barrel of F-76 was estimated to be $91 based on review of an offer data sheet with listings of Diesel Fuel Marine quantities and prices (Defense Logistics Agency July 2010). The costs of CTL FT S-5 used the previously discussed cost of $89/bbl and the BTL FT S-5 used the cost of $252/bbl. The use of CTL or BTL FT S-5 will require 14% more fuel to complete the mission profile as compared to using F-76. The use of CTL FT S-5 represents an 11% increase in fuel cost, and the use of BTL FT S-5 represents a 214% increase in the fuel cost to complete the mission profile when compared to the cost of using F-76. The results are summarized in Table 15. While the CTL FT S-5 looks like a promising alternative given that there is not much of a cost increase compared to F-76, there would still be the additional costs associated with storage and other costs associated with switching to FT S-5 as previously discussed. Furthermore, as mentioned in the previous paragraph, the CTL FT S-5 may not be considered to be as good a "green" alternative as the BTL FT S-5.

Table 15. FISTSIM Comparison of FT S-5 versus F-76 for Djibouti Option

Comparison of the cost associated to supply the Djibouti DFSP with fuel for F-76, CTL FT S-5, and BTL FT S-5.

	Djibouti (F-76)	**Djibouti (CTL FT S-5)**		**Djibouti (BTL FT S-5)**	
	Value	Value	Delta	Value	Delta
Fuel Received (bbls)	481,000	546,000	14%	546,000	14%
Cost of Fuel Received	$43.8M	$48.6M	11%	$137.6M	214%

To arrive at the conclusion that FT S-5 has the *most potential* to support the deployment of the GSG, FIST compared ten alternative fuels against criteria identified as a result of the following research question:

> *Research Question 2*: What are the necessary criteria for evaluating an alternative fuel to meet the goal of deploying a Green Strike Group by 2016?

Twelve criteria were identified, either from critical physical properties or derived from Secretary Mabus' energy goals. These are listed below in Table 16:

Table 16. Alternative Fuel Evaluation Criteria

This table lists the criteria for selecting an alternative fuel.

Criterion
Reduce Dependence on Foreign Sources
Available through DESC by 2016
Flash Point
Overall Safety
Storage Stability
Energy Density
Compatibility with Shipboard Equipment
Viscosity
Corrosiveness
Lubricity
Solubility in Water
Density

Of these criteria, energy density will likely have the most significant impact to the Navy in the long-term. Fuel availability can improve with sufficient economic investment. Furthermore, additives can be engineered to address the impacts of differing physical properties such as viscosity and lubricity. However, the lower energy density will have an operational impact to the Navy in terms of less operational range, a greater number of UNREPs during deployment, and additional storage requirements.

> *Research Question 3*: What are the current ashore and afloat fuel distribution systems used to provide fuel for selected ship classes?

Infrastructure requirements were generated from the study and documentation of existing ashore and afloat fuel distribution systems. The existing fuel systems were used as a basis for determining the key modifications that will be required with the introduction of the FT S-5 fuel.

The organizations involved in the ashore and afloat fuel distribution systems were documented along with their responsibilities and relationships.

Using the Universal Navy Task List (UNTL) as a guide, functional descriptions of the fuel infrastructure were created along with physical descriptions of the major components.

With a fuel selected and existing infrastructure documented, FIST completed the final step required to support requirements generation—the development of a mission profile. FIST postulated a six-month mission for the GSG, departing and returning to Norfolk, Virginia after patrolling two operational areas in the Arabian Sea, totaling 43,860 nautical miles.

Using the existing architecture, characteristics of the FT S-5 fuel, and the mission profile, FIST developed the requirements detailed in Table 10. These included functional requirements traceable to the top level functions of the infrastructure and non-functional requirements. FIST used these requirements as a launching point to answer the last research question:

Research Question 4: What key modifications to existing ashore and afloat fuel distribution systems are necessary to facilitate the identified alternative fuel?

To determine the extent of the modifications required, FIST generated several options that could support the GSG's completion of the mission profile. Requirements-based metrics were developed, along with a selection process that included a cost benefit analysis of the options. For the documented mission profile, the key modifications required are:

- Storage will be needed for a minimum of 546,000 barrels of FT S-5 fuel at the Djibouti DFSP.
- The number of UNREPS to support the mission will increase by 5% as compared to the same operations conducted with F-76.
- The number of times the oiler will need to be refueled will increase by 11% as compared to the same operations conducted with F-76.

It was estimated that the storage and fuel costs for this single mission will be in excess of $110M, nearly half of which is due to the additional storage requirement.

FIST recognizes that these modifications are dependent on the selected mission profile. However, similar modifications will be required for any mission simply due to the reduced energy density of alternative fuels and the lack of alternative fuel storage infrastructure within the existing architecture.

FIST also noted modifications that will need to be made to the non-functional requirements derived from the existing infrastructure. This includes the need for additional training, changes in fuel quality testing, and impacts to Environment, Safety, and Occupational Health.

In summary, FIST researched and proposed an alternative fuel for the GSG, documented the existing fueling infrastructure, and created a mission profile. This information was used to generate requirements and for examining the key modifications that will be required to support the sailing of the GSG.

B. RECOMMENDATIONS

FIST concludes that sailing a GSG by 2016 is technologically possible, but the FIST recommends the following to reduce the risk of sailing the GSG by 2016:

- The Navy should determine the alternative fuel that will power the GSG immediately. This study identified several characteristics of alternative fuels that will have an impact on the fueling infrastructure, including reduced energy density. This, for instance, drives the need for additional storage which in turn requires significant construction costs. Identifying the fuel now will reduce the risk to sailing the GSG in 2016, allowing time to assess the infrastructure impacts and account for necessary changes in the appropriate DoD budget cycle.
- The Navy should concurrently decide on a GSG mission and identify the sites or manner in which the alternative fuel will be stored.
- The Navy should consider a phased approach to implementing an alternative fuel for the GSG. The research conducted during this study indicates that alternative fuels made from a biomass feedstock, that could substantially improve life cycle green house gas emissions, are considered higher risk to be available in sufficient and affordable quantity by 2016. However, there are fuels, such as the FT S-5 with coal as a feedstock, that have price projections comparable to F-76, and are lower risk to be available in sufficient quantity by 2016. Thus, it may be preferable to initially sail the GSG with an interim source of FT S-5 and switch to a “greener” FT S-5 when affordable.

C. AREAS OF FURTHER STUDY

Based on the research and analysis conducted during this study, the FIST recommends the following areas for further study:

- In mapping DOTMLPF impacts against requirements, FIST determined that additional training will be required across several organizations to implement an alternative fuel. It would be appropriate to study this in more detail after the Navy selects the alternative fuel for the GSG.
- FIST investigated the near-term costs associated with construction of storage tanks and fuel to power the GSG. Additional research is needed to determine the full life cycle costs of introducing an alternative fuel, to include operations, support, and maintenance for facilities and platforms running at new OPTEMPOs.
- FIST also limited its research to the infrastructure impacts from a single mission profile. Further research is needed to evaluate the impacts of sustained operations of the GSG over its entire area of responsibility.

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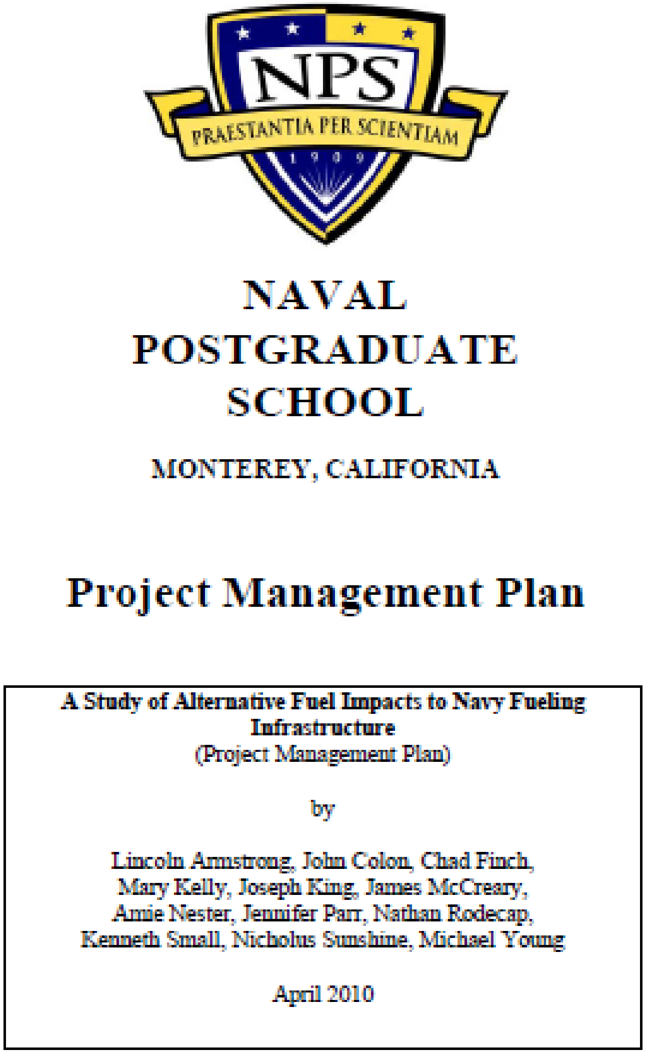
APPENDIX A: PROJECT MANAGEMENT PLAN



NAVAL
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MONTEREY, CALIFORNIA

Project Management Plan

A Study of Alternative Fuel Impacts to Navy Fueling Infrastructure
(Project Management Plan)

by

Lincoln Armstrong, John Colon, Chad Finch,
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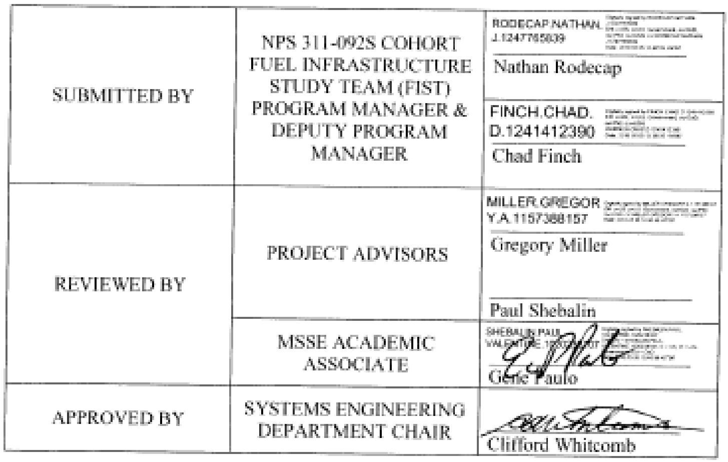
April 2010

Signature Page



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Revision History

Revision	Description of Changes	Date
0	Original Document	
1	Initial Release Document	

I. PROJECT INTRODUCTION

A. TOPIC CONTEXT

"Reforming energy use and policy within the Department of the Navy (DON) will assure long-term energy security of the United States, encourage development of efficiencies, and promote environmental stewardship [Mabus, Strategy, 2009]."

The Honorable Ray Mabus, Secretary of the Navy

1. Background

On October 14, 2009, the Honorable Ray Mabus, Secretary of the Navy (SECNAV), addressed representatives from the United States Navy (USN), Marine Corps, academia, industry, and the media during an address to the Naval Energy Forum in McLean, Virginia. In his opening remarks to the audience, he stressed that "energy reform is a strategic imperative" and as such will be one of the areas he will focus his attention on during his tenure as SECNAV [Mabus, *Forum*, 2009].

The need for energy reform in the USN is vital from a strategic perspective. Current USN operations depend heavily on fossil fuels, with most of the supply coming from volatile regions of the world in which state-run oil companies control 77 percent of the world's production [Jaffe 2007]. The current dependence upon foreign supplies is a critical vulnerability, since it is conceivable that the United States may be denied access to critical resources. Additionally, fossil fuels are ultimately a limited resource; as global supplies dwindle, competition will drive costs higher.

During his address, Secretary Mabus announced five specific energy targets that the USN will meet within the next ten years. These goals address such areas as contracting practices, environmental stewardship, energy efficiency, and alternative energy supply. Yet the one goal with perhaps the greatest near-term implications for supporting infrastructure and ship systems engineering is the second one promulgated during the address:

> *The Navy will demonstrate in local operations, by 2012, a Green Strike Group composed of nuclear vessels and ships powered by biofuel. And by 2016, we will sail that Strike Group as a Great Green Fleet composed of nuclear ships, surface combatants equipped with hybrid electric alternative power systems running biofuel, and aircraft flying only biofuels – and we will deploy it [Mabus, Forum, 2009].*

2. Problem Statement

This capstone project team, hereafter referred to as the Fuel Infrastructure Study Team (FIST), proposes researching areas that are in line with the second SECNAV goal and will thus restrict its attention to deploying a Green Strike Group by 2016. The overall question addressed by this study is: What modifications to the Navy's logistics infrastructure are required to best accommodate alternative fuels most suitable for use by the Green Strike Group?

3. Assumptions

In support of Secretary Mabus' Green Strike Group goal and the Problem Statement above, there are several key assumptions FIST makes:

- Biofuels employed by the USN will have fewer negative environmental impacts than the currently utilized fossil fuels and can hence be accurately labeled "green."
- Developing and utilizing biofuels is a productive activity consistent with addressing the strategic and tactical issues underpinning the goal of deploying a Green Strike Group by 2016.
- Production and consumption of biodiesel is consistent with the current United States' national energy strategy and is likely to remain part of that strategy for years to come.

- Non-liquid alternative fuels are undesirable since the relatively large changes to the USN’s ships, fuel storage infrastructure, and fuel delivery equipment would be uneconomical.

B. RESEARCH QUESTIONS

1. What is the current ashore fuel distribution system, including storage and delivery, used to provide fuel for selected ship classes? Specific ship classes to be addressed are the CG 47, DDG 51, and FFG 7, which are all powered by General Electric LM 2500 or LM 2500+ gas turbine engines [Federation of American Scientists, 2010].
2. What are the necessary criteria for evaluating an alternative fuel to meet the goal of deploying a Green Strike Group by 2016, with emphasis on the selected ship classes?
3. What fuel has the most potential to fulfill selected criteria for meeting the goal of deploying a Green Strike Group by 2016, based on published research?
4. Based upon a selected alternative fuel, what key modifications to USN fuel ashore and afloat distribution systems are needed to facilitate use of the alternative fuel with greatest potential for use by the Green Strike Group of 2016?

C. EXPECTED ACCOMPLISHMENTS

FIST shall apply a tailored systems engineering (SE) process to answer the research questions proposed in the previous section. Expected accomplishments include:

- Description of an existing architecture for a USN-owned shore-based fossil fuel (e.g., F-76) supply chain system. This includes subsystems used for storage, transport, and delivery of fuels to non-nuclear surface combatants located pier-side. This does not include external systems that are part of contractor delivery or free market energy infrastructure (delivery trucks, commodity transport pipelines, or other similar systems not owned and operated by the USN).

- Description of one representative existing fossil fuel delivery architecture for non-nuclear surface combatants deployed and underway. The scope of this architecture includes underway replenishment (UNREP) from a single oiler, along with the relevant fuel support architecture for the oiler.
- An Analysis of Alternatives (AoA) for a feasible alternative fuel for surface combatants. The most likely candidate for USN adoption will be used in the remainder of FIST development and activities.
- Development and description of a proposed architecture for a USN-owned shore-based alternative fuel supply chain system. This architecture will use the fuel specified by the AoA and meet all associated fuel handling and quality requirements.
- Development and description of a proposed alternative fuel delivery architecture for non-nuclear surface combatants deployed and underway. This architecture will use the alternative fuel recommended by the AoA and meet all associated fuel handling and quality requirements.

II. ORGANIZATION, ROLES & RESPONSIBILITIES

A. GENERAL

1. Students

The following students, all employees at Naval Surface Warfare Center Dahlgren Division, will be involved in the Capstone 311-092S Cohort Fuel Infrastructure Study Team (FIST): Lincoln Armstrong, John Colon, Chad Finch, Mary Kelly, Joseph King, James McCreary, Amie Nester, Jennifer Parr, Nathan Rodecap, Kenneth Small, Nicholus Sunshine, and Michael Young. Students will submit work journals to the project advisors on an “as requested” basis as a means of informing them on individual effort and progress.

2. Advisors

The following are capstone advisors for FIST: Dr. Paul Shebalin (Lead Advisor) and Gregory Miller (Co-Advisor).

B. FIST ORGANIZATION

The organization will establish temporary Working Groups (WG) to address specific needs. Each WG shall employ modular characteristics to maintain a common structure within each WG. This means all WGs will have similar processes that will be used interchangeably and will also be tailor-able to the unique requirements of the project to be addressed. This reduces duplication of effort and allows for common leveraging of the overall system engineering processes.

At times there may be more than one WG functioning with several team members concurrently serving in each group. However, each WG will only be operational until the task is complete. Once tasking is complete, team members will be released to assist with other activities in support of the organization. This is similar to the way tiger teams are stood up for a task and then disbanded upon completion.

During the life cycle of this Cohort several WGs are expected to be activated to address tasking related to the following:

- Supply chain for alternative fuel storage and delivery. The WGs expected to be utilized include System Engineering, Analysis, Architecture, Cost Modeling, and Risk Management.
- Delivery systems for afloat naval combatants. The WGs expected to be utilized include Needs/Requirements, modeling and simulation (M&S), Analysis, System Engineering, and Architecture.
- Modification requirements for USN fuel distribution systems. The WG's expected to be utilized include Project Administration, System Engineering, Analysis, Cost Modeling, and Risk Management.

The team will be nominally organized as follows in order to execute the project:

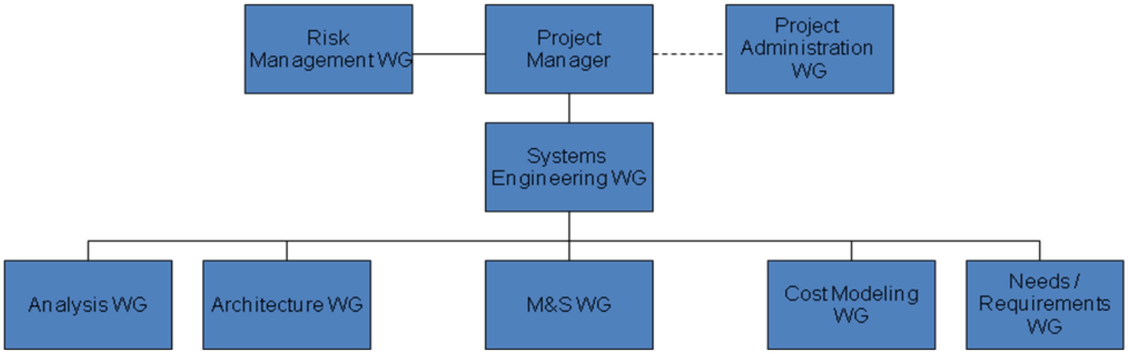


Figure 32. FIST Organizational Structure

FIST reserves the right to reorganize as necessary. The Program Manager will periodically review effectiveness of this organization as WGs are assigned to tasks and complete them. If changes are required, this Project Management Plan will be updated to reflect them.

C. FIST ROLES AND RESPONSIBILITIES

1. Purpose of Roles and Responsibilities

The purpose of Roles and Responsibilities are as follows:

- Define the roles and responsibilities of everyone involved in a FIST working group (WG).
- Focus accountability and authority within a system engineering process.
- Focus the interactions among the team members.
- Accelerate decision making within FIST.

In addition, by establishing Roles and Responsibilities FIST will be able to answer the following two questions:

- What functions, activities and tasks must be performed within each WG?
- Who must perform these functions, activities and tasks?

2. General Roles and Responsibilities

In general FIST members are expected to:

- Contribute to project schedule development and maintenance in collaboration with Project Manager.
- Contribute to overall project objectives and team deliverables.
- Escalate issues to the Project Manager.
- Attend and actively participate in team meetings. If this is not possible on a given week, advance notice is expected to be sent to the Project Manager.
- Provide an estimate of progress for assigned activities.
- Maintain appropriate records of work including any necessary documentation.

- Communicate items requiring decisions to the appropriate authority within the relevant WG(s) in a timely manner.
- Provide status updates on open action items at weekly team meetings.

3. Working Group Roles and Responsibilities

The Roles and Responsibilities for the WGs outlined in Figure 32 (above) are detailed below. While the leads of these WGs are accountable for the responsibilities noted below, it is recognized that the leads will not carry the full burden of the associated work load; it is a team effort. As the work involved in the associated tasks ebbs and flows through the SE process, the Project Manager will coordinate the resources of the FIST team to appropriately staff each WG.

Architecture Working Group	
Responsibility	Responsible for designing the system architecture in terms of a set of building blocks, and for showing how the building blocks fit together. Encompasses tools and specification of a common vocabulary.

Cost Modeling Working Group	
Responsibility	Identifies and estimates costs from initiation through disposal of the resulting system at the end of its useful life. Assess the extent to which the system is affordable and consistent with both U.S. Navy and DoD-wide overall long-range investment and force structure plans.

Modeling and Simulation (M&S) Working Group	
Responsibility	Establishes, maintains, and executes an M&S Strategy (the scope of which is to be determined). Oversees the definition of M&S requirements, M&S technique selection, and the VV&A process.

Requirements Working Group	
Responsibility	Responsible for building, allocating, controlling, and maintaining an integrated requirements baseline.

Analysis Working Group	
Responsibility	Responsible for examining stakeholder requirements, and defining Operational Concepts which guide analysis activities in support of the project. Responsible for performing analyses and interpreting validated M&S results.

Risk Management Working Group	
Responsibility	Identifies and analyze risks and their root causes using specific risk assessment criteria. Report risks using a Risk Reporting Matrix or applicable document. Reports program risks to the Project Manager. Develops appropriate risk mitigation strategies for each identified root cause, and, if appropriate, estimates funding requirements to implement risk mitigation plans. This WG will leverage the "*Risk Management Guide for DoD Acquisition*", version 1.0, August 2006.

Systems Engineering Working Group	
Responsibility	Performs planning, coordination, and performance tracking of technical tasks. Responsible for the development and quality control of refined technical information needed for decision making. Ensures that the system is effective and can be produced economically and supported throughout its projected life cycle.

Project Administration Working Group	
Responsibility	Records meeting minutes, schedules meetings, and manages Sakai and other resources. Responsible for document configuration management.

4. Specific Individual Roles and Responsibilities

Each WG will be led by a designated WG Lead. To the maximum possible extent, the WG lead position will be filled by an individual with prior experience in the activities to be performed by their respective WG. Each WG will utilize the experience and skills from assigned WG members to accomplish all tasking. The WG Lead will have recommendations on WG membership and will assign the specific tasks each member will perform.

Primary responsibilities for each FIST team member are specified below. It is anticipated that personnel may need to perform additional duties in support of secondary WGs, and will do so at the discretion of the Project Manager and WG Leads.

Project Manager Role	
Assigned to	Nathan Rodecap
Responsibility	Manages and executes the FIST project according to the Project Management Plan. This includes balancing the technical, schedule, and relevant cost performance aspects of the project. Coordinates project tasking with the System Engineer. Final decision making authority for all FIST activities. Tracks **project schedules and tracks group progress versus planned due dates.**

Project Administrator Role	
Assigned to	Amie Nester
Responsibility	Assists the Project Manager with administrative tasks; records and/or distributes meeting minutes; coordinates scheduling; organizes a repository for the project team's reports, presentations, and resource documentation; and provides document version control. Keeps track of assigned Action Items and their statuses (Open, Closed and In Process).

Lead Systems Engineer Role	
Assigned to	Joseph King
Responsibility	Develops, implements, and ensures that proper SE processes are being followed as well as makes recommendations to WGs for proper use of tools to apply to the SE Process. Responsible for the Analysis of Alternatives (AoA), trade-offs and research related to Capstone Project. Supports the Project Manager in maintaining the project schedule.

Modeling and Simulation Roles	
Assigned to	James McCreary and Jennifer Parr
Responsibility	Investigate and define M&S tools and assist the WGs in conducting M&S. Research previously developed models for possible extension.

Cost Modeling and Estimation Role	
Assigned to	Chad Finch

Responsibility	Ensures that all the categories of cost are considered to support a cost-benefit analysis. Supports Analysis WG in evaluating trade-offs that may potentially reduce cost, while ensuring that potential solutions meet all operational requirements.

Configuration Management Role	
Assigned to	John Colon
Responsibility	Responsible for maintaining a complete audit trail of decisions, design modifications, and documented changes. This includes gathering and cataloguing all reference material provided by the team. The configuration manager will also be responsible for version control of all project documentation including the final report and briefing packages.

System Architect Role	
Assigned to	Kenneth Small
Responsibility	Oversees and coordinates development of the architecture framework definition for FIST. Participates in preparation of a high level system definition and establishment of requirements for the development plan, coordinates with the Project Manager and System Engineering Lead to support the execution of all technical aspects of the system design.

Requirements Analysis Role	
Assigned to	Mary (Chele) Kelly
Responsibility	Responsible for building, allocating, controlling, and maintaining the requirements list. Maintains all requirements in a selected database. Ensures FIST requirements are captured, documented and clearly understood before any further tasking is performed.

Risk Management Role	
Assigned to	Lincoln Armstrong
Responsibility	Conducts risk identification and analysis during all phases of the program. Develops appropriate risk mitigation strategies and plans. Assesses impacts of risk during development and proposes risk mitigation strategies and activities.

Stakeholder Interface Role	
Assigned to	Michael Young
Responsibility	Interfaces with stakeholders as necessary. Operates as the single point of contact for Stakeholders with FIST. Develops and manages relationships between FIST and external parties. Disseminates information gathered to the team and alternately collects questions and queries to pass to Stakeholders.

Systems Analysis Role	
Assigned to	Nicholus Sunshine
Responsibility	Responsible for trade studies, assisting with analyses of alternatives and leading research activities as required. Additionally, evaluates technical data, maintenance planning, supply support, training, and training systems for alternative solutions. Assists WGs in evaluating M&S outputs.

III. STAKEHOLDERS

Potential stakeholders have been identified, and will be contacted as appropriate for information during the development of the FIST project. Information provided by stakeholders will be used for requirements development and systems analysis supporting the research questions. They may be asked to share briefs and documents, be interviewed, respond to questionnaires concerning needs, or provide feedback at various stages of the development process. No interviews will be conducted or questionnaires sent out until approval to do so is obtained from the NPS Internal Review Board (IRB). FIST will respect any limitations on information dissemination that may be requested by stakeholders.

Inconsistent requests or information from stakeholders will be presented to FIST members. The involved stakeholders will be contacted for clarification. The group will discuss the discrepancies, look at all available data, and make a judgment in accordance with FIST's established decision making process which requires a 3/4th's majority to make an important decision—failing that, the Project Manager is authorized to make the final decision. Project advisors will be notified whenever this situation is encountered. If required, advisors will be contacted during discussion to provide guidance.

Additional stakeholders may be identified by the FIST team as development progresses. As these are identified, all applicable documents (such as this Project Management Plan), requirements baselines, and processes will be updated. Stakeholders are categorized as follows: project resource support, naval fuel logistics community, and the operational user community. While not technically stakeholders, alternative energy subject matter experts will be listed here for completeness.

The following organizations have some part in the development, storage, transportation, or utilization of biofuels in a strike group:

A. PROJECT RESOURCE SUPPORT

- *Deputy Assistant Secretary of the Navy (Energy)*: Establishes the Navy's Operational Energy Policy [Tindal, 2010].
- *Office of Naval Research – Sea Warfare and Weapons (Code 33) - Future Naval Fuels Science and Technology Program*: Researches the impacts of introducing alternative fuels into current Navy fuel systems [Office of Naval Research, 2010].
- *Department of Agriculture (USDA)*: Partners with the Department of the Navy to explore the use of sustainable biofuels [USN, *USDA*, 2010].

B. NAVAL FUEL LOGISTICS (INFRASTRUCTURE) COMMUNITY

- *Naval Facilities Engineering Command (NAVFAC)*: Manages USN's Storage Tank Program and ensures compliance with all applicable recommendations [Naval Facilities Engineering Command, 2010].
- *Military Sealift Command – Naval Fleet Auxiliary Force*: Operates fleet replenishment oilers and fast combat support ships to supply fuel to USN ships at sea [Military Sealift Command, 2010].
- *Naval Supply System Command (NAVSUP) – Naval Operational Logistics Support Center (NOLSC) Petroleum (N42)*
    - *Petroleum Systems (N421)*: Encompasses all matters relating to petroleum systems of interest (e.g., Fuel Automated Systems, Automatic Tank Gauging, and Automated Fuels Handling Equipment). N421 also establishes petroleum policy and performs associated fiscal and administrative functions.
    - *Facilities Engineering (N422)*: Functions as the technical support and engineering services provider for fuel related military construction (MILCON) projects and Maintenance, Repair and Environmental (MRE) projects at NAVSUP fuel activities and other Navy claimant activities (USN, USMC and Air Stations).

  N4222 personnel coordinate the submission of projects and provide daily advice and guidance on programs related to the operation of Navy fuel terminals.

  - *Fuel Management (N423)*: Oversees all Navy/DESC fuel programs and provides contractual and technical assistance (i.e., technical assistance via phone and/or on-site visits to all Navy and Marine Corps fuel activities). Additionally, it acts as the interface for all fleet petroleum related issues [Naval Supply Systems Command, 2010].

C. USER COMMUNITY

- *Surface Type Commanders (TYCOMs)*: Ensure surface ships of the Pacific and Atlantic Fleets are properly trained, maintained and crewed to support military operations [United States Navy, *Navy Organization*, 2010].
- *Commander, Carrier Strike Group / Commander, Expeditionary Strike Group (Green Strike Groups)*
  - *FFG/DDG/CG Supply and Deck Departments*: Support underway replenishment operations and provide hazardous material control and coordination.
  - *FFG/DDG/CG Engineering Departments*: Operate and maintain fuel burning equipment (boilers and engines) on-board ships [Commander, Carrier Strike Group 11, 2010].

D. NON-STAKEHOLDER TECHNICAL EXPERTS

- *Dept. of Energy National Laboratories*: Provide insight into various alternative fuel research methods and modeling techniques [Department of Energy, 2010].

  - Argonne National Laboratory –Transportation Technology R&D Center
  - Lawrence Berkeley National Laboratory –Environmental Energy Technologies Division
  - Pacific Northwest National Laboratory – Energy and Environmental Directorate
  - Sandia National Laboratory – Energy Systems
  - National Renewable Energy Laboratory
  - National Energy Technology Laboratory
- *NSWC Carderock Division*: Serves as the interface between Fleet and the shore infrastructure. Provides the facilities and expertise to develop the concepts, technologies, equipment, systems and procedures necessary to enable all existing and future Navy ships to reliably, affordably, and effectively meet performance and mission requirements [Naval Surface Warfare Center Carderock Division, 2010].
- *Defense Logistics Agency (DLA)*
  - *Defense Energy Support Center (DESC) – Product Technology and Standardization Division (DESC-QT)*: Provides technical support to resolve problems in storage tanks, transportations and handling systems caused by fuel chemistry. Serves as DESC focal point for metric and measurement issues. Provides technical support for the introduction of new items of supply such fuels.
  - *Defense Logistics Information Service (DLIS)*: Provides a variety of logistics support service including green procurement reports, hazardous material resource information and DoD standardization [Defense Energy Support Center, 2010].

- *Naval Air Warfare Center Aircraft Division (NAWCAD) - Propulsion System Evaluation Facility (PECF)*
    - Fuel and Lubricants Chemistry Laboratory
    - Fuel and Lubricants Facility [Naval Air Warfare Center, 2010]

IV. SYSTEMS ENGINEERING PROCESS

A. OBJECTIVES

FIST will apply a tailored SE process to address the research questions. After consideration of multiple approaches, the team selected an SE process based on the old DoD SE process model which specifies the following general phases: 1) Requirements Analysis, 2) Functional Analysis/Allocation, and 3) Synthesis [Defense Acquisition University, 2001].

B. TAILORED SYSTEMS ENGINEERING PROCESS

The tailored SE process selected by the team is shown in Figure 33. It follows the old DoD SE process but adds an initial Alternative Fuel Selection phase which feeds activities in subsequent phases.

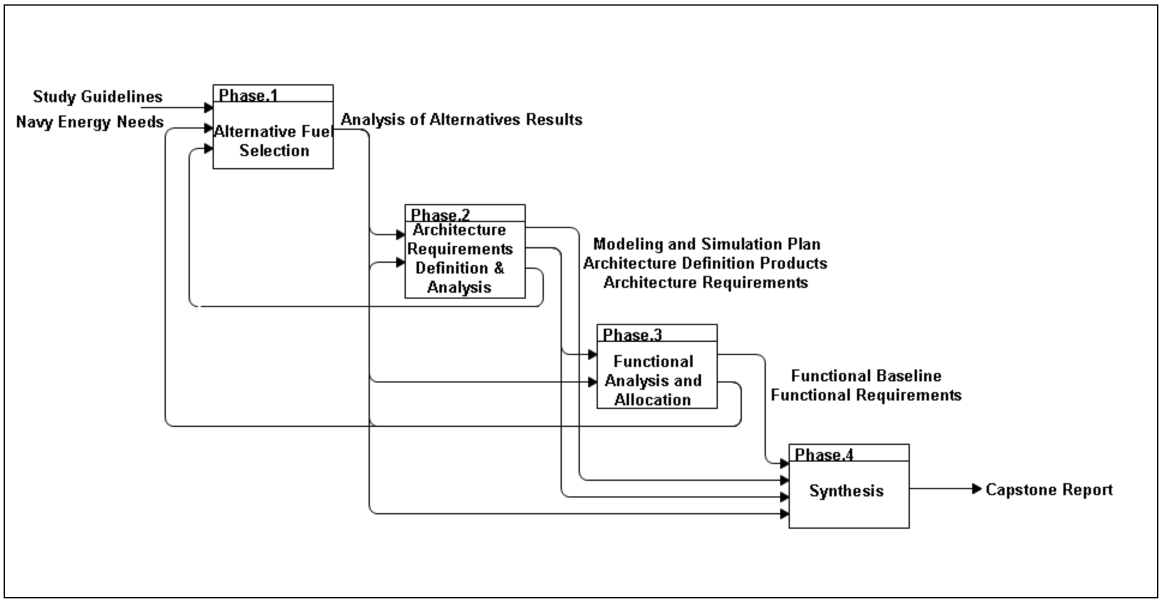


Figure 33. FIST Tailored SE Process (IDEF0 Representation)

1. Alternative Fuel Selection Phase

The team will identify relevant fuel criteria, perform a stakeholder needs assessment, and define the top-level fuel requirements for suitable alternative fuels. A set of candidate alternative fuels will be compiled, and a fuel comparison and analysis of alternatives (AoA) will be conducted. The output of this phase will include an AoA report including an alternative fuel recommendation. It is understood that there will, by necessity, be significant interaction between some activities in this phase and those activities in the Architecture Requirements Definition and Analysis Phase, including iteration of specific processes as needed.

2. Architecture Requirements Definition and Analysis Phase

The team will capture and analyze relevant documents and subject matter expert (SME) inputs for the existing fueling infrastructure (referred to hereafter as “Existing Architecture”) and proposed alternative fueling infrastructure (referred to hereafter as “Proposed Architecture”)—both ashore and afloat elements. FIST will also conduct a stakeholder needs assessment for fueling infrastructure. Additionally, FIST will identify assumptions and constraints, and develop operational concept descriptions (OCDs) for the Existing and Proposed Architectures.

These processes facilitate requirements capture from Existing Architecture elements, and enable requirements definition and analysis for Proposed Architecture elements. All classes of requirements (operational, functional, non-functional, and performance) will be considered. Outputs of this phase include architecture description products (the appropriate set of which remains to be defined), requirements lists, and OCDs. The overall architecture approach will be to define a top-level architecture, refine that to a lower-level functional architecture, and finally allocate those functions to physical components where appropriate. In addition, the team will define its modeling and simulation (M&S) approach and capture it in a document that will be refined in the following phases.

3. Functional Analysis and Allocation

The team will perform Existing and Proposed Architecture functional decomposition, and allocate functions to the requirements identified during the Architecture Requirements Definition and Analysis phase. Identifying the functional representation of the existing fuel infrastructure will provide a basis to analyze any modifications that may be necessary to support the recommended alternative fuel. In addition, the team will identify and define functional interfaces within the architectures. Since it is expected that this process will identify missing or conflicting requirements, Functional Analysis and Allocation may be performed iteratively with Requirements Definition. Consistent with this approach, these phases will not be executed in a strictly sequential manner. The CORE model-based systems engineering tool will be used to capture functions and interfaces, and an M&S approach document will be generated to guide further analysis.

4. Synthesis

The team will describe the Existing and Proposed physical architectures by identifying components (e.g., storage tank—with required properties) and mapping them to functions. Also included in this activity is identification of physical interfaces in the architectures. Once the physical architectures are defined, the team will assess Proposed Architecture options. The definition of the Existing fuel architecture will be completed first, followed by the definition of the Proposed Architecture that is based on the recommended fuel alternative from the AoA and the captured requirements and constraints for the Proposed Architecture.

It is expected that multiple potential Proposed Architecture variants will be defined, and M&S will be performed to assess performance of potential architectures relative to system requirements. In addition to the use of M&S to assess architecture alternatives, a review of the alternatives with respect to impacts to DOTMLPF will be conducted. Additionally, the team will perform appropriate cost-benefit analyses to aid in reaching an appropriate decision.

This phase will also be where all of the proposed fuel infrastructure architecture changes will be analyzed, assessed, and documented. While the overall output of the phase will be the final report, interim products within the phase will include Proposed Architecture recommendations and supporting analyses. With respect to the report development, it is expected that results within each phase will be documented as each phase is executed. By the start of the Synthesis phase all project activities executed to that point should be documented in the final report. At the end of the Synthesis Phase, all that should be needed is clean-up of the overall report and preparation of the final presentation.

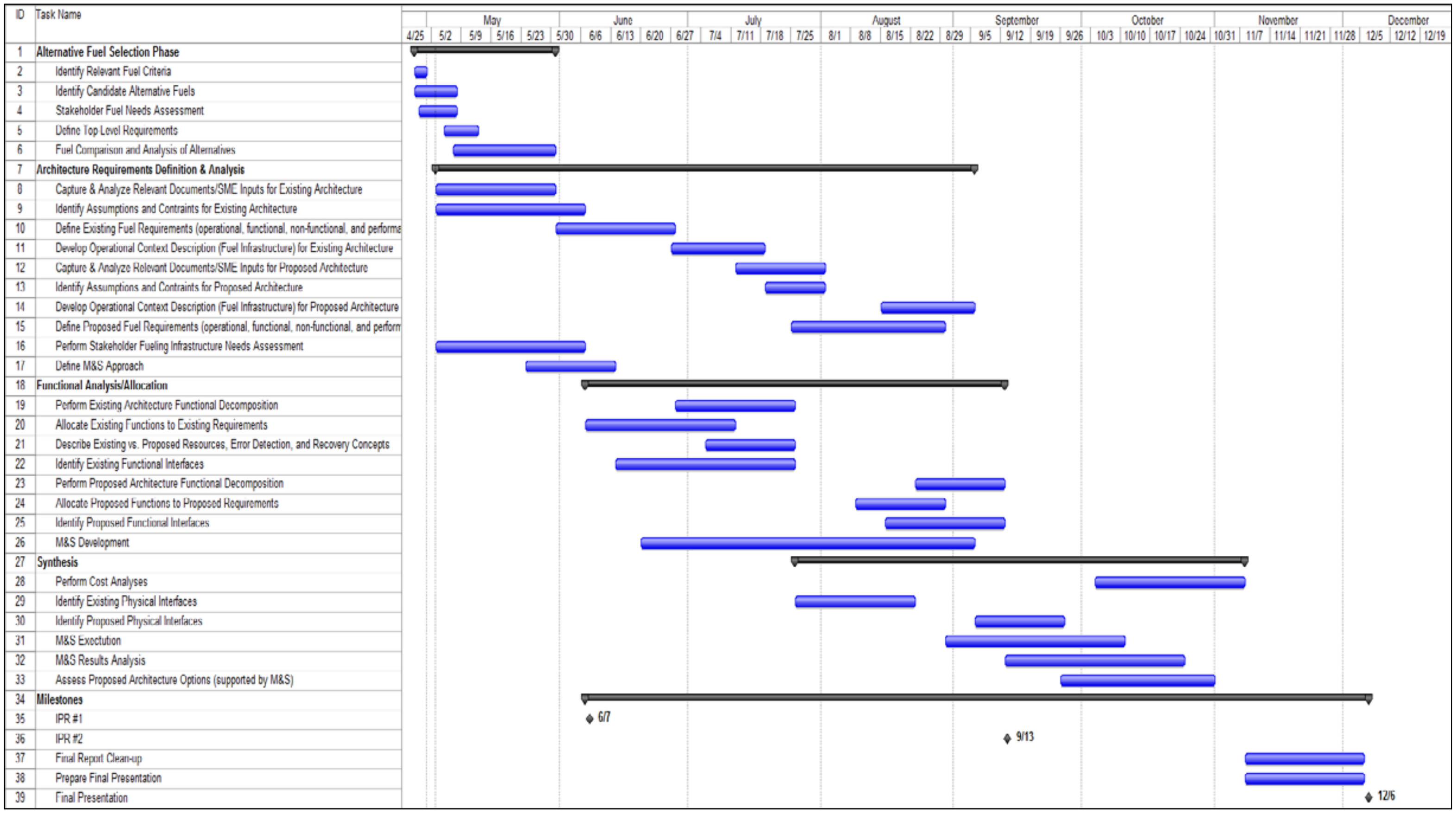
V. MILESTONES AND DELIVERABLES

A. PLANNED SCHEDULE

The project scheduled developed provides a more detailed view of the overall system engineering process to be used. The initial phase will be to select an alternative fuel for the project, however there will be overlap with defining the Existing fuel infrastructure. While that effort is taking place there will likely be some overlap with the early steps in defining the Proposed Architecture (e.g., requirements definition).

Documentation of project efforts and results is expected throughout the execution of the capstone project; however there is a period for clean-up of the overall report towards the end of the project. Likewise, though not singled out on the schedule, risk management activities are expected to be executed during all phases concurrent with the execution of specific tasks.

Actual durations of activities depicted on this schedule may change during the execution of the capstone project. Updates to the project schedule will occur on a bi-weekly basis and will be maintained in a stand-alone document.



ID	Task Name
1	**Alternative Fuel Selection Phase**
2	Identify Relevant Fuel Criteria
3	Identify Candidate Alternative Fuels
4	Stakeholder Fuel Needs Assessment
5	Define Top Level Requirements
6	Fuel Comparison and Analysis of Alternatives
7	**Architecture Requirements Definition & Analysis**
8	Capture & Analyze Relevant Documents/SME Inputs for Existing Architecture
9	Identify Assumptions and Contraints for Existing Architecture
10	Define Existing Fuel Requirements (operational, functional, non-functional, and performa
11	Develop Operational Context Description (Fuel Infrastructure) for Existing Architecture
12	Capture & Analyze Relevant Documents/SME Inputs for Proposed Architecture
13	Identify Assumptions and Contraints for Proposed Architecture
14	Develop Operational Context Description (Fuel Infrastructure) for Proposed Architecture
15	Define Proposed Fuel Requirements (operational, functional, non-functional, and perform
16	Perform Stakeholder Fueling Infrastructure Needs Assessment
17	Define M&S Approach
18	**Functional Analysis/Allocation**
19	Perform Existing Architecture Functional Decomposition
20	Allocate Existing Functions to Existing Requirements
21	Describe Existing vs. Proposed Resources, Error Detection, and Recovery Concepts
22	Identify Existing Functional Interfaces
23	Perform Proposed Architecture Functional Decomposition
24	Allocate Proposed Functions to Proposed Requirements
25	Identify Proposed Functional Interfaces
26	M&S Development
27	**Synthesis**
28	Perform Cost Analyses
29	Identify Existing Physical Interfaces
30	Identify Proposed Physical Interfaces
31	M&S Exectution
32	M&S Results Analysis
33	Assess Proposed Architecture Options (supported by M&S)
34	**Milestones**
35	IPR #1
36	IPR #2
37	Final Report Clean-up
38	Prepare Final Presentation
39	Final Presentation

Figure 34. FIST Notional Schedule (as of 03-May-2010)

B. PLANNED MILESTONES AND DELIVERABLES

Major Milestones and Deliverables

Milestone	Deliverable	Description	Date
1	Project Management Plan	PMP Approval	7 May
2	IPR 1		07 June (TBC)
Phase 1 – Alternative Fuel Selection Phase			
		Stakeholder Fuel Needs Assessment	
		Top Level Requirements Definition	
		Fuel Comparison and Analysis of Alternatives	
Phase 2 – Architecture Requirements Definition & Analysis Phase			
		Existing Architecture	
		Risk Identification and Mitigation	
3	IPR 2		13 September
		Operational Context Description	
		Stakeholder Fueling Infrastructure Needs Assessment	
		Fuel Requirements – Existing and Proposed Definition	
Phase 3 - Functional Analysis/Allocation			
		Requirements – Interface and Integration	
		Functional Baseline	
		Functional Architecture Description	
		Functional Interface Descriptions	
		Modeling and Simulation	
		Risks and Mitigations	
Phase 4 – Synthesis Phase			
4	IPR 3		13 December
		Cost Analysis	
		Physical Architecture Description	
		Alternative Fuel Impact List	
		Recommendations	
5		Final Report	13 December

VI. RISK MANAGEMENT

Risk is a measure of the inability to achieve project objectives within cost, schedule, and technical constraints. There are two primary risk components: (1) the probability of failing to achieve an outcome, and (2) the consequences of failing to achieve that outcome. The goal of risk management is to identify risks early in the systems engineering process.

FIST will develop a Risk Management Plan (RMP) and implement it to identify and track project risks and mitigation efforts. The FIST risk management strategy will be based on the Risk Management Guide for DoD Acquisition (6th edition, V1.0). Risk management will primarily address risks to the execution of the project, but will also address risk to performance of components and the overall system, and those associated with integration and implementation.

Each team member will have risk management responsibilities aligned to their specific position. All risks shall be reviewed by the appropriate WG during regularly scheduled meetings and when additional contributing or mitigating factors are observed and brought to the Project Manager's attention. Risks and mitigations will be captured in a tracking document. Items will be reviewed on an "as needed" basis.

Currently, FIST has identified five major areas of risk to address:

1. *Schedule*. FIST must be completed on schedule. The program must complete in December on time for all grading and degree decision activities to take place.
2. *Scope*. Currently the scope of the project is undergoing change as ideas are generated and the advisors and FIST team members work together to form harder guides and boundaries on the program. There is the potential for the scope to reach beyond that which may be accomplished in our limited time. Until all required groups are in firm agreement, this will be a risk area.

3. *Organization*. The turnaround of the program is quite short at 9 months. This timeframe does not provide much time for teambuilding and allowing a natural progression through storming, norming, and into the performing phase. If continued deadlines and deliverable schedules overtake the team before they have an opportunity to fully integrate, the team may not have determined effective work strategies, leading to reduced ability to produce deliverables.

4. *Technical*. There may be a lot of conflicting information concerning alternative fuels due to recent and evolving ways of evaluating fuel viability and sustainability. Additionally, existing fueling infrastructure may be poorly documented making it difficult to define an Existing Architecture at appropriate depth. Finally, Corporate Navy has a large amount of infrastructure and fuel needs. Secretary Mabus has set an ambitious goal for 2016, and the size of the changes necessary may outstrip the ability to implement the necessary changes in a timely, cost effective manner.

5. *Policy issues*. The Navy is an extremely large consumer of fuel. For this program to be sustainable, commercial production will need to be able to meet Corporate Navy consumption and delivery requirements. This will, in the long term, require a sustained effort on the part of the United States Government to encourage the growth of the biofuel sector and possible allocations of land for fuel production. Additionally, commercial facilities will need to be created or customized to the needs of biofuel. These issues lie above the Department of the Navy and will need to be national policy goals with synergistic milestones to provide for the Navy.

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APPENDIX B: FISTSIM

A. PURPOSE

In order to determine the effects of an alternative fuel on the fleet, the fuel infrastructure study team (FIST) needed to evaluate fuels using a standard comparison to F-76. The best method to do this was with a model that would walk the 2016 Green Strike Group (GSG) through our mission profile and calculate fuel usage along the way. A standard model would provide a constant set of outputs that could compare fuels used in the GSG and provide statistical data allowing FIST to determine the effectiveness of the fuel and any impacts on operational capability that may result.

During the analysis of the infrastructure required to support the GSG, FIST developed a Microsoft Excel fuel estimation spreadsheet to calculate the amount of alternative fuel required to support the GSG while executing the reference mission. The spreadsheet had the ability to calculate fuel quantity based on number of ships, operational speeds, distances, times, and fuel burn rates. The spreadsheet provided a good first-order approximation to the amount of fuel required. However, the spreadsheet could not take into account operational considerations such as time, geographical boundaries of oceans and continents, distances between the fleet and varying Defense Fuel Supply Points (DFSPs) during mission execution, and any distance the oiler had to travel to refuel. Calculations of fuel tank levels over time, the oilers' limited top speed, and other factors were also unimplemented in the Excel spreadsheet model. FIST deemed that a more detailed model was required to geographically position DFSPs in support of a GSG.

Various modeling approaches were considered including a more sophisticated Excel model, developing a discrete event model (e.g. using ExtendSim) or developing a high-resolution simulation program from scratch. FIST opted to develop a computer-based simulation using the object-oriented C# programming language due to the complexities of modeling the interrelationships of the ships moving over a threedimensional ellipsoidal surface (the Earth). FIST opted to create a model from scratch. The completed model is hereafter referred to as FISTSIM. Developing FISTSIM in C# with the Windows .NET runtime environment allowed the development team to use existing open source World Geodetic System (WGS) libraries to perform complex calculations on the Earth's surface. Specifically, FISTSIM incorporated the latest implementation of WGS, called WGS-84.

The resultant simulation program allowed FIST to explore alternatives and examine, in detail, the operational performance of the fleet over time and distance on the Earth while executing the reference mission. Additionally the model allowed for stochastic modeling of certain parameters and the generation of statistical performance data using Monte Carlo simulation techniques.

B. OBJECTIVES

FISTSIM was designed to study the performance characteristics of the GSG supported solely by a single escort oiler and one or more shore-based DFSPs. A single oiler was selected due to the desire to minimize impact to the current F-76 infrastructure supporting conventionally fueled ships. Using two or more oilers was deemed a relatively trivial solution with regard to transporting fuel in support of the GSG. However, the associated costs with reserving two of the USN's limited supply of existing oilers in support of a single GSG deployment was deemed an undesirable solution.

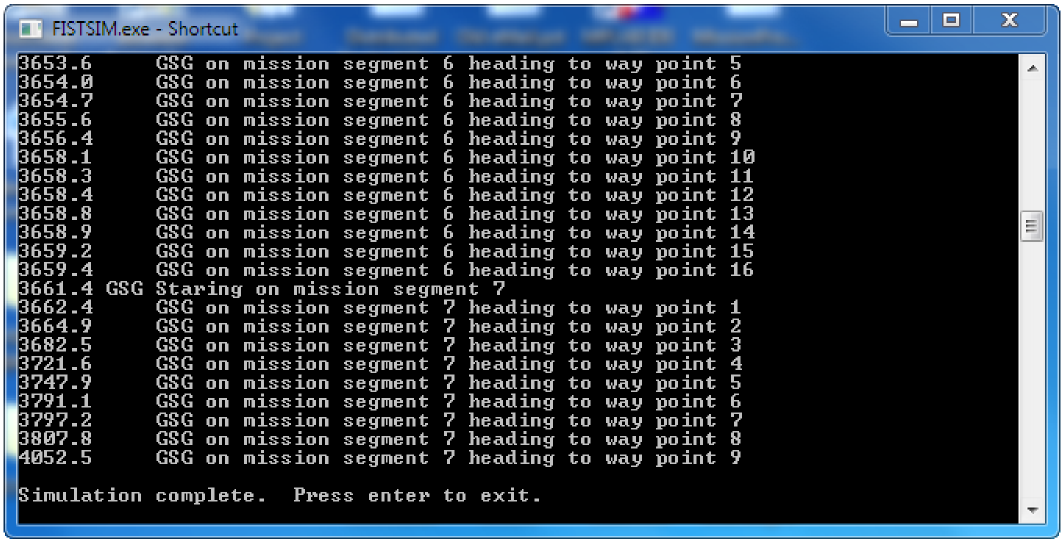
During the deployment, the GSG's escort oiler remains with the GSG and refuels ships as necessary. Once the oiler's fuel level becomes low, the oiler travels to the nearest available DFSP (as configured by the model's input parameters), refuels and returns to the fleet. FISTSIM models the interactions of the various system components on an hour-by-hour basis for the entire six month deployment.

FIST analyzed the operational performance of the GSG by varying the number and location of available shore-based DFSPs with the goal of:

- Identifying viable solutions to support a GSG deployment per the proposed reference mission
- Minimizing shore infrastructure requirements to sustain the GSG
- Minimizing operational impacts to the GSG due to limitations of the refueling infrastructure

C. COMPONENTS

FISTSIM is comprised of several components including the model's executable program, necessary input files, output files, and tools for examining the output data. The model's executable program is a Windows command line executable named "FISTSIM.EXE". Running this program requires Microsoft's .NET runtime. Figure 35 shows the standard output following execution of the model. The remaining components of the model are discussed in detail in the following sections.



```
3653.6      GSG on mission segment 6 heading to way point 5
3654.0      GSG on mission segment 6 heading to way point 6
3654.7      GSG on mission segment 6 heading to way point 7
3655.6      GSG on mission segment 6 heading to way point 8
3656.4      GSG on mission segment 6 heading to way point 9
3658.1      GSG on mission segment 6 heading to way point 10
3658.3      GSG on mission segment 6 heading to way point 11
3658.4      GSG on mission segment 6 heading to way point 12
3658.8      GSG on mission segment 6 heading to way point 13
3658.9      GSG on mission segment 6 heading to way point 14
3659.2      GSG on mission segment 6 heading to way point 15
3659.4      GSG on mission segment 6 heading to way point 16
3661.4 GSG Staring on mission segment 7
3662.4      GSG on mission segment 7 heading to way point 1
3664.9      GSG on mission segment 7 heading to way point 2
3682.5      GSG on mission segment 7 heading to way point 3
3721.6      GSG on mission segment 7 heading to way point 4
3747.9      GSG on mission segment 7 heading to way point 5
3791.1      GSG on mission segment 7 heading to way point 6
3797.2      GSG on mission segment 7 heading to way point 7
3807.8      GSG on mission segment 7 heading to way point 8
4052.5      GSG on mission segment 7 heading to way point 9

Simulation complete.  Press enter to exit.
```

Figure 35. FISTSIM Command line window

This figure is an example of what may be found as raw output when running FISTSIM.EXE.

1. Inputs

All of the model's configurable parameters are contained in a single text file called "FISTSIMConfig.txt". This file must be in a sub-folder called "Input". In this file, the user can configure all of the Configurable Items (CIs) of the model. Some of the CIs that can be modified are:

- The entire reference mission
- Operational speeds of the GSG
- Defense Fuel Supply Points that the GSG oiler can refuel at during the simulated run.
- Composition of the GSG (types and numbers of ships)
- Characteristics of the fuel (energy density)
- Desired operational performance goals
- Operational restrictions

A complete list and description of the parameters, sections, and tables that can be configured is shown in Table 17.

The input file is broken into sections indicated by "[SECTION:____]". For example, the global model configurable parameters are in the section [SECTION:MODEL_INIT], the speed profile data is contained in the section [SECTION:SPEED_PROFILE], information regarding the Djibouti DFSP is located in the section [SECTION:DFSPDjibouti], and so on.

Comments in the input file are denoted by a preceding semicolon (;). The model's executable searches the "FISTSIMConfig.txt" file looking for specific entries (called parameters) such as "Google Earth File:." It is important not to modify the name of any parameter; only modify the value that follows the colon (:) at the end of the parameter. If a particular parameter name is altered or deleted, FISTSIM will not recognize the value in the configuration file, and instead use a preconfigured default value for the parameter. The result is the model's response may not be as expected.

Table 17. FISTSIM Top-Level Parameters

This table contains the FISTSIM top-level parameters and their descriptions.

Top-Level Parameter	**Description**
Google Earth File	This parameter allows the name of the file to be customized. Enter the name of the Google Earth KML file to be generated. To view the file, one should have Google Earth version 5.0 or newer installed. Google Earth can be downloaded from: http://www.google.com/earth/index.html.
Simulation Output Log File	Provide the name for the raw data generated by the model. Once FISTSIM is executed, this file contains detailed data from the simulation.
Number of Simulation Runs	This parameter specifies how many runs will be performed by the model. For Monte Carlo simulations, enter the desired number of runs. For a single run, enter the value 1. The model takes approximately one second per run on a typical PC. *It should be noted that each run takes about 3.8MB of disk storage space for the resultant data set. A 1000 run simulation will require approximately 3.8GB of drive space.*
Generate Separate Output Files For Each Run	This is a 'Y' or 'N' parameter. A value of 'Y' will cause the model to generate a separate output file for each simulation run.
Randomize Speed Profile	This is a 'Y' or 'N' parameter. A value of 'Y' will cause the simulator to randomly select a speed profile entry from the speed profile table using a uniform distribution. This is one of the stochastic CIs of the model. The model will either iteratively select speeds and times by moving row by row down the table or randomly select an entry from the table.
Use Normal Distribution for Speed Profile	This is a 'Y' or 'N' parameter. A value of 'Y' will cause the model to select a speed and time from the speed profile using a normal distribution curve based on the mean and standard deviation data provided for each entry in the speed profile. A value of 'N' will cause model to always use the mean value for the speed and time for the entry in the speed profile. This is one of the stochastic CIs of the model.
Max Fill Level	This parameter should be between 0.0 and 1.0. This controls how full the ship's tanks are filled. A value of 0.95 is recommended. This will result in the ship's tanks being filled to 95% capacity. Typically tanks are not filled to 100% to allow for thermal expansion and prevent spilling of the fuel. Whenever the ships are refueled, their tanks will be filled to this level.
Ships Refuel at Level	This parameter sets the low level when the ships will request to be refueled from the oiler. This value should be set between 0.0 – 1.0. A value of 0.75 will result in the ships requesting refueling when their tanks drop to 75%.
Ships Slow Down for Oiler At Level	This parameter is used to trigger an operational restriction for the GSG. When the fuel level in any of the individual GSG ships drops to this level, the GSG will slow down to the speed specified in the parameter "*Max Speed Moving Away From Oiler*". This is necessary to allow the oiler to catch up with the fleet. Since the fleet's maximum speed is significantly higher than the top speed of the oiler, it is possible for the fleet to outrun

	the oiler leaving far behind its only source of fuel. Additionally, when the oiler has to make a long trip to a DFSP to on load fuel, the GSG may find itself burning through fuel too quickly resulting in unsafe fuel levels before the oiler returns. When any of the ships' fuel levels drop to this level, the GSG operates at the restricted speed as specified in the parameter: "*Max Speed Moving Away From Oiler*". The amount of time the GSG is operating in a restricted speed mode is tracked and is available in the output data files.
Fuel Energy Density	This parameter sets the relative fuel energy density of the green fuel as compared to F-76. For example S-5 has 33.0 MJ/L compared to F-76's 38.6 MJ/L. This results in an energy density of 0.854922 (i.e. a ratio of 0.855 : 1).
Fleet Max Speed	This parameter sets the maximum permissible speed of the GSG. Since a normal distribution is used for selecting speeds, it is possible for the selected speed to exceed the maximum possible speed. Any speed selected that is greater than this parameter is truncated to this value. *Note: fuel consumption values must be specified for every integer speed from 0 to Fleet Max Speed in the fuel burn rates section.*
Max Speed Moving Away From Oiler	This parameter sets speed the maximum speed the GSG will operate at when required by the rules based on the parameter "*Ships Slow Down For Oiler At Level*".
Number of DDGs	This parameter sets the number of DDGs that are part of the GSG.
DDGx Delta Efficiency	This parameter sets the relative fuel efficiency for each DDG in the GSG. An entry is required for each DDG as specified by the parameter "*Number of DDGs*". For example, if three DDGs are to be used, then the following entries must exist in the FISTSIMConfig.txt file: • DDG0 Delta Fuel Efficiency: • DDG1 Delta Fuel Efficiency: • DDG2 Delta Fuel Efficiency: The value of each parameter sets the relative fuel efficiency of each ship. For example, 0.05 indicates that the ship is 5% more fuel efficient compared to the nominal ship. A value of -0.07 indicate the ship is 7% less fuel efficient than the nominal ship. Factors such as cleanliness of the hull, damage to the propeller, etc. can impact ship fuel efficiencies.
DDG Tank Capacity (gal)	This parameter specifies the total fuel capacity of the DDGs fuel tanks. This represents the 100% full level in gallons.
Number of CGs	This parameter sets the number of CGs that are part of the GSG.
CGx Delta Efficiency	This parameter sets the relative fuel efficiency of each CG. See the discussion on "*DDGx Delta Efficiency*".
CG Tank Capacity (gal)	This parameter specifies the total fuel capacity of the CGs fuel tanks. This represents the 100% full level in gallons.
Oiler Fuel Tank Capacity (gal)	This parameter is the oiler's storage capacity for the **ship propulsion** fuel in gallons. For example a T-AO that has 50% of its fuel capacity allocated for the GSG propulsion fuel should have the number 3238200 for this parameter. *Note: oilers can carry different fuels. Only input the amount used for the ships main engines.*
Oiler Max Fill Level	This parameter should be between 0.0 – 1.0. This controls how full the oiler's tanks are filled. A value of 0.95 is recommended. This will result in the ship's tanks being filled

	to 95% capacity. Typically tanks are not filled to 100% to allow for thermal expansion and prevent spilling of the fuel. Whenever the oiler is refueled, its tanks will be filled to this level.
Oiler Min Fuel Level	This parameter sets the level below which the oiler would like to detach from the GSG and head to a DFSP to on load fuel. This parameter must be a value between 0.0 and 1.0. A value of 0.2 sets the low level to 20%. The model assumes the GSG and the oiler are in communications. The oiler considers the amount of fuel available in its tanks and the amount of fuel needed in real-time by the fleet. When the amount of fuel available minus the amount needed by the fleet will result in the oiler's tanks dropping to this level, the oiler notifies the GSG ships to top off their tanks. Then the oiler detaches (if the rules allow) to head to a DFSP for refueling.
Oiler Max Speed (knots)	This parameter sets the oiler's maximum cruising speed in knots. Whenever the fleet's speed exceeds the oiler's, the oiler will cruise at its maximum speed and plot an intercept course to re-join the GSG. Similarly, when the oiler detaches from the GSG to bring on fuel, it will cruise at its maximum speed until it rejoins the fleet.
Refuel Rate (gph)	This parameter establishes the pumping rate from the oiler to a GSG ship during refueling operations in gallons per hour.
Refuel Setup Time (hr)	This parameter established the amount of time the ships spend in preparing to come along side, connecting and disconnecting tensioning wires and hose, and separating. This results in a more time-realistic refueling sequence by the model. *Note: the model assumes the oiler can refuel ships on its port and starboard sides. When more than 2 ships require refueling, each ship takes a turn coming alongside the oiler for refueling.*
Absolute Min Level (gal)	This value sets the lowest level in the oiler's tanks below which the pumps are not able to provide fuel to ships. This value is specified in gallons. For example, when the GSG is returning to Norfolk and in the middle of the Atlantic, it does not make sense for the oiler to return to a DFSP. In this case, the ship's will continue to draw fuel from the oiler below the level set by the parameter "*Oiler Min Fuel Level*" until the oiler's fuel level drops to the value specified by this parameter. At which point, no additional fuel is available for refueling operations.
Num of DFSPs	The parameter informs the model how many DFSPs are available during the execution of the simulation.
DFSPx	For each DFSP, as specified by the parameter "*Num of DFSPs*", a corresponding entry must be made using this parameter. This parameter provides the section name that fully describes the DFSP. For example, if three DFSPs are to be used, a total of three DFSPs must be declared similar to: • DFSP0:DFSPDjibouti • DFPS1:DFSPSoudaBay • DFSP2:DFSPFujairah In the FISTSIMConfig.txt file, a section named [SECTION:DFSPDjibouti] must exist along with the required data. Similar entries must exist for each DFSP specified.

Section	*Description*
[SECTION: SPEED_PROFILES]	This is a table type parameter field. The actual table of values must be provided between the [BEGIN_TABLE:SPEED_PROFILE] and [END_TABLE] tags. The data are comma separated values (CSV) as follows: Segment Number, mean hours, standard deviation hours, mean speed in knots, standard deviation of speed in knots.

<table>
<tr>
<td></td>
<td>
<p>For each mission segment (as created in the section [SECTION:WAYPOINTS] one or more speed profile entries must be provided. For example the entry “0,2,1,5,3” means that during mission segment 0, the GSG will operate for 2 ± 1 hours at 5 ± 3 knots. The mean and standard deviation values are used to select a value from a normal distribution based on the mean and standard deviation specified. The model will select a value for speed and time from a normal distribution when the parameter “<i>Use Normal Distribution for Speed Profile</i>” is set to ‘Y’. Otherwise the model will use the mean value for time and speed. Once the fleet has operated for the specified amount of time at the specified speed, the model will select another speed/time combination from the speed profile for the current segment.</p>
<p>Based on the value of the parameter “<i>Randomize Speed Profile</i>”, the model will either iterate through all available entries for the active segment looping back to the top or randomly select an entry from all available entries for the active segment using a uniform distribution selection process.</p>
<p>Unlike the Fuel Estimates spreadsheet, the total number of operational hours in a segment does not have to equal 24 hrs. For example, the mission segment that governs the GSG sailing though the Suez Canal consists of only two entries is as follows:</p>
<p>1,1,0,5,0</p>
<p>1,5,2,10,2</p>
<p>The initial transit of the Suez is segment number 1. The ships will operate for 1 ± 0 hours at 5 knots then 5 ± 2 hours at 10 ± 2 knots. These numbers were selected based on the standard Suez transit plan where the ships maintain 10 knots until East and West bound ships cross in the center, then continue to the exit at 10 knots.</p>
</td>
</tr>
<tr>
<td>[SECTION: WAYPOINTS]</td>
<td>
<p>This section defines the reference mission profile for the GSG. It is a CSV table with the following parameters: Segment Number, Waypoint Number, Latitude, Longitude, Segment Type, Duration, and Special Instructions. These parameters are discussed below.</p>
<table>
<tr><th><i>Section Parameter</i></th><th><i>Description</i></th></tr>
<tr><td>Segment Number</td><td>The reference mission is broken into one or more segments. The concept of a segment is a portion of the reference mission with a common objective (travel a distance or patrol an area) and uses a unique set of speed profile values. For example the GSG transit from Norfolk to the Suez requires different speed profile entries than the transit of the Suez Canal. All ships using the Suez Canal must transit at a nominal 10 knots until they cross East/Westbound ships in the center of the Suez. During the 5,300 nm transit from Norfolk to the Suez, the ships will want to spend most of their time operating the most fuel efficient speed per nm distance traveled (not 10 knots).</td></tr>
<tr><td>Waypoint Number</td><td>Each segment is broken into distinct waypoints. The ships start at waypoint 0 and sail to waypoint 1, etc. Each waypoint is specified by a latitude/longitude coordinate.</td></tr>
<tr><td>Latitude</td><td>This is the latitude coordinate of the waypoint entered in decimal degrees. North latitudes are positive values, south latitudes are negative.</td></tr>
<tr><td>Longitude</td><td>This is the longitude coordinate of the waypoint entered in decimal</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><td></td><td>degrees. West longitudes are negative, east longitudes are positive values.</td></tr>
<tr><td>Segment Type</td><td>The entry that corresponds with Waypoint 0 for each segment must have the segment type declared. The value can be either “Distance” or “Time”. If the type is “Distance” the simulator has the GSG transit from waypoint 0 to waypoint *n* at which point, the next segment becomes active.

If the type is “Time”, the “Duration” field informs the simulator how long the GSG is to spend operating in the current segment. This type is used for patrolling operational areas. When a “Time” type segment is created, the waypoints comprise the four corners of a rectangular box of the area to patrol:
<table>
<tr><th></th><th>Rectangular Position</th></tr>
<tr><td></td><td>Lower left corner of the operational area box</td></tr>
<tr><td></td><td>Lower right corner of the operational area box</td></tr>
<tr><td></td><td>Upper left corner of the operational area box</td></tr>
<tr><td></td><td>Upper right corner of the operational area box</td></tr>
</table></td></tr>
<tr><td>Duration</td><td>This parameter is only used when the “*Segment Type*” is type “Time”. This parameter specifies how long (in hours) the GSG remains in this segment.</td></tr>
<tr><td>Special Instructions</td><td>This parameter is used to provide clues to the model and to impose operation restrictions on the fleet. These clues and restrictions are in effect while the GSG is heading towards the corresponding waypoint. The special instructions codes are:
<table>
<tr><th>Code</th><th>Meaning</th></tr>
<tr><td>**X**</td><td>Don’t allow the ships to refuel while heading to this waypoint</td></tr>
<tr><td>**Z**</td><td>Don’t allow the oiler to detach for refueling while heading to this waypoint</td></tr>
<tr><td>**S**</td><td>Oiler must observe speed limits of the speed profile</td></tr>
<tr><td>**F**</td><td>When this waypoint becomes active, the GSG ships will top off their fuel tanks</td></tr>
<tr><td>**D**</td><td>Detach oiler to refuel</td></tr>
</table>
The special instruction codes can be combined. For example, while the ships are transiting the Suez Canal, the following special instructions codes are used: XZS. This tells the model to prevent the ships from trying to refuel from the oiler, don’t allow the oiler to detach from the GSG to bring on fuel, Oiler must observe speed limits as specified in the speed profile. The reasons for these codes should be obvious.

The “F” parameter is useful to prompt the ships to top-off before they</td></tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr><td></td><td>enter the Suez Canal or other geographically restrictive areas. The “D” parameter is useful to instruct the oiler to detach for refueling when passing by a DFSP even though it may still have plenty of fuel in its tanks.</td></tr>
</table>
</td>
</tr>
<tr>
<td>[SECTION: DFSPn]</td>
<td>Each DFSP as specified in “<i>[SECTION:SPEED_PROFILES]</i>” must have a corresponding section that contains the following parameters:
<table>
<tr><th><i>Section Parameter</i></th><th><i>Description</i></th></tr>
<tr><td>Name</td><td>This is the noun name used for the DFSP. This name is used in the output files for the corresponding DFSP.</td></tr>
<tr><td>Position</td><td>This parameter contains the CSV values for the DFSP latitude and longitude in decimal degrees.</td></tr>
<tr><td>Capacity (gal)</td><td>This parameter provides the starting value of the amount of fuel stored at the DFSP. FISTSIM allows the DFSPs tanks to be drawn below zero to provide a relative indicator the amount of fuel required from the DFSP.</td></tr>
<tr><td>Transfer Rate (gph)</td><td>This parameter specifies the pumping rate in gallons per hour from the DFSP to a docked oiler. The oiler will remain docked at the DFSP until the required amount of fuel has been transferred from the DFSP to the oiler’s tanks.</td></tr>
<tr><td>Num Approach Vectors</td><td>The model uses the concept of approach vectors to assist the oiler in navigating to the DFSP from the open ocean without crossing over land. Some DFSPs such as Djibouti are tucked away inland and require the oiler to essentially follow a route consisting of waypoints to arrive at the DFSP. A DFSP can have any number of approach vectors to assist with transiting from different geographical areas.

When the oiler needs to refuel, it first calculates the distance to all the available DFSPs, selects the closest, identifies the closest approach vector and follows the approach vector’s waypoints into the DFSP.

Figure 36 shows the approach vectors created for Souda Bay. Figure 37 shows the approach vectors to Djibouti. Figure 38 shows the approach vectors to Fujairah. The oiler will use the closest approach vector to guide the ship into port without running into land.</td></tr>
</table>
</td>
</tr>
</table>

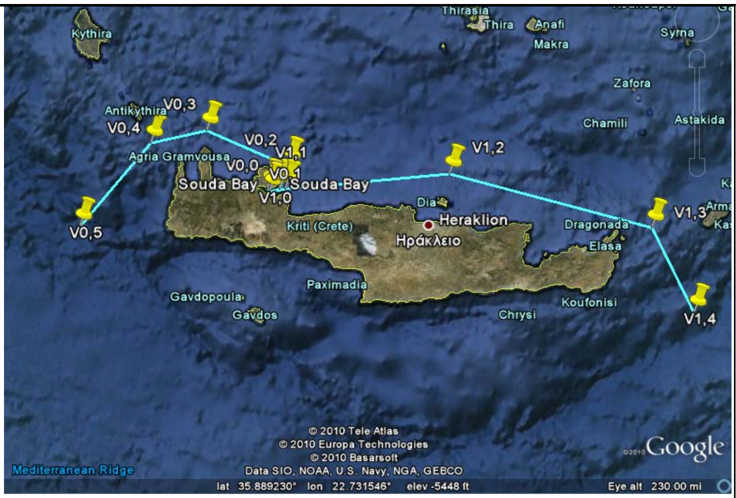


Figure 36. DFSP Souda Bay approach vectors

Image detailing typical approaches to DFSP Souda Bay from the West and East sides of Crete. After (Google Earth 2010, Souda Bay)

Figure 37. DFSP Djibouti approach vectors

Image detailing typical approaches to DFSP Djibouti from the Suez Canal or the Arabian Sea. After (Google Earth 2010, Djibouti)

Figure 38. DFSP Fujariah approach vector

Image detailing a typical approach to DFSP Fujariah after exiting the Suez Canal. After (Google Earth 2010, Fujariah)

Each approach vector must have a corresponding section identified by the tag [BEGIN_TABLE:VECTORn] where n=0 for the first vector, n=1 for the second, etc. The contents of the table are CSV as follows:

- waypoint latitude: The approach vector is comprised of a set of waypoints specified as latitude and longitude coordinates in decimal degrees. Waypoints start closest to the DFSP and end at the furthest point from the DFSP along the approach vector. Any number of waypoints can be created for each vector.

- waypoint longitude: (See waypoint latitude above)

- Special Codes: Currently only the special code of "N" is defined. If 'N' is used, this instructs the oiler that it may not enter the approach vector by starting at this waypoint. Normally the oiler will identify the closest waypoint to the oiler when it starts on the approach vector. Under certain circumstances, starting an approach at a particular vector waypoint is undesirable and the 'N' code should be used.

- Start Angle: The oiler can enter an approach vector from the closest waypoint (unless the 'N' codes issued); however, based on geography, this may not make sense. The start angle, end angle and effective distance can be used to limit the visibility of the waypoint for the oiler.

	The oiler must lie within a cone defined by the start angle, end angle and effective distance (in nautical miles) from the waypoint to be able to enter the vector at the specified waypoint • End Angle: (See start angle above) • Effective Distance: (See start angle above)
[SECTION: CG_BURN_ RATES]	This is a CVS table of integer values that define the fuel burn rates for a CG ship operating at speeds between 0 and its maximum speed. The fuel burn rate is referenced to F-76 fuel. The table must contain one and only one entry for each integer speed value. The fuel burn rate is entered as gallons per hour for the ship.
[SECTION: DDG_BURN _RATES]	This is a CVS table of integer values that define the fuel burn rates for a DDG ship operating at speeds between 0 and its maximum speed. The fuel burn rate is referenced to F-76 fuel. The table must contain one and only one entry for each integer speed value. The fuel burn rate is entered as gallons per hour for the ship.
[SECTION: OP_AREAS]	This section contains Google Earth KML data (a form of XML understood by Google Earth) that is used to draw the operational areas in the Google Earth application. The contents of this section are appended to the KML data file created by the simulation program. *Note: additional information on KML files can be found at Google Earth's web site.*

It is important to note that the fuel burn rates are referenced to F-76. Fuel burn rates for an alternative fuel are calculated by dividing the F-76 burn rate by the relative energy density of the alternative fuel as compared to F-76. This results in an identical energy flow rate into the gas turbine engines, which is assumed to yield identical shaft horsepower and ship cruising speeds.

Regarding the speed profile data, FISTSIM has the ability to apply randomizations based on a normal distribution. A normal distribution was chosen over other distributions by the opinion of FIST that a ship's commander was equally likely to choose a speed that was one or two knots lower or higher than the stated speed profile. The use of normal distributions for both the selected speed and time values from the speed profile improves the stochastic simulation. This feature aids in the goal of generating statistical data that will more closely resemble the performance of the actual GSG due to the uncertainties in actual operations.

2. Outputs

FISTSIM generates several output files following execution of the simulation. The output files are discussed below.

This file "Multirun.csv" is generated in a subfolder to FISTSIM.EXE. This file contains summary data for each individual run when a multi-run simulation is performed (as specified by the parameter: "*Number of simulation runs:*"). The following data for each run is generated as specified in Table 18.

Table 18. "Multirun.csv" Contents

This table provides the summary data available for each individual run of a multi-run simulation

Parameter	**Meaning**
Run	The simulation run number. The first run is run 0, the last is run n-1 where n is the number of runs.
Mission Time	The amount of hours from start to finish the GSG was underway performing the reference mission
Distance Traveled	The total distance traveled in nm by the GSG from start to finish.
Avg Speed	The average speed over the entire deployment of the GSG in knots.
Total Fuel Burned (bbls)	The total fuel burned by the entire GSG while performing the mission. This does not include the amount of fuel remaining the fuel tanks at the end of the mission. The quantity is in bbls of fuel.
Restricted Ops (hrs)	The total amount of time in hours the GSG had to operate at a slower speed than desired.
Rest. Ops Fuel Savings (bbls)	This represents the amount of fuel saved by the GSG operating at a restricted speed vice the desired speed. The usefulness of this data is marginal but was generated to gain a better understanding of the model's performance.
DFSP xxx Fuel Used (bbls)	Each named DFSP will have corresponding entries in this CSV file. This field contains the total amount of fuel transferred to the oiler during oiler refueling.
DDGn Burned (bbls)	Each DDG will have a corresponding entry in this CSV file. This field reports the total amount of fuel burned in bbls by the specified ship while performing the reference mission.
DDGn Remaining	Each DDG will have a corresponding entry representing the total amount of fuel

(bbls)	remaining (in bbls) in its fuel tanks at the end of the mission.
DDGn Lowest Lvl %	Each DDG will have a corresponding entry representing the lowest fuel tank level achieved over the entire mission. The value is in percent of tank capacity.
DDGn LL At	Each DDG will have a corresponding entry representing at what simulation time (in hours) when the DDG reached its lowest fuel level.
DDGn Refuels	Each DDG will have a corresponding entry representing the number of times the DDG was refueled from the oiler over the entire mission.
CGn Burned (bbls)	Each CG will have a corresponding entry in this CSV file. This field reports the total amount of fuel burned in bbls by the specified ship in performing the reference mission.
CGn Remaining (bbls)	Each CG will have a corresponding entry representing the total amount of fuel remaining (in bbls) in its fuel tanks at the end of the mission.
CGn Lowest Lvl %	Each CG will have a corresponding entry representing the lowest fuel tank level achieved over the entire mission. The value is in percent of tank capacity.
CGn LL At	Each CG will have a corresponding entry representing at what simulation time (in hours) when the CG reached its lowest fuel level.
CGn Refuels	Each CG will have a corresponding entry representing the number of times the CG was refueled from the oiler over the entire mission.
Oiler nm Traveled	The total distance traveled (in nm) by the oiler during the entire mission.
Oiler Refuels	The total number of times the oiler brought on fuel from DFSPs during the entire mission
Oiler Total Fuel Rx (bbls)	The total amount of fuel brought on by the oiler from the DFSPs in bbls. Note: this does not include the initial load of fuel before the oiler starts on the mission.
Oiler Remaining (bbls)	The total amount of fuel remaining in the oiler’s tanks at the end of the mission in bbls. Note this is the fuel used for refueling ships not the oiler’s own propulsion fuel.
Seg: n hrs	The total amount of time spent operating in each segment by the GSG.
Seg: n Dist. Trav	The total distance traveled by the GSG while operating in the specified segment.
Seg: n Fuel (bbls)	The total amount of fuel burned by the GSG while operating in the specified segment.

FISTSIM creates an hour by hour data file called “FISTSIM.csv” containing information concerning the GSG during the execution of the simulation. When multi-run simulations are performed, each individual run has its own “FISTSIM.csv” file stored in the “\output\mutirun” subfolder. For single run simulations, the file is stored in the folder “\output”. Multi-run simulations preface the run number to the “FISTSIM.CSV” file name, allowing for post-simulation analysis of any individual run from a multi-run simulation. This is extremely useful when unusual results are generated by one or more specific runs. Each “FISTSIM.CSV” file contains the values as presented in Table 19.

Table 19. FISTSIM.csv Contents

This table provides the hour by hour data available for single or multi-run simulations

Parameter	**Meaning**
Mission Time	The time according to the simulation clock when the entry was recorded. Normally the simulation clock is advanced one hour at a time unless an event is going to happen in less than 1 hour. In which case, the simulation clock is advanced to the time of the event.
Latitude	The latitudes coordinate in decimal degrees of the GSG at the specified simulation time.
Longitude	The longitudes coordinate in decimal degrees of the GSG as the specified simulation time.
Seg#	The current active segment number of the reference mission.
WP#	The current active waypoint the GSG is heading towards.
Bearing	The bearing in degrees to the active waypoint.
Range	The distance in nm to the active waypoint.
Seg Time	The amount of time (in hours) the GSG has operated in the specified segment.
Desired Speed	The desired speed of the GSG based on the speed profile entries. For normally distributed speed profiles, this number is generated by the simulator based on the mean and standard deviations of the speed profile.

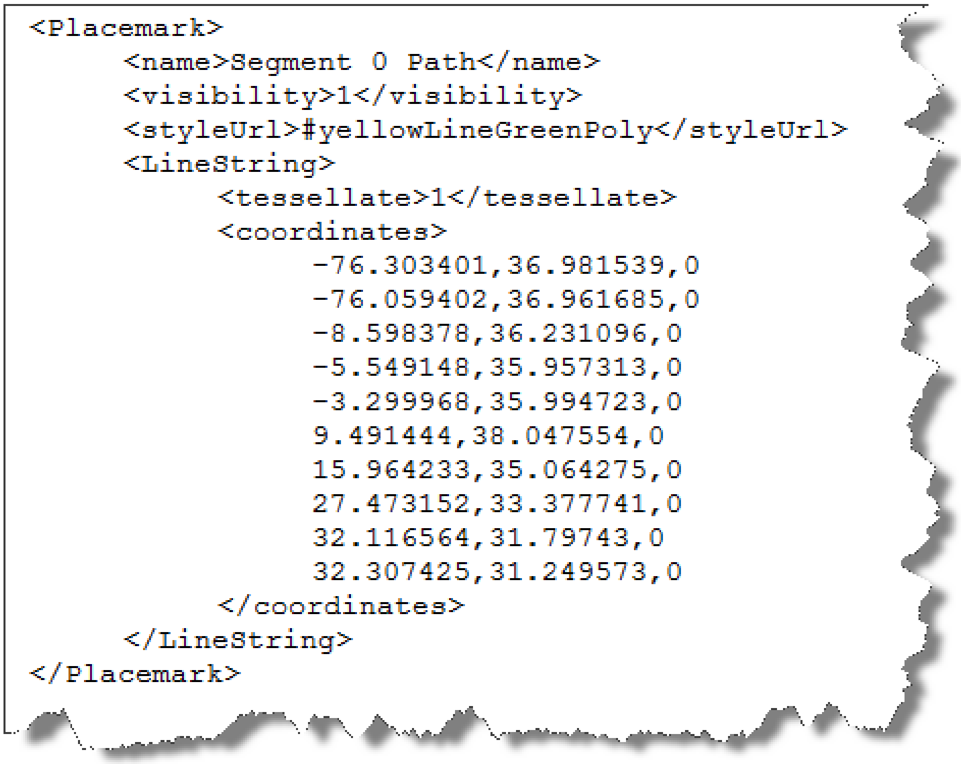
<table>
<tr><td>Actual Speed</td><td>This is the speed at which the GSG is operating dureing the specified time. Normally, this should be equal to the desired speed unless the GSG is operating in a restricted speed mode.</td></tr>
<tr><td>Seg Distance</td><td>The total distance traveled by the GSG on the specified segment.</td></tr>
<tr><td>DDG n Fuel</td><td>The amount of fuel in gallons that is remaining in the specified (n) DDG. Each ship will have a corresponding entry.</td></tr>
<tr><td>DDG n Status</td><td>This value reflects the current state of the specified (n) ship. The states are as follows:
<table>
<tr><td>NORMAL</td><td>Normal operations</td></tr>
<tr><td>NEEDSFUEL</td><td>The fuel level in the ships tanks have dropped to the point where the ship would like to refuel.</td></tr>
<tr><td>PREPARING_ TO_RECEIVE</td><td>The ship has received permission to come alongside the oiler to begin refueling operations.</td></tr>
<tr><td>REFUELING</td><td>The ship is currently bringing on fuel from the oiler</td></tr>
</table></td></tr>
<tr><td>CG n Fuel</td><td>The gallons of fuel in g remaining in the specified (n) CG.</td></tr>
<tr><td>CG n Status</td><td>This value reflects the current state of the specified ship. The states are as follows:
<table>
<tr><td>NORMAL</td><td>Normal operations</td></tr>
<tr><td>NEEDSFUEL</td><td>The fuel level in the ships tanks have dropped to the point where the ship would like to refuel</td></tr>
<tr><td>PREPARING_ TO_RECEIVE</td><td>The ship has received permission to come alongside the oiler to begin refueling operations.</td></tr>
<tr><td>REFUELING</td><td>The ship is currently bringing on fuel from the oiler.</td></tr>
</table></td></tr>
<tr><td>Oiler Fuel</td><td>The amount of fuel remaining the oiler’s tanks (in gallons) for refueling the GSG ships.</td></tr>
<tr><td>Oiler Status</td><td>This value reflects the current state of the oiler. The states are as follows:
<table>
<tr><td>NORMAL</td><td>Normal operations.</td></tr>
</table></td></tr>
</table>

	CHASING_FLEET	The GSG ships have left the oiler behind by operating at speeds faster than the maximum speed of the oiler. The oiler will remain in this state until it catches up with the GSG.
	REFUELING_ONE_SHIP	The oiler has one GSG ship alongside for refueling.
	REFUELING_TWO_SHIPS	The oiler has two GSG ships alongside for refueling (one on the port and one on the starboard sides).
	IN_ROUTE_FOR_FUEL	The oiler has detached the GSG and is heading towards a DFSP to pick up fuel.
	BRINGING_ON_FUEL	The oiler is currently on loading fuel from a DFSP.
	RETURNING_TO_FLEET	The oiler has left the DFSP and is in route to return to the GSG.
Oiler Lat	The current latitude in decimal degrees of the oiler.	
Oiler Lon	The current longitude in decimal degrees of the oiler.	
DFSP n Fuel	Each DFSP's current fuel level in gallons.	
DDG n Fuel Burned	The cumulative fuel burned by each DDG.	
CG n Fuel Burned	The cumulative fuel burned by each CG.	

FISTSIM creates a data file called "FISTSIM.KML" that can be read by Google Earth. The file type is in KML, and follows a syntax required by Google Earth. A KML file is essentially an XML file containing parameters and values specified by Google Earth application programming interface (API). Additional information regarding the structure of a KML file can be found on Google Earth's web site.

An excerpt from a FISTSIM generated KML file is shown in Figure 39. This piece of data draws segment zero's path on the Earth in the Google Earth application. The contents of each run's KML file are created at runtime by "FISTSIM.EXE". A typical

FISTSIM.EXE created KML file contains over 72,000 lines of data.



```
<Placemark>
     <name>Segment 0 Path</name>
     <visibility>1</visibility>
     <styleUrl>#yellowLineGreenPoly</styleUrl>
     <LineString>
          <tessellate>1</tessellate>
          <coordinates>
               -76.303401,36.981539,0
               -76.059402,36.961685,0
               -8.598378,36.231096,0
               -5.549148,35.957313,0
               -3.299968,35.994723,0
               9.491444,38.047554,0
               15.964233,35.064275,0
               27.473152,33.377741,0
               32.116564,31.79743,0
               32.307425,31.249573,0
          </coordinates>
     </LineString>
</Placemark>
```

Figure 39. Excerpt from a KML File

This figure provides an example of the type and XML structure that can be found in the FISTSIM.KML file

3. Tools

Two spreadsheets are created to aid in the reading of FISTSIM data files named “MULTIRUN.CSV” and “FISTSIM.CSV”. These spreadsheets import the CSV file data and perform processing to render it into a more human readable format. Each spreadsheet is discussed in detail below. Additionally, the use of the Google Earth and the displaying of the “FISTSIM.KML” data are discussed below.

The “MultiRunAnalysis.xlsx” spreadsheet is provided by FISTSIM to aid in the analysis of MULTIRUN.CSV, which is generated during runtime by the FISTSIM.EXE simulation program. A user views the “MULTIRUN.CSV” file by opening the

"MutiRunAnalysis.xlsx" spreadsheet using Microsoft Excel or equivalent application and performing a "Refresh All" as shown in Figure 40.

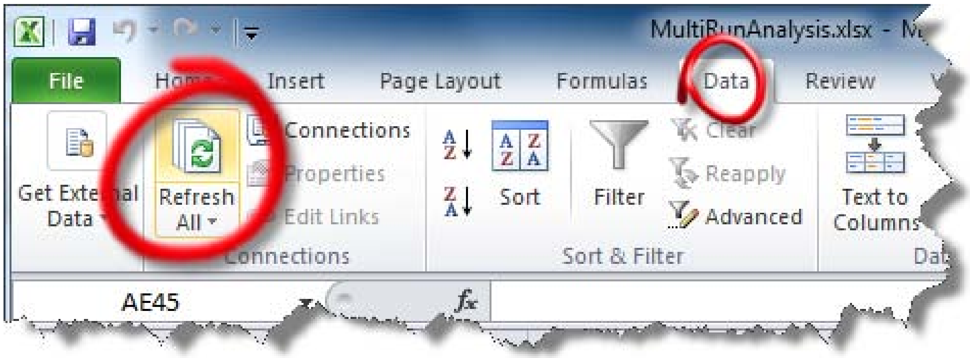
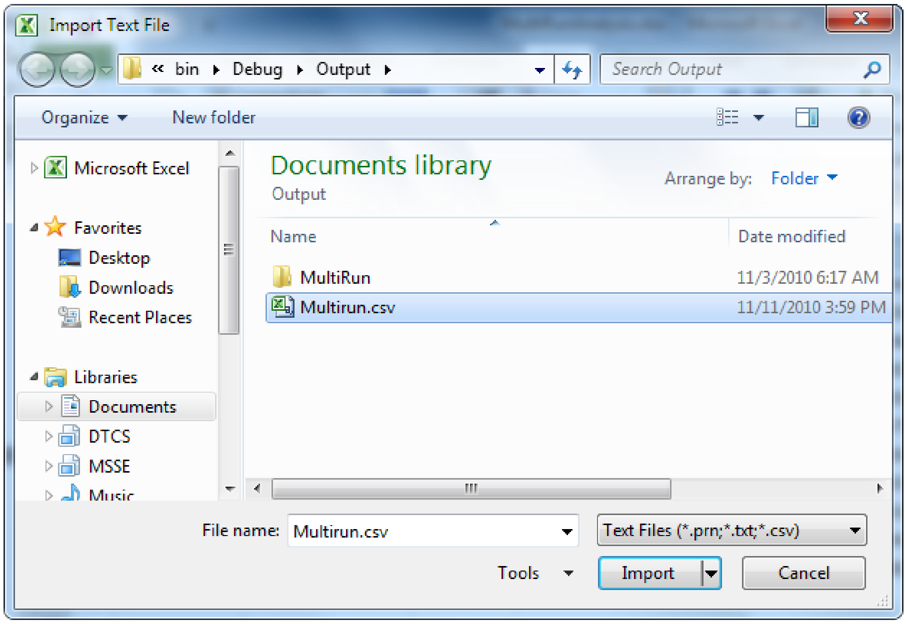


Figure 40. MultiRunAnalsyis Refresh All

This image provides a view of how to refresh the data in the spreadsheet in Excel 2007

This will bring up a file selection dialog box. The user then selects the "MULTIRUN.CSV" generated by "FISTSIM.EXE" as shown in Figure 41.



Name	Date modified
MultiRun	11/3/2010 6:17 AM
Multirun.csv	11/11/2010 3:59 PM

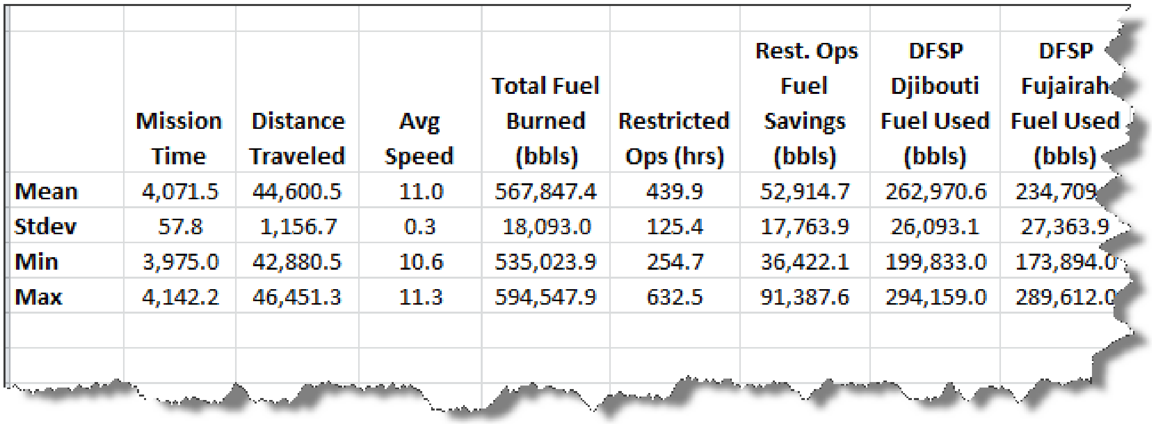
File name: Multirun.csv

Text Files (*.prn;*.txt;*.csv)

Figure 41. Multirun.csv File Selection

This image provides a view of the file selection dialog box after following the directions in Excel 2007

Under Excel's "Statistics" tab of the MultiRunAnalysis.xlsx file, statistical data is generated for every field in the "MULTIRUN.CSV" data that was just imported as shown in Figure 42.

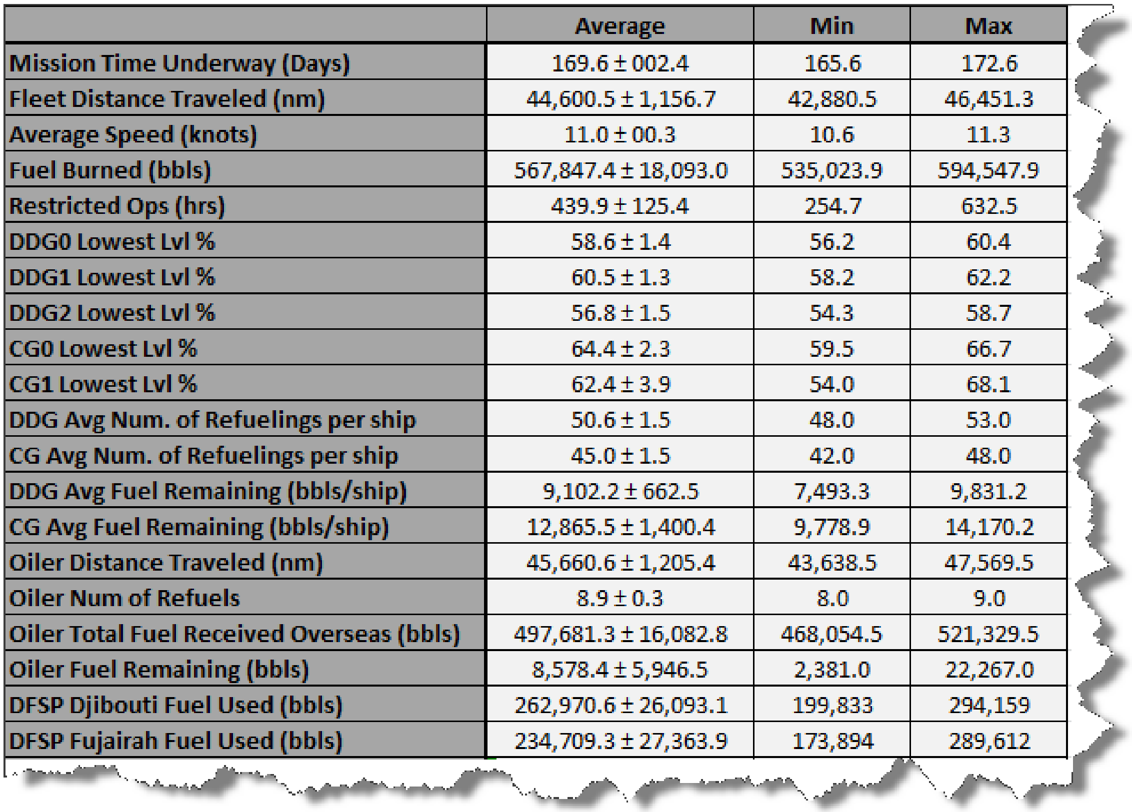


	Mission Time	Distance Traveled	Avg Speed	Total Fuel Burned (bbls)	Restricted Ops (hrs)	Rest. Ops Fuel Savings (bbls)	DFSP Djibouti Fuel Used (bbls)	DFSP Fujairah Fuel Used (bbls)
Mean	4,071.5	44,600.5	11.0	567,847.4	439.9	52,914.7	262,970.6	234,709
Stdev	57.8	1,156.7	0.3	18,093.0	125.4	17,763.9	26,093.1	27,363.9
Min	3,975.0	42,880.5	10.6	535,023.9	254.7	36,422.1	199,833.0	173,894.0
Max	4,142.2	46,451.3	11.3	594,547.9	632.5	91,387.6	294,159.0	289,612.0

Figure 42. MultiRun.csv Raw Statistical Data

This image provides an example of the statistical data generated for each field in "MULTIRUN.CSV"

The tab page "Formatted Stats" displays calculated statistical data in a formatted table suitable for pasting into documents as shown in Figure 43. The data shown with a ± value displays the mean with ± one standard deviation.

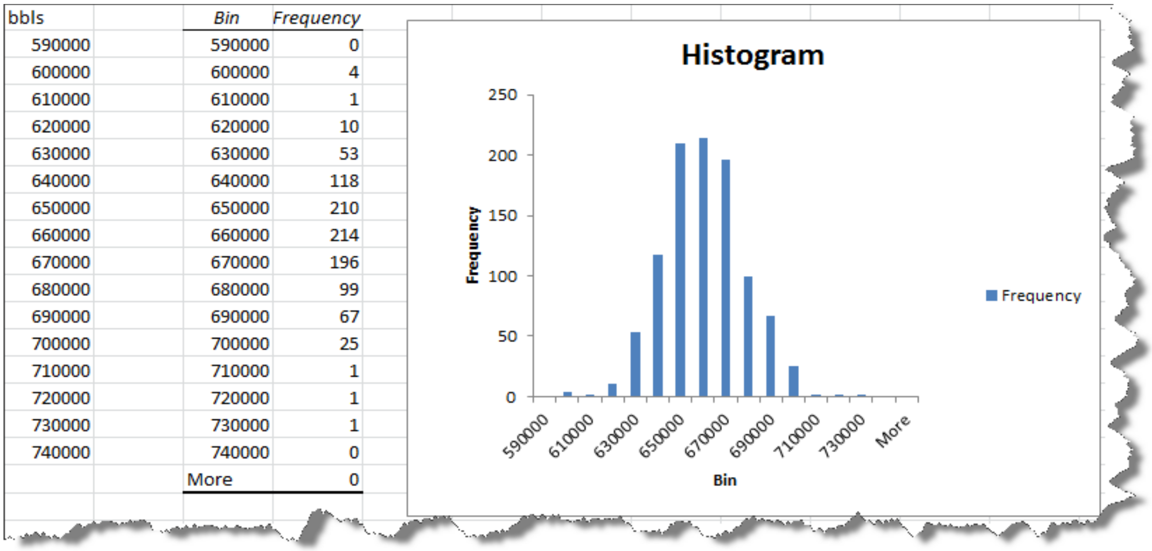


	Average	Min	Max
Mission Time Underway (Days)	169.6 ± 002.4	165.6	172.6
Fleet Distance Traveled (nm)	44,600.5 ± 1,156.7	42,880.5	46,451.3
Average Speed (knots)	11.0 ± 00.3	10.6	11.3
Fuel Burned (bbls)	567,847.4 ± 18,093.0	535,023.9	594,547.9
Restricted Ops (hrs)	439.9 ± 125.4	254.7	632.5
DDG0 Lowest Lvl %	58.6 ± 1.4	56.2	60.4
DDG1 Lowest Lvl %	60.5 ± 1.3	58.2	62.2
DDG2 Lowest Lvl %	56.8 ± 1.5	54.3	58.7
CG0 Lowest Lvl %	64.4 ± 2.3	59.5	66.7
CG1 Lowest Lvl %	62.4 ± 3.9	54.0	68.1
DDG Avg Num. of Refuelings per ship	50.6 ± 1.5	48.0	53.0
CG Avg Num. of Refuelings per ship	45.0 ± 1.5	42.0	48.0
DDG Avg Fuel Remaining (bbls/ship)	9,102.2 ± 662.5	7,493.3	9,831.2
CG Avg Fuel Remaining (bbls/ship)	12,865.5 ± 1,400.4	9,778.9	14,170.2
Oiler Distance Traveled (nm)	45,660.6 ± 1,205.4	43,638.5	47,569.5
Oiler Num of Refuels	8.9 ± 0.3	8.0	9.0
Oiler Total Fuel Received Overseas (bbls)	497,681.3 ± 16,082.8	468,054.5	521,329.5
Oiler Fuel Remaining (bbls)	8,578.4 ± 5,946.5	2,381.0	22,267.0
DFSP Djibouti Fuel Used (bbls)	262,970.6 ± 26,093.1	199,833	294,159
DFSP Fujairah Fuel Used (bbls)	234,709.3 ± 27,363.9	173,894	289,612

Figure 43. MultiRun.csv Formatted Statistical Data

This image provides an example of the formatted data found in the“Multirun.csv”

The “Histograms” tab in the “MultiRunAnalysis.xlsx” file contains several histograms of the data. Unfortunately, histograms do not automatically update when data is refreshed in Excel. New histograms have to be manually recreated. Figure 44 shows a sample total fuel burned histogram from a 1000 run simulation of FISTSIM. Note the shape is consistent with a normal distribution.

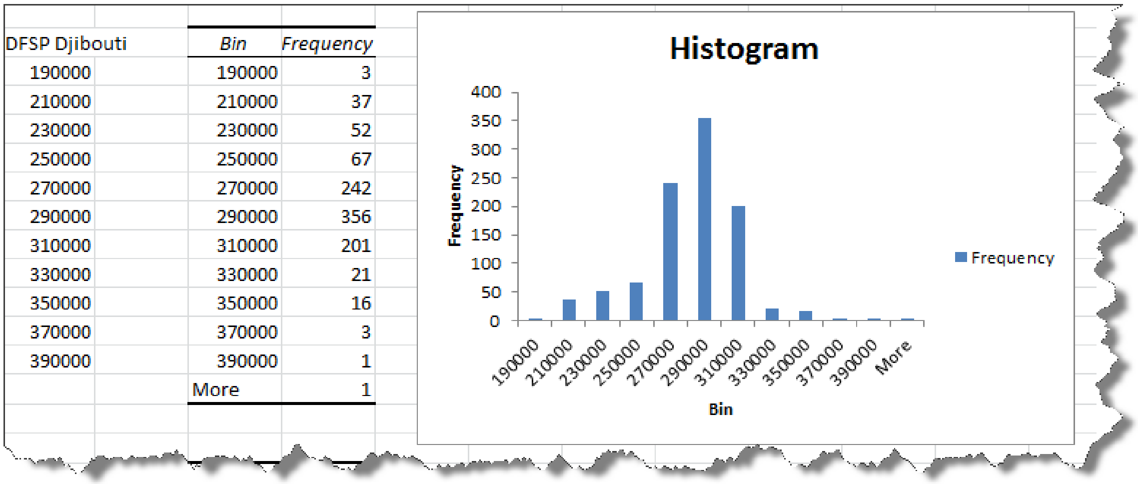


bbls	Bin	Frequency
590000	590000	0
600000	600000	4
610000	610000	1
620000	620000	10
630000	630000	53
640000	640000	118
650000	650000	210
660000	660000	214
670000	670000	196
680000	680000	99
690000	690000	67
700000	700000	25
710000	710000	1
720000	720000	1
730000	730000	1
740000	740000	0
	More	0

Figure 44. Total Fuel Burned Histogram

This figure contains an example of a histogram plot to be expected from running the Data Analysis Tool in Excel 2007.

Figure 45 is a histogram showing the total amount of fuel received by the oiler from the Djibouti DFSP over the 1000 runs.

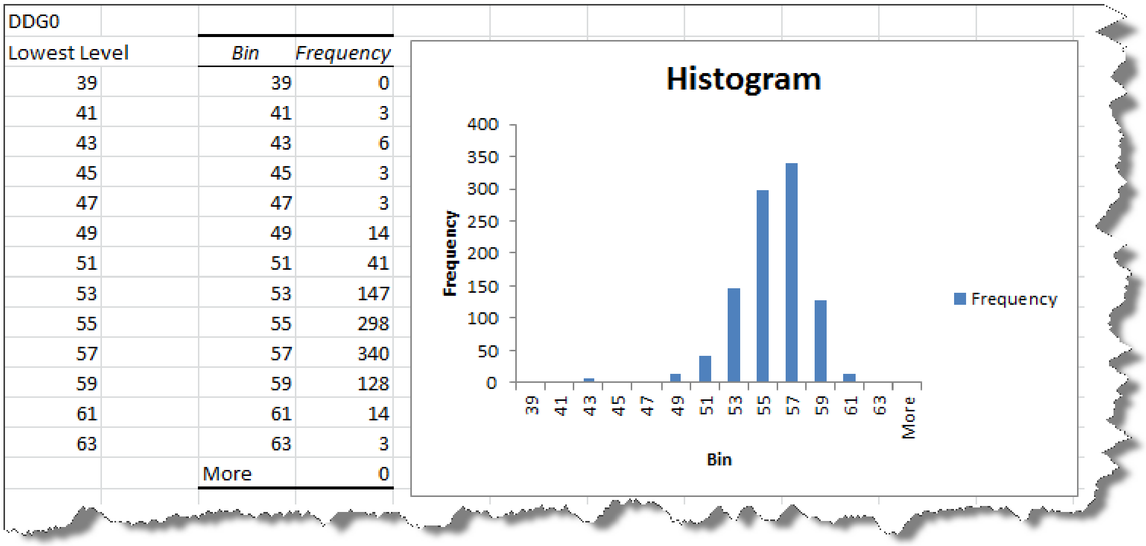


DFSP Djibouti	Bin	Frequency
190000	190000	3
210000	210000	37
230000	230000	52
250000	250000	67
270000	270000	242
290000	290000	356
310000	310000	201
330000	330000	21
350000	350000	16
370000	370000	3
390000	390000	1
	More	1

Figure 45. Total Fuel Received from DFSP Djibouti

This histogram shows the amount of fuel provided to the oiler by DFSP Djibouti over 1000 runs

Figure 46 is a histogram showing the lowest fuel level of DDG0 during the 1000 simulations. Note that a few runs had an outlier of 43%.



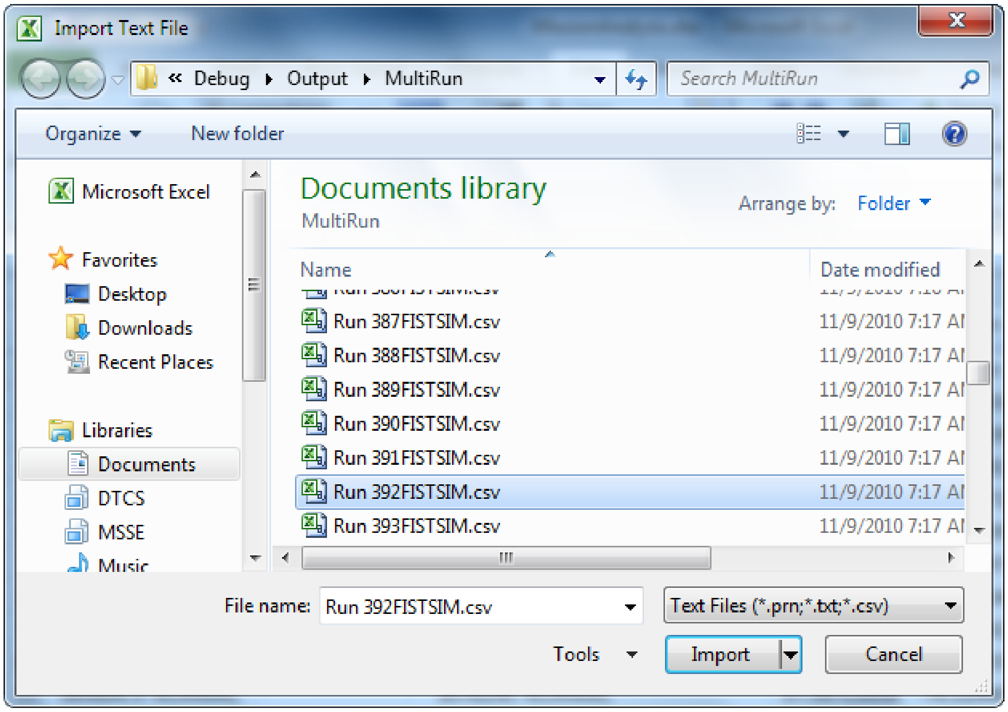
DDG0		
Lowest Level	*Bin*	*Frequency*
39	39	0
41	41	3
43	43	6
45	45	3
47	47	3
49	49	14
51	51	41
53	53	147
55	55	298
57	57	340
59	59	128
61	61	14
63	63	3
	More	0

Figure 46. DDG0 Lowest Fuel Level Histogram

This histogram shows the minimum fuel level of DDG0 over 1000 runs

It should be noted that sometimes the model's rules governing the movement of the oiler fail to apply the full scope of human reasoning. Occasionally, individual runs exhibit behaviors vastly different from the others. Using the data available in the "MultiRunAnalysis.xlsx" file, the individual run or runs can be identified and a detailed inspection of the specific runs in question can be performed using the "MissionAnalysis.xlsx" tool and a Google Earth analysis of the mission.

An Excel spreadsheet called "MissionAnalysis.xlsx" is provided to facilitate data analysis of individual runs. Similar to the "MultiRunAnalysis.xlsx", data is loaded into the "MissionAnalysis.xlsx" by using the "Refresh All" option. A user my then utilize the "Import Text File" dialog box to select the desired run to be analyzed. An example is shown in Figure 47. In this case, run number 392 is about to be loaded for analysis.



Name	Date modified
Run 387FISTSIM.csv	11/9/2010 7:17 AI
Run 388FISTSIM.csv	11/9/2010 7:17 AI
Run 389FISTSIM.csv	11/9/2010 7:17 AI
Run 390FISTSIM.csv	11/9/2010 7:17 AI
Run 391FISTSIM.csv	11/9/2010 7:17 AI
Run 392FISTSIM.csv	11/9/2010 7:17 AI
Run 393FISTSIM.csv	11/9/2010 7:17 AI

File name: Run 392FISTSIM.csv

Text Files (*.prn;*.txt;*.csv)

Figure 47. Selecting Run # 392

This image shows how to select a specific run (in this case, #392) in Excel 2007

The tab page “MissionLog” shows the hour by hour data contained in the “Run 392FISTSIM.csv” file. This data is useful for understanding the current status and sequence of events leading up various events during an individual run.

The tab “Processed Data” holds selected data from the “MissionLog” tab and performs calculations on the data such as converting gallons of fuel to percent total fuel. Constants specified in the “Constants” tab page are used in the conversion.

The tab page “Charts” provides several charts that assist in visualizing the performance of the fleet and will be discussed below.

Combo Chart: The top chart on the “Charts” tab page provides a complete view of the critical model parameters from time zero until the end of the mission. The chart is quite complex (48) and will be presented in detail to help the reader understand the variety of behaviors that can be deciphered by careful analysis.

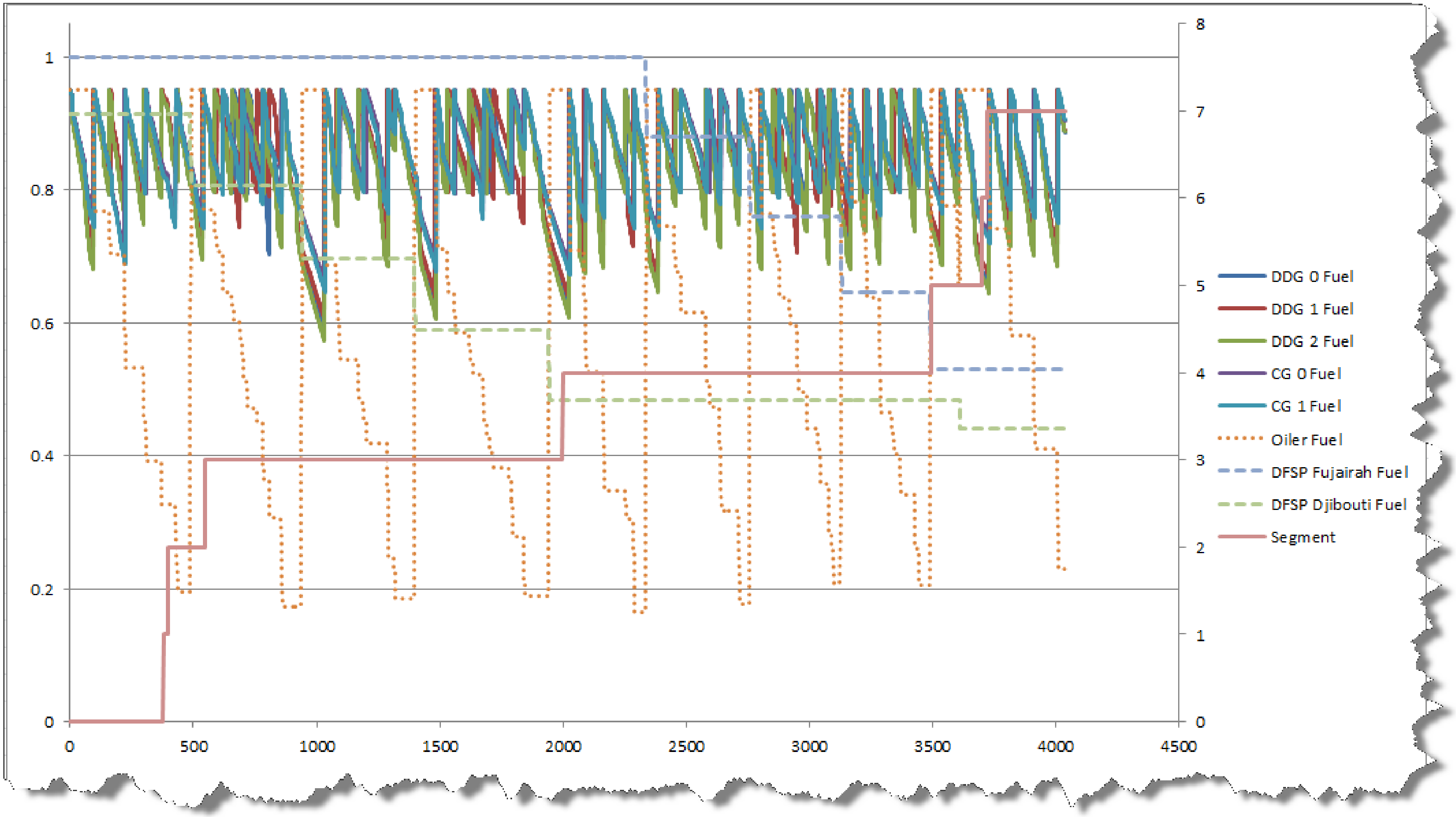


Figure 48. MissionAnalysis.xlsx Combo Chart

This image provides an example of a Combo Chart

The X-axis represents time from the start to the end of the mission. The values are in hours. Each ship's fuel level, expressed in percent of full capacity, is plotted on the Y-axis using primary Y-axis on the left side. The lowest level of each ship is quickly identifiable from "minimums" on each ship's plot. In this particular case, the ship's refueling level was set at 0.8 (80%) as specified by the parameter "*Ships Refuel at Level*". When the ship's fuel level dropped below 80%, the ship wanted to refuel. Each refueling event can be seen as a near-vertical line from the minimum to the 0.95 value.

In this particular case, DDG0 had nominal fuel efficiency. DDG1 was 5% more fuel efficient and DDG2 was 5% less efficient than the nominal ship. Similarly, CG0 had nominal fuel efficiency and CG1 was 5% less fuel efficient. This resulted in a separation of the fuel curves for ships of the same class over time and can be clearly seen. By changing time scales on the X-axis, a more detailed inspection of the behaviors can be studied as shown in Figure 49. In this case above the time scale was set to span between 400 hours and 800 hours.

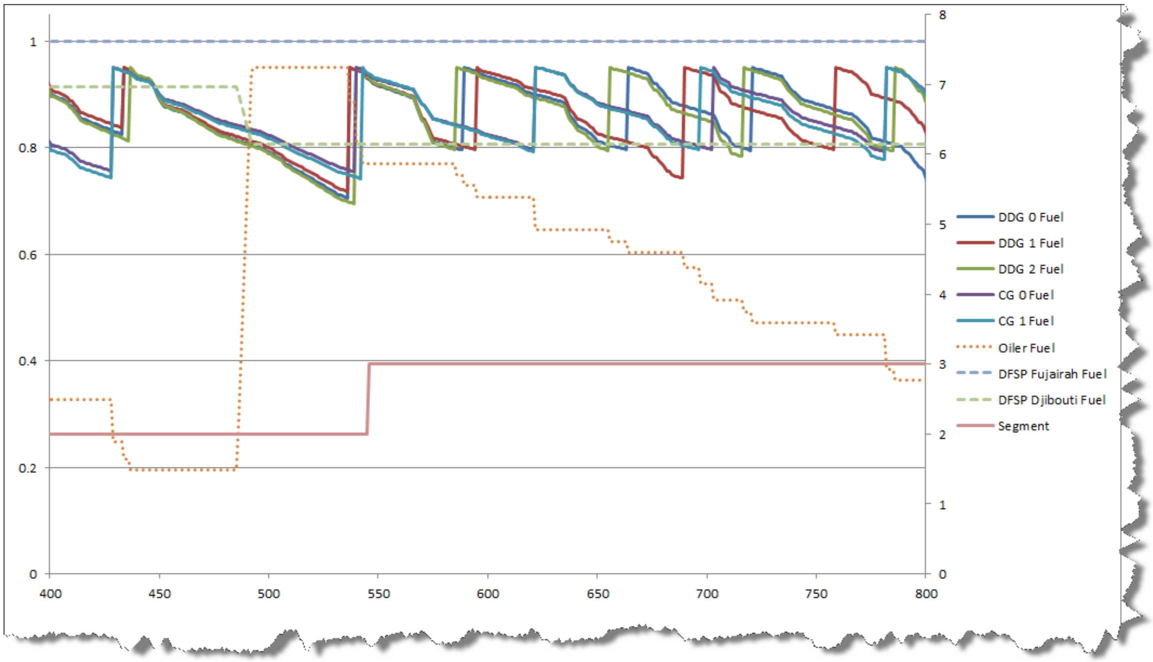


Figure 49. Detailed Time Study

This image provides a more detailed view by changing the time scales on the X-axis

The oiler's fuel level was also plotted over time using the primary Y-axis as its reference. Each refueling event for the ships corresponds to a similar drop the on-board fuel level of the oiler. Once the oiler's fuel level dropped to the value specified by the parameter "*Oiler Min Fuel Level*", the oiler detached from the GSG and headed to a DFSP. The amount of time the oiler spent traveling from the GSG to the DFSP and the amount of time traveling back from the DFSP to the GSG can be seen in Figure 50.

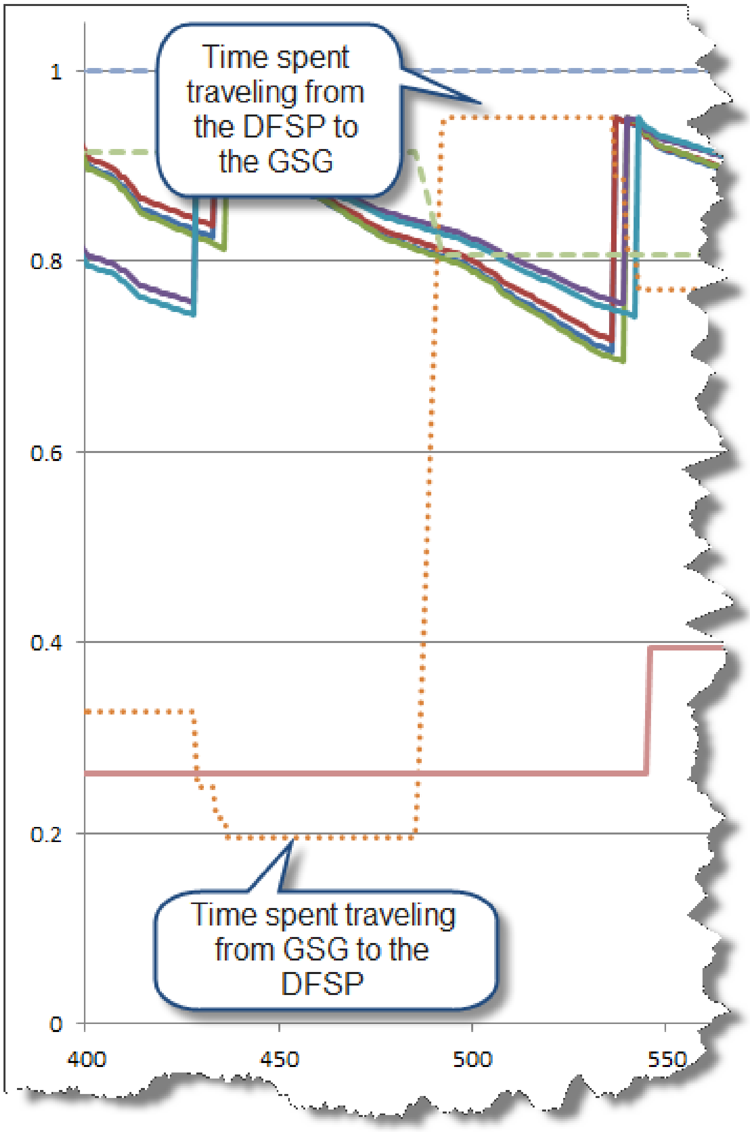


Figure 50. Time Traveling to and from the DFSP

This image shows the amount of time the oiler spent travelling between the GSG and the DFSP

Once the oiler departs the GSG the ships continued to burn fuel, often going well below the desired refueling level. If the fuel level dropped below the value specified by the parameter "*Ships slow down for oiler at level*", the ships would slow to a maximum speed specified by the parameter "*Max Speed Moving Away From Oiler*". This can be clearly seen through a change in the fuel burn rate slope as highlighted in Figure 51. In this particular case, the oiler had to travel a great distance to and from the closest DFSP, resulting in the ship's fuel level dropping below 70%. At this point, the GSG slowed and held a constant 5 knots until the oiler returned. Once the oiler arrived, all 5 ships refueled and resumed normal cruising speeds. The slope of the fuel remaining curve reflects fleet speeds. Shallow slopes correspond to slow speeds; similarly, steep slopes correspond to high speed operations.

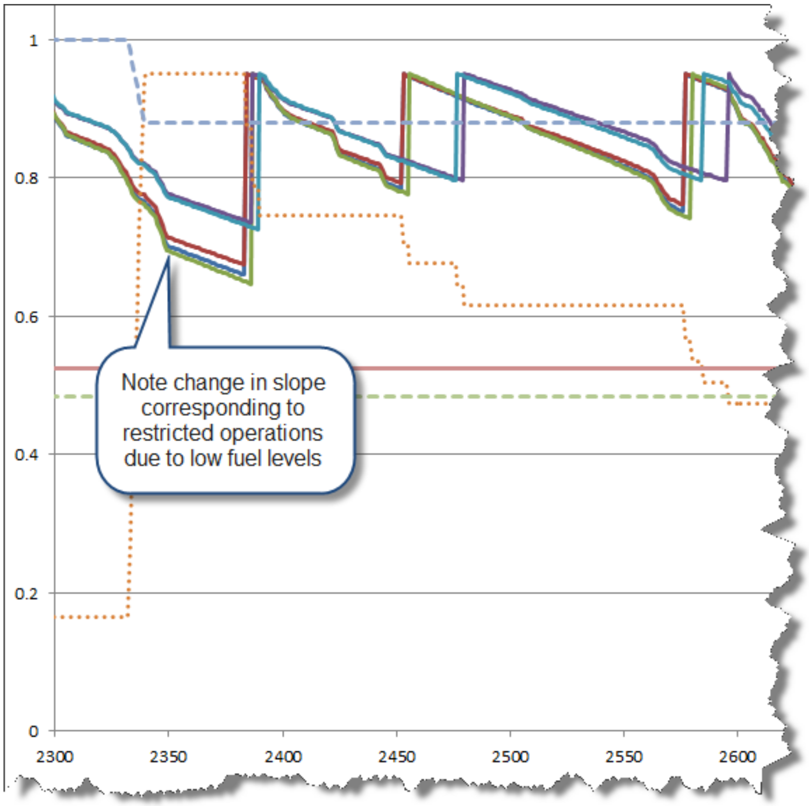


Figure 51. Speed Restricted Operations Due to Low Fuel Levels

This image shows changes in fuel rate slope when the ships must slow due to low fuel reserves

In addition to the ship's and oiler's fuel levels, the fuel levels of the DFSPs are plotted using the primary axis as a reference. Figure 52 is the same graph as Figure 51, but with the DDG and CG fuel levels turned off. By comparing the fuel levels at the two DFSPs plotted to when the oiler refuels, it can be seen which DFSP supplied the fuel to the oiler. For example, at about 500 hours, the oiler refueled at DFSP Djibouti. At about 2400 hours the oiler then refueled from DFSP Fujairah.

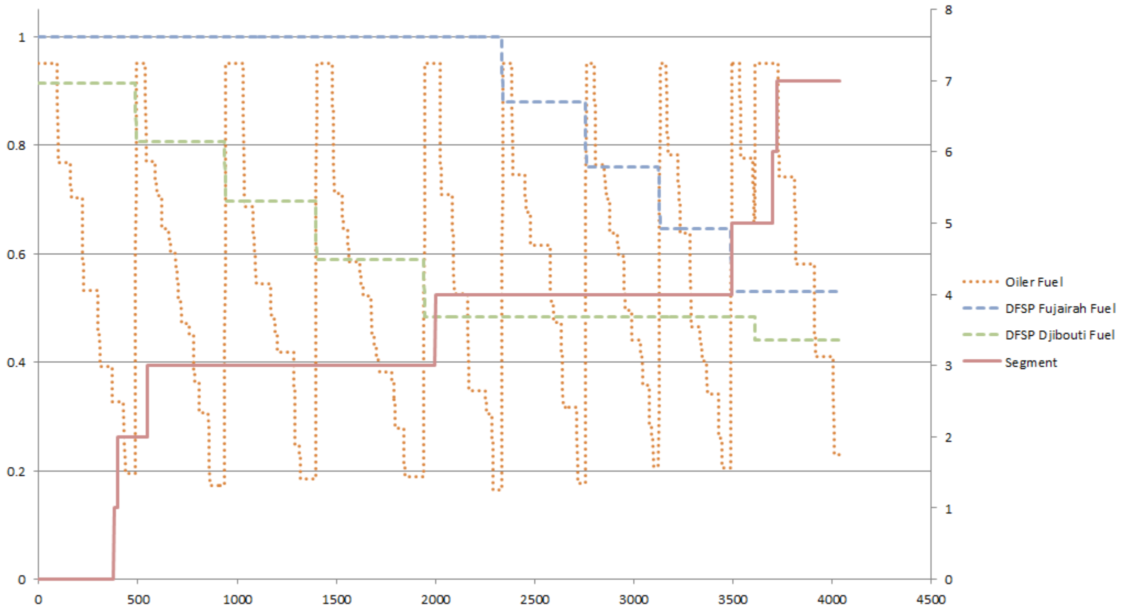
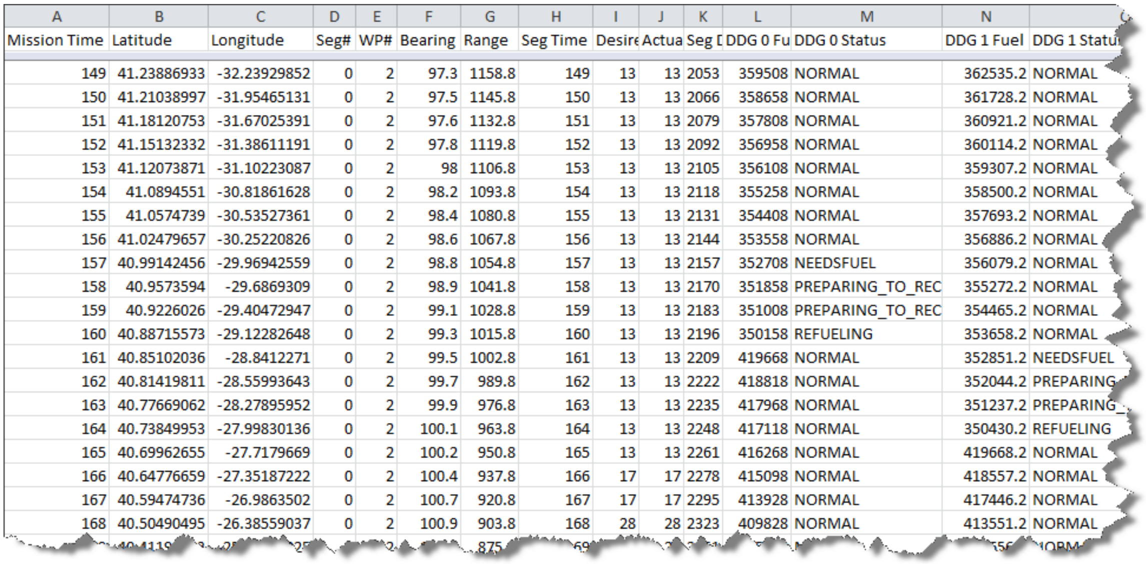


Figure 52. DFSP Fuel Levels over Time

This figure shows how to compare the fuel levels at the DFSP's to the oilers to tell where the oiler refueled from.

Another parameter that was plotted on the combo chart is the active segment number. The segment number is referenced to the secondary axis (shown on the right side of the plot). Referring to Figure 52, from time t=0 until about 400 hours, the GSG was on segment 0 – the transit from Norfolk to the Suez. Segment 1, the transit of the Suez Canal is relatively very short. Segment 2 is the transit from the Suez to Operational Area 1. At about 600 hours, the GSG entered Operation Area 1 and patrolled this area until about simulation time of 2000 hours. Comparing the active segment to the other parameters provides additional insight into the operations of the GSG.

As always, detailed hour-by-hour analysis can be performed by examining the raw data in the “MissionLog” tab as shown in Figure 53.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	
Mission Time	Latitude	Longitude	Seg#	WP#	Bearing	Range	Seg Time	Desire	Actua	Seg [	DDG 0 Fu	DDG 0 Status	DDG 1 Fuel	DDG 1 Statu
149	41.23886933	-32.23929852	0	2	97.3	1158.8	149	13	13	2053	359508	NORMAL	362535.2	NORMAL
150	41.21038997	-31.95465131	0	2	97.5	1145.8	150	13	13	2066	358658	NORMAL	361728.2	NORMAL
151	41.18120753	-31.67025391	0	2	97.6	1132.8	151	13	13	2079	357808	NORMAL	360921.2	NORMAL
152	41.15132332	-31.38611191	0	2	97.8	1119.8	152	13	13	2092	356958	NORMAL	360114.2	NORMAL
153	41.12073871	-31.10223087	0	2	98	1106.8	153	13	13	2105	356108	NORMAL	359307.2	NORMAL
154	41.0894551	-30.81861628	0	2	98.2	1093.8	154	13	13	2118	355258	NORMAL	358500.2	NORMAL
155	41.0574739	-30.53527361	0	2	98.4	1080.8	155	13	13	2131	354408	NORMAL	357693.2	NORMAL
156	41.02479657	-30.25220826	0	2	98.6	1067.8	156	13	13	2144	353558	NORMAL	356886.2	NORMAL
157	40.99142456	-29.96942559	0	2	98.8	1054.8	157	13	13	2157	352708	NEEDSFUEL	356079.2	NORMAL
158	40.9573594	-29.6869309	0	2	98.9	1041.8	158	13	13	2170	351858	PREPARING_TO_REC	355272.2	NORMAL
159	40.9226026	-29.40472947	0	2	99.1	1028.8	159	13	13	2183	351008	PREPARING_TO_REC	354465.2	NORMAL
160	40.88715573	-29.12282648	0	2	99.3	1015.8	160	13	13	2196	350158	REFUELING	353658.2	NORMAL
161	40.85102036	-28.8412271	0	2	99.5	1002.8	161	13	13	2209	419668	NORMAL	352851.2	NEEDSFUEL
162	40.81419811	-28.55993643	0	2	99.7	989.8	162	13	13	2222	418818	NORMAL	352044.2	PREPARING
163	40.77669062	-28.27895952	0	2	99.9	976.8	163	13	13	2235	417968	NORMAL	351237.2	PREPARING_
164	40.73849953	-27.99830136	0	2	100.1	963.8	164	13	13	2248	417118	NORMAL	350430.2	REFUELING
165	40.69962655	-27.7179669	0	2	100.2	950.8	165	13	13	2261	416268	NORMAL	419668.2	NORMAL
166	40.64776659	-27.35187222	0	2	100.4	937.8	166	17	17	2278	415098	NORMAL	418557.2	NORMAL
167	40.59474736	-26.9863502	0	2	100.7	920.8	167	17	17	2295	413928	NORMAL	417446.2	NORMAL
168	40.50490495	-26.38559037	0	2	100.9	903.8	168	28	28	2323	409828	NORMAL	413551.2	NORMAL

Figure 53. Raw Hour-by-Hour Simulation Data

This image provides an example of the raw data output on an hour by hour basis

Segment and Waypoint Chart: The second chart shown on the “Charts” tab displays the active segment and active waypoint vs. time as shown in Figure 54. Comparing GSG behavior to the active segment and active waypoint yields additional behavior data for post mission analysis. Segments are referenced to the primary Y-axis on the left and the waypoints are referenced to the secondary Y-axis on the right side of the plot.

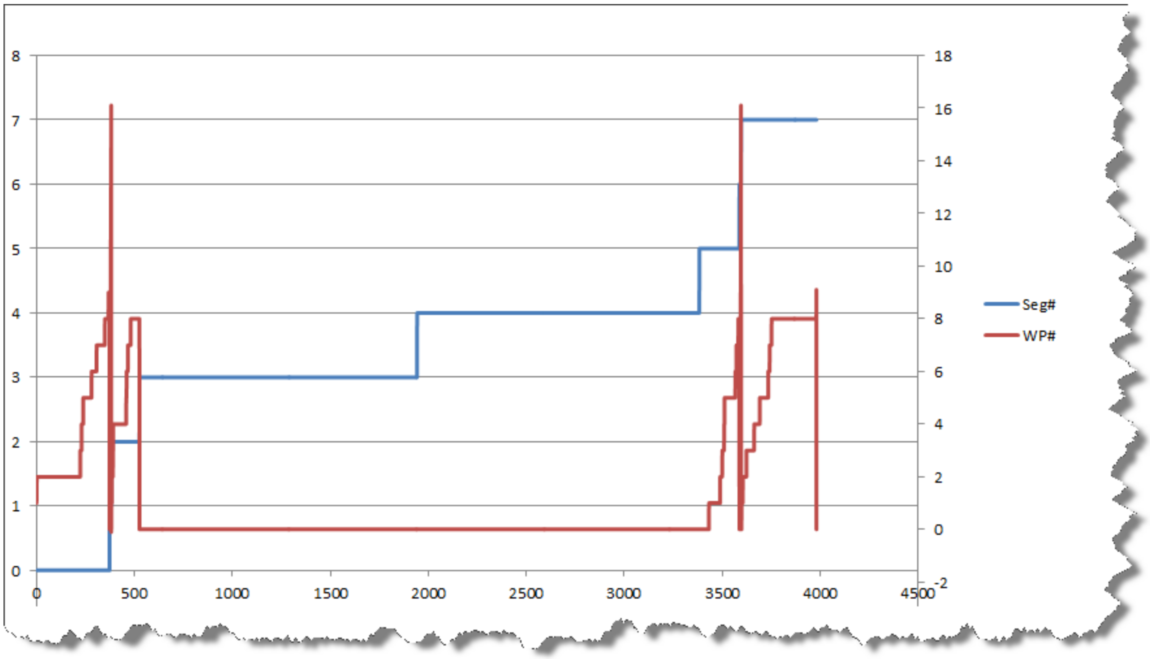


Figure 54. Segment and Waypoint Chart

This figure is an example of a Segment and Waypoint Chart

Speed vs. Time Chart: The last chart on the "Charts" tab shows the desired and actual GSG speeds vs. time as shown in Figure 55. In this figure the time axis was set from 0 to 800 hours. Normally, the actual speed matches the desired speed unless a speed restriction rule is activated. In this case, around time 90 hours, the fleet had a desired speed of approximately 18 knots but was restricted to 5 knots.

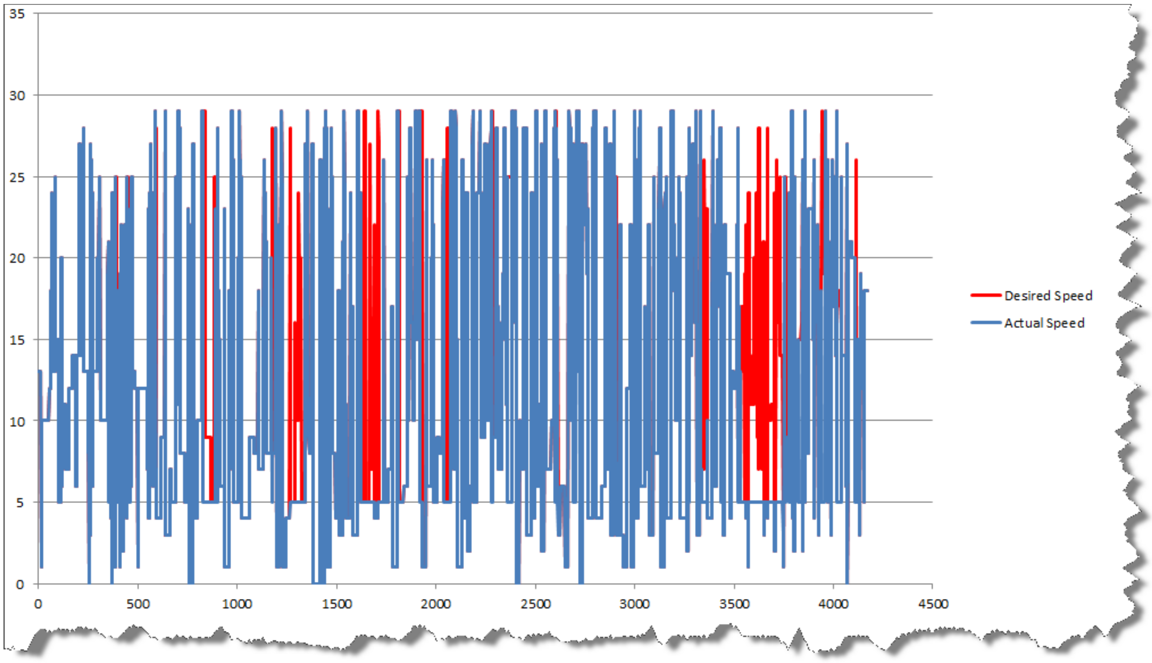


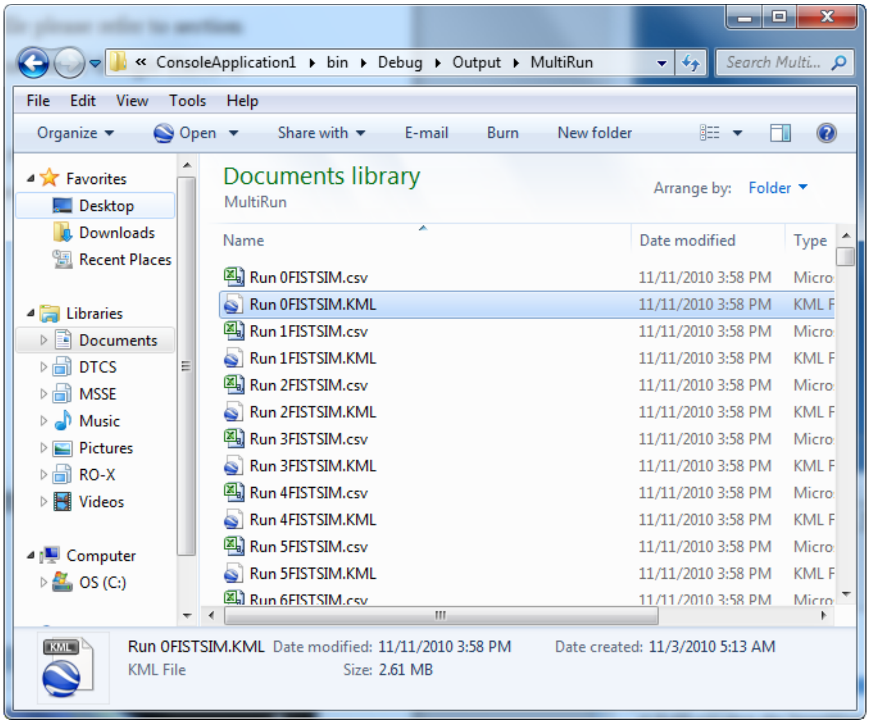
Figure 55. Speed vs. Time Chart

This figure provides an example of a Speed vs. Time Chart

The supplied charts are just a few ways of examining the vast data available in the FISTSIM data set. Additional graphs can be generated from the raw data revealing additional behaviors.

a) Google Earth and FISTSIM.KML: FISTSIM generates a data file for each simulation run called a KML file. The KML file is an XML formatted file with data that Google Earth can import and graphically display. To view the KML data, the user will need version 5.0 or newer of Google Earth.

To view the data for a particular simulation run, double click on the desired run's KML file from Windows File Explorer as shown in Figure 56. Alternatively the KML file can be loaded from the Google Earth application using the "File Open" menu.



Name	Date modified	Type
Run 0FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 0FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 1FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 1FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 2FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 2FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 3FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 3FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 4FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 4FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 5FISTSIM.csv	11/11/2010 3:58 PM	Micro
Run 5FISTSIM.KML	11/11/2010 3:58 PM	KML F
Run 6FISTSIM.csv	11/11/2010 3:58 PM	Micro

Run 0FISTSIM.KML Date modified: 11/11/2010 3:58 PM Date created: 11/3/2010 5:13 AM
KML File Size: 2.61 MB

Figure 56. KML File Selection

This shows the Load KML File Box from Google Earth.

Once the KML file is loaded, Google Earth will show enabled model data on the globe (see Figure 57) and show a list of selectable data on the left-side pane as shown in Figure 58. By default, only a small sub-set of data is initially displayed on the globe. Displaying all the data at once would present an overwhelming amount of content.

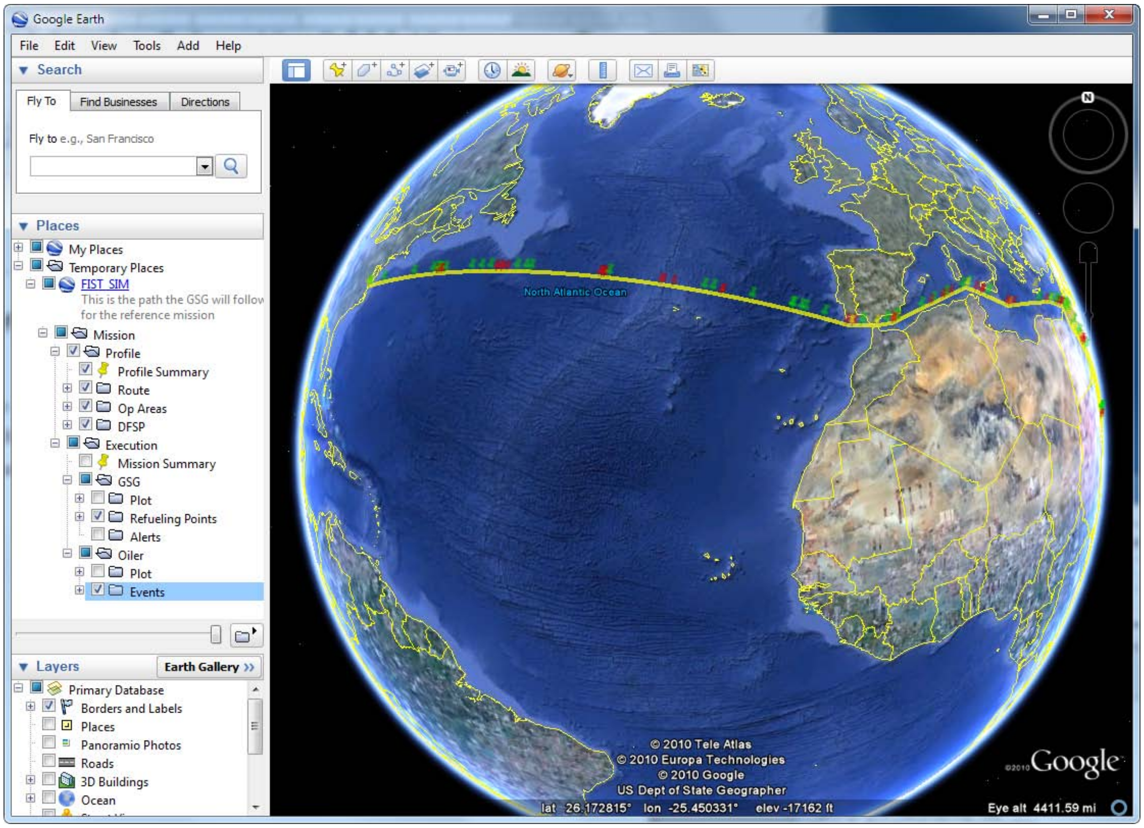
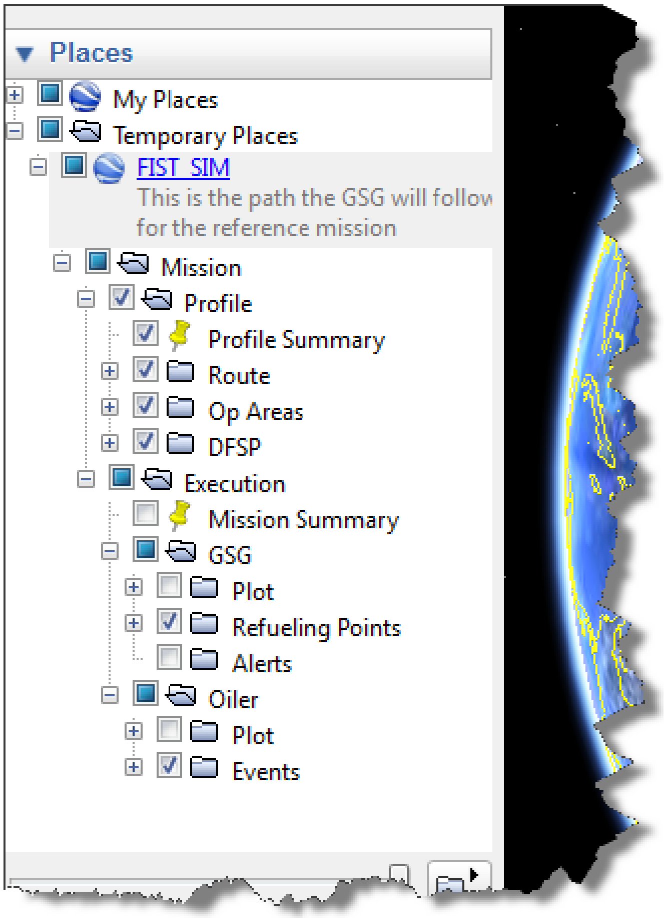


Figure 57. Google Earth Application

This image demonstrates how Google Earth shows model data on the globe.



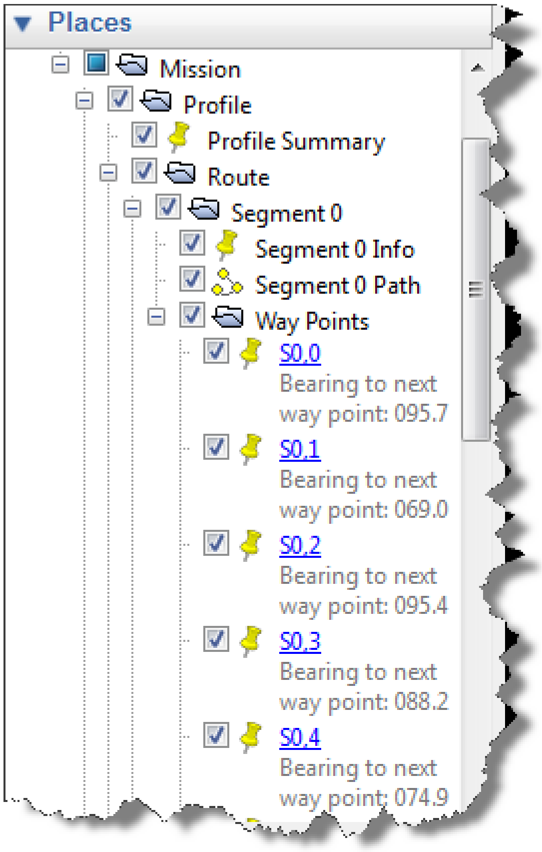
Places

- ■ My Places
- ■ Temporary Places
  - ■ FIST SIM
    This is the path the GSG will follow for the reference mission
    - ■ Mission
      - ☑ Profile
        - ☑ Profile Summary
        - ☑ Route
        - ☑ Op Areas
        - ☑ DFSP
      - ■ Execution
        - ☐ Mission Summary
        - ■ GSG
          - ☐ Plot
          - ☑ Refueling Points
          - ☐ Alerts
        - ■ Oiler
          - ☐ Plot
          - ☑ Events

Figure 58. FISTSIM Selectable Data Elements

This image provides a close up of the selectable data available from within Google Earth produced by FISTSIM.

Each of the data element types is discussed in detail below. The mission folder contains a folder called “Profile”. This folder contains all the data elements that define the reference mission, including the GSG route to follow, plotting of the operational areas and DFSP information. By clicking on the “+” symbol, the various elements can be expanded as shown in Figure 59. When the user double clicks a data element, Google Earth zooms to the graphical location of the element and displays a pop-up balloon, if additional data exists. An example is shown in Figure 60.

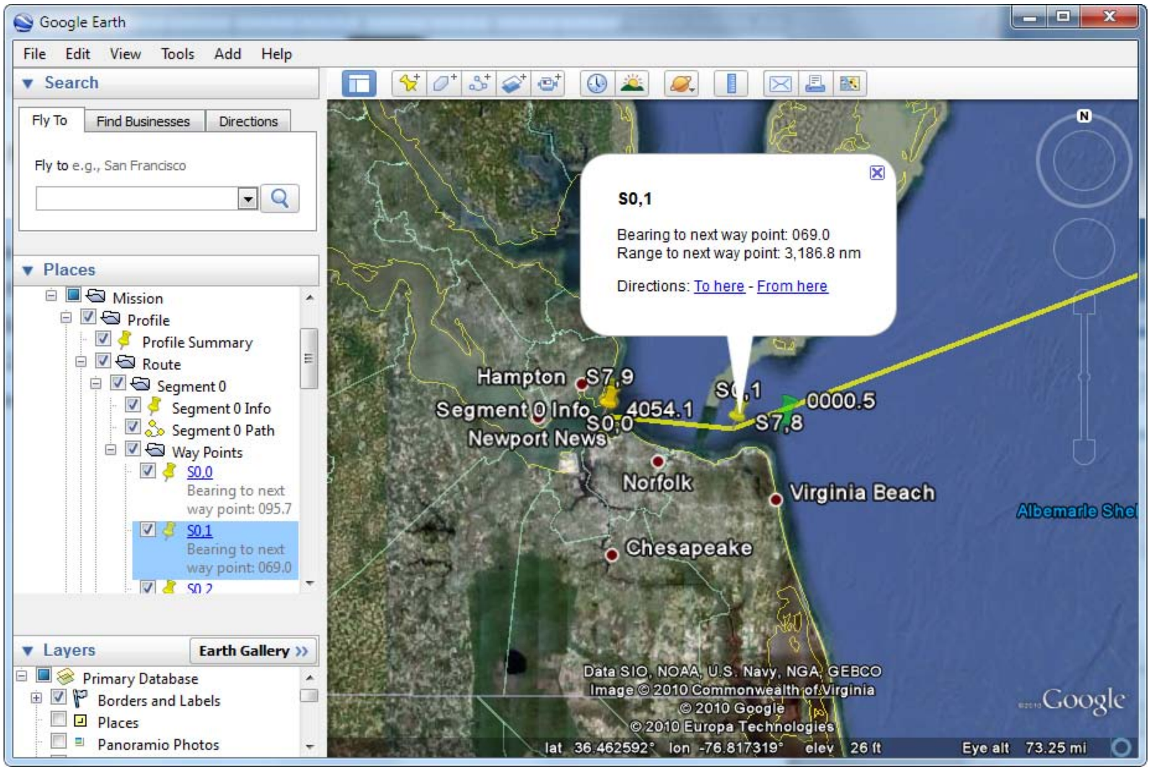


▼ Places

- ⊟ ■ Mission
  - ⊟ ☑ Profile
    - ☑ Profile Summary
    - ⊟ ☑ Route
      - ⊟ ☑ Segment 0
        - ☑ Segment 0 Info
        - ☑ Segment 0 Path
        - ⊟ ☑ Way Points
          - ☑ S0.0 Bearing to next way point: 095.7
          - ☑ S0.1 Bearing to next way point: 069.0
          - ☑ S0.2 Bearing to next way point: 095.4
          - ☑ S0.3 Bearing to next way point: 088.2
          - ☑ S0.4 Bearing to next way point: 074.9

Figure 59. Expanded Route Element

This image shows a fully expanded "Route" under the Profile data element type..



S0,1

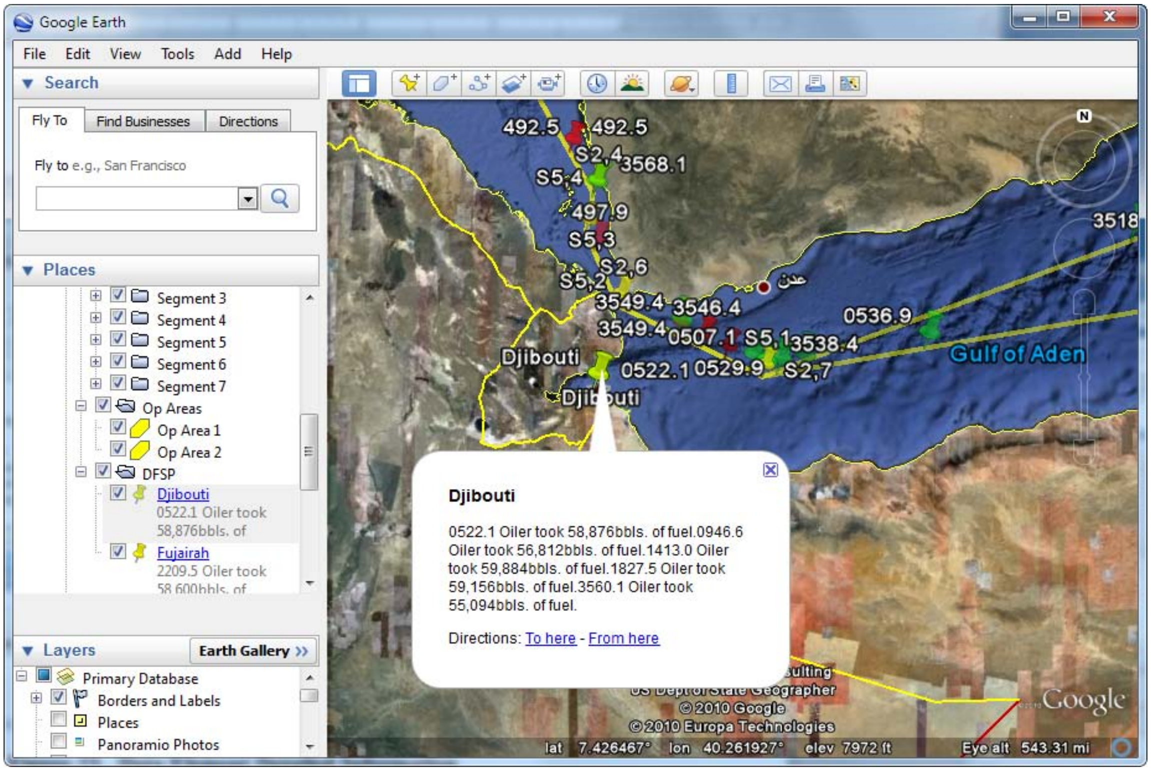
Bearing to next way point: 069.0
Range to next way point: 3,186.8 nm

Directions: To here - From here

Figure 60. Data Element Detailed Information

This image provides an example of Google Earth's ability to zoom to a point on the globe where for a data element and bring up extra data available in a pop-up balloon..

In addition to all the segments and waypoints that define the reference mission, data about the DFSPs is obtained by double clicking on the desired DFSP data element as shown in Figure 61. In this case, the balloon lists every time the oiler stopped at that DFSP for fuel and includes the amount of fuel provided to the oiler.



Djibouti

0522.1 Oiler took 58,876bbls. of fuel.0946.6 Oiler took 56,812bbls. of fuel.1413.0 Oiler took 59,884bbls. of fuel.1827.5 Oiler took 59,156bbls. of fuel.3560.1 Oiler took 55,094bbls. of fuel.

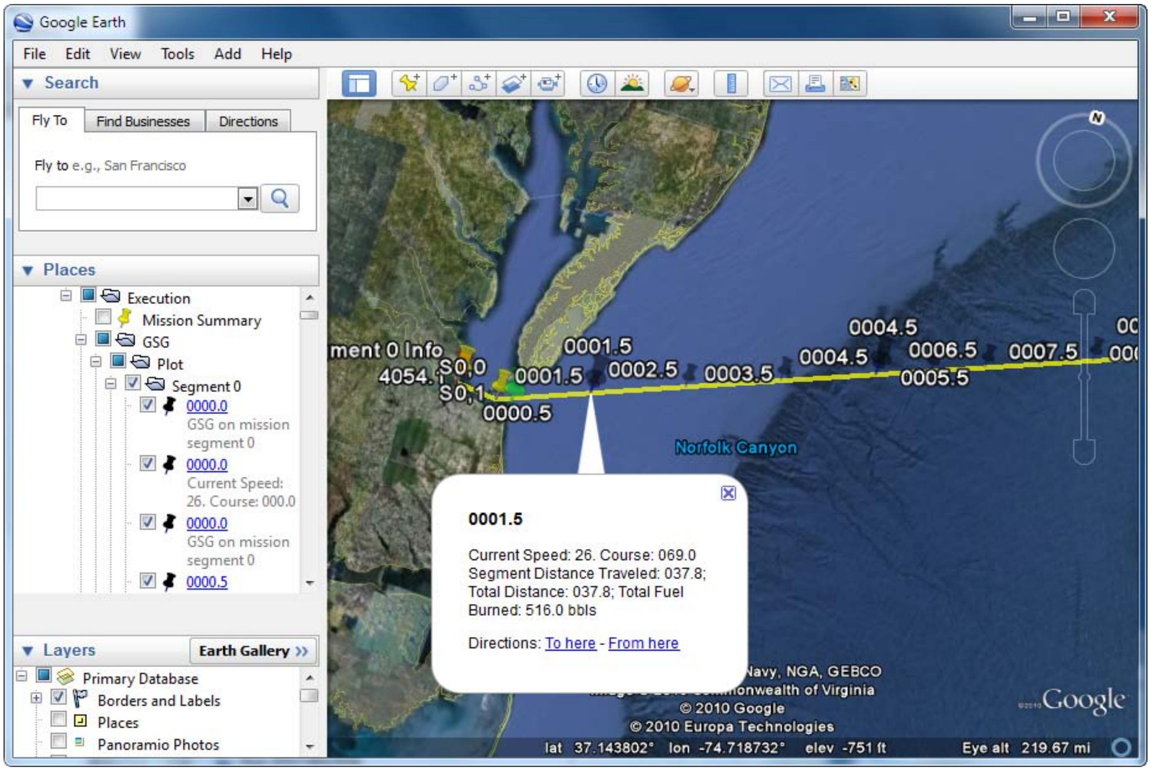
Directions: To here - From here

Figure 61. Djibouti Information

This image provides an example of Google Earth displaying the times the oiler stopped by a DFSP and the amount of fuel transferred.

When the user looks under the “Mission” folder there are two subfolders: “Execution\GSG” and “Execution\Oiler”. The Execution\GSG subfolder contains data elements associated with the movement and events of the GSG ships. Likewise, the Execution\Oiler subfolder contains movement and event data for the oiler.

Figure 62 shows the data elements for the GSG, segment 0, at t=1.5 hours. Google Earth would zoom to the geographical point on the globe where the GSG was located at t=1.5 hrs. Information about the GSG would include current speed, course, segment distance traveled, total distance traveled, and total fuel burned for the GSG is visible in the display. The user can plot any explore any and all of the thousands of data points for the entire mission in this manner.



0001.5

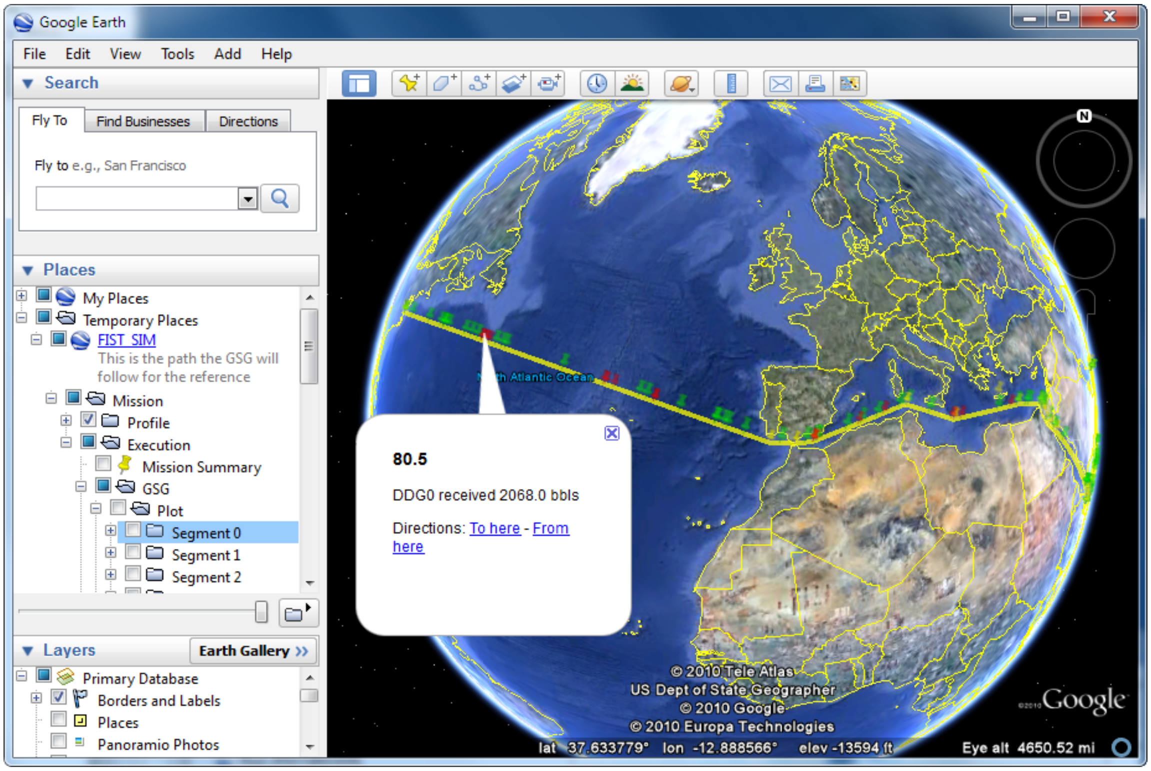
Current Speed: 26. Course: 069.0
Segment Distance Traveled: 037.8;
Total Distance: 037.8; Total Fuel
Burned: 516.0 bbls

Directions: To here - From here

Figure 62. Segment 0 GSG Plots

This image provides an example of Google Earth displaying all active data elements for the GSG during modeling segment #0.

In addition to fleet locations, events such as refueling events can be displayed. Figure 63 shows an example of each refueling event along segment 0. The refueling points are highlighted with red stick pins. The first refueling event occurred at t=80.5 hours, and was performed by DDG0. DDG0 received 2068 barrels of fuel from the oiler. The exact location on the globe for each refueling event can be examined in this fashion.



80.5

DDG0 received 2068.0 bbls

Directions: To here - From here

Figure 63. Refueling Points Along Segment 0

This image provides an example of Google Earth displaying each refueling event along modeling segment #0.

Under the “oiler” folder there is a folder for oiler plots. Data elements are stored in this folder whenever the oiler operates independent of the GSG. This occurs when the GSG sails at speeds beyond the oiler’s maximum speed. When this occurs, the oiler falls behind and trails the fleet. The oiler sails at its maximum speed and plots an intercept course to rendezvous with the GSG. Additionally, whenever the oiler detaches from the GSG and sails to/from a DFSP to bring on fuel, data elements are plotted and stored under the ”oiler” folder. Example oiler plots are provided in Figure 64 as green stick pins.

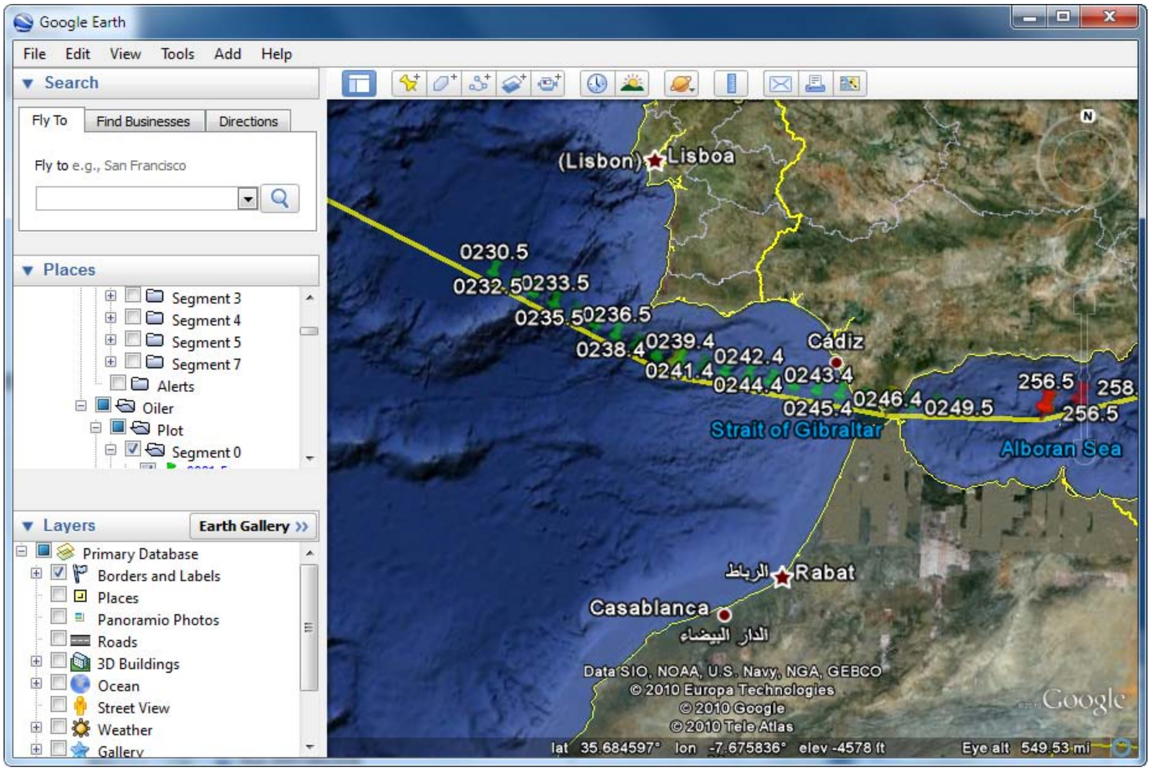
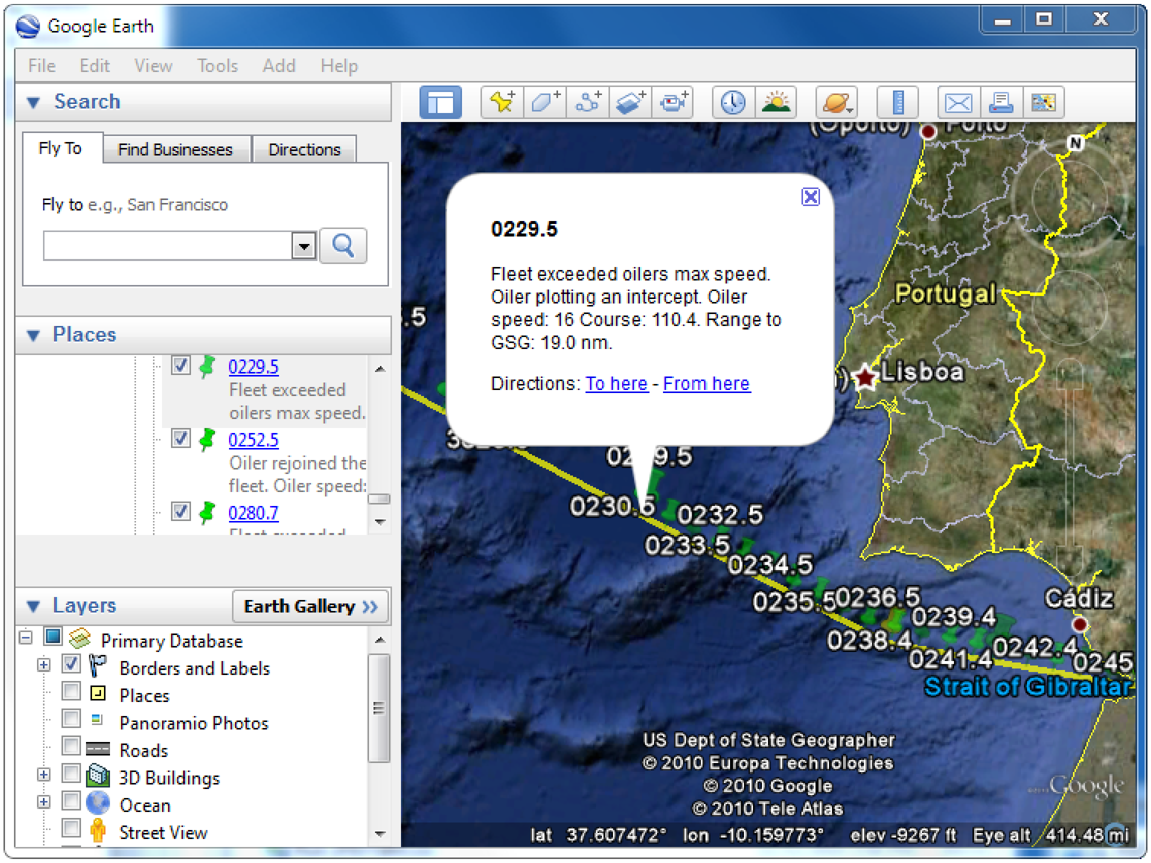


Figure 64. Oiler Independent Steaming

This image provides an example of Google Earth displaying oiler plots.

The "Events" data elements folder contains events, such as when the oiler first separates from the GSG and again when the oiler rejoins the GSG. When the user clicks on any of the stick pins, additional information will pop-up regarding the data element as shown in Figure 65.



0229.5
Fleet exceeded oilers max speed.

0252.5
Oiler rejoined the fleet. Oiler speed:

0280.7

0229.5

Fleet exceeded oilers max speed. Oiler plotting an intercept. Oiler speed: 16 Course: 110.4. Range to GSG: 19.0 nm.

Directions: To here - From here

Figure 65. Oiler Event at Time 229.5 Hours

This image provides an example of Google Earth displaying additional information after clicking an one of the green stick pins associated with the oiler's position.

The amount of data that can be displayed and analyzed is immense. Figure 66 shows the activity around Operational Area 2 and the DFSP Fujairah. Careful filtering of data and zooming in to certain geographical areas can be useful for following the GSG and understanding the GSG's behaviors.

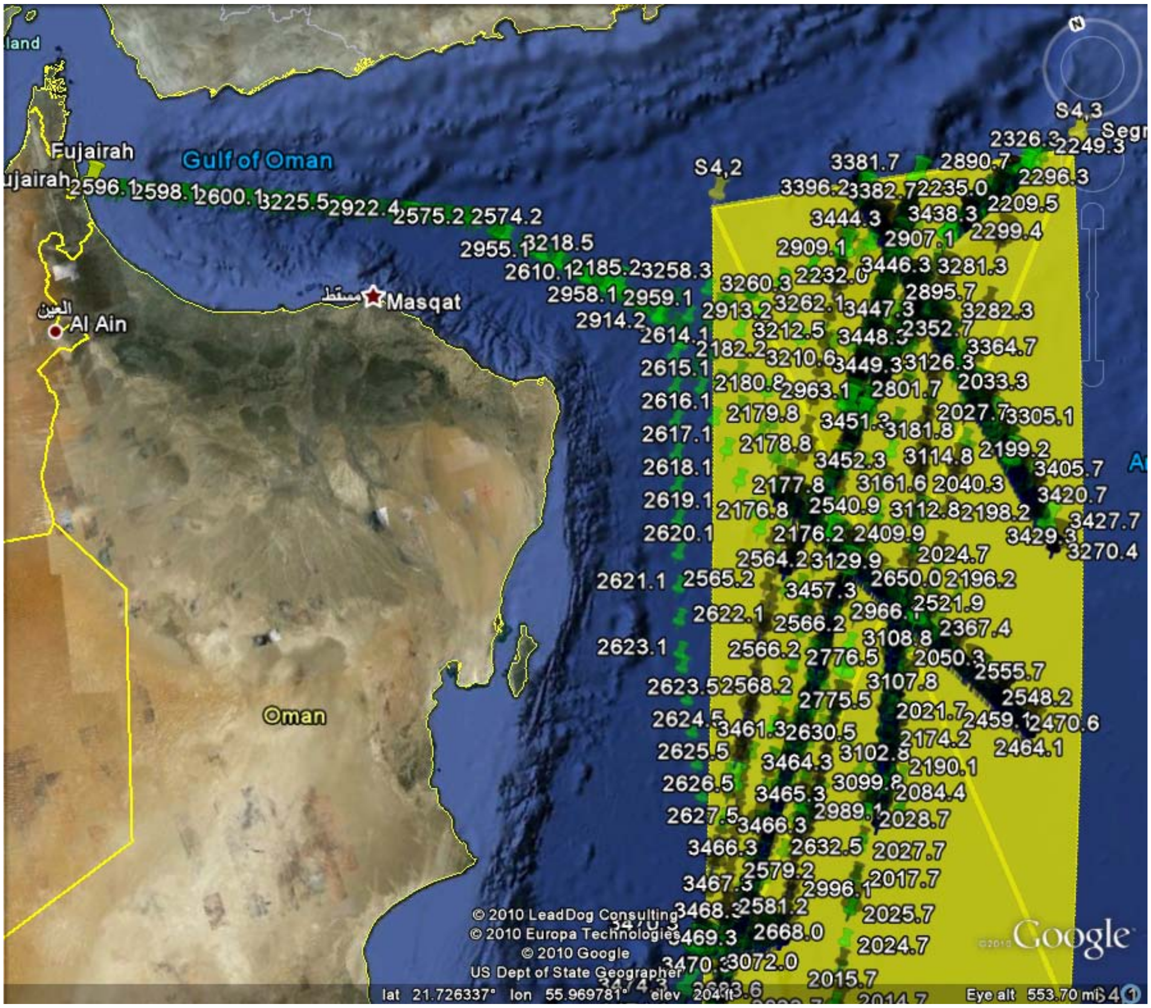


Figure 66. Op Area 2 and Fujairah DFSP

This image shows the scale of the data available through Google Earth just in Operational Area #2.

D. DESIGN

FISTSIM was written using the C# programming language in Microsoft Visual Studio 2010 and compiled to run under Microsoft Windows .NET framework. At the time of this writing, FISTSIM consists of 1,965 lines of code.

1. Objects

Along with the custom code, FISTSIM uses two open source libraries shown in Figure 67 to support WGS-84 based calculations and generation of normal distributions used by the speed profile code.

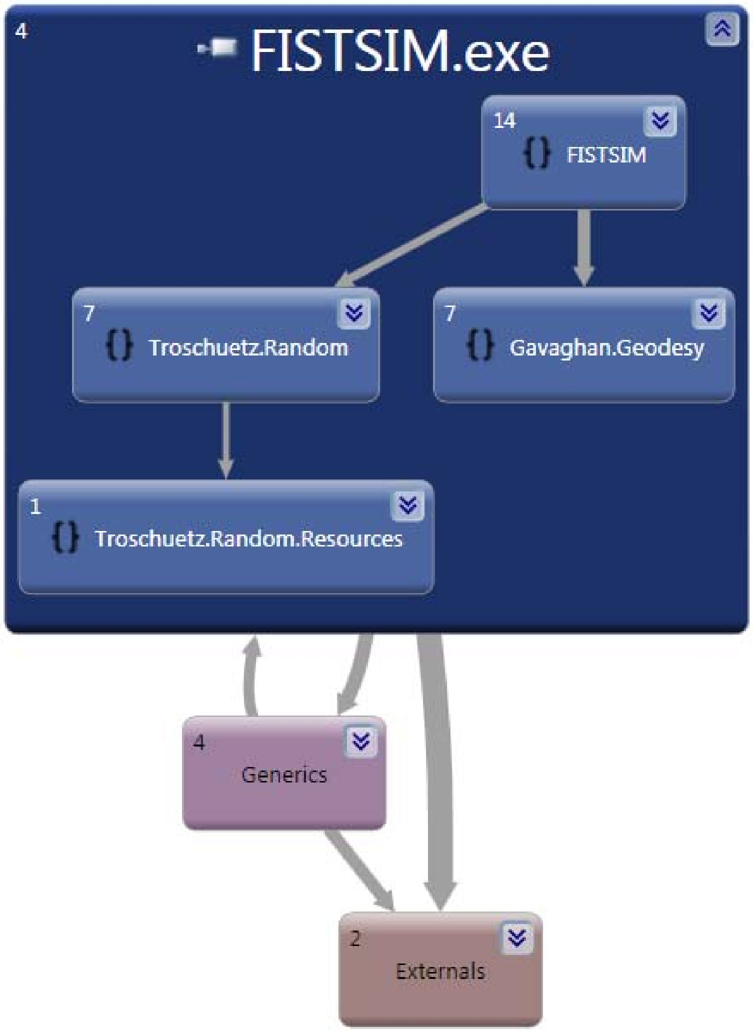


Figure 67. FISTSIM Assembly Dependencies

This figure shows FISTSIM's dependency tree as a flowchart..

A complete software description of FISTSIM is beyond the scope of this document; a brief overview of the composition of FISTSIM is provided to give the reader a basic understanding of the software architecture. The application specific objects and their dependencies are shown in Figure 68 and further detailed in Table 20.

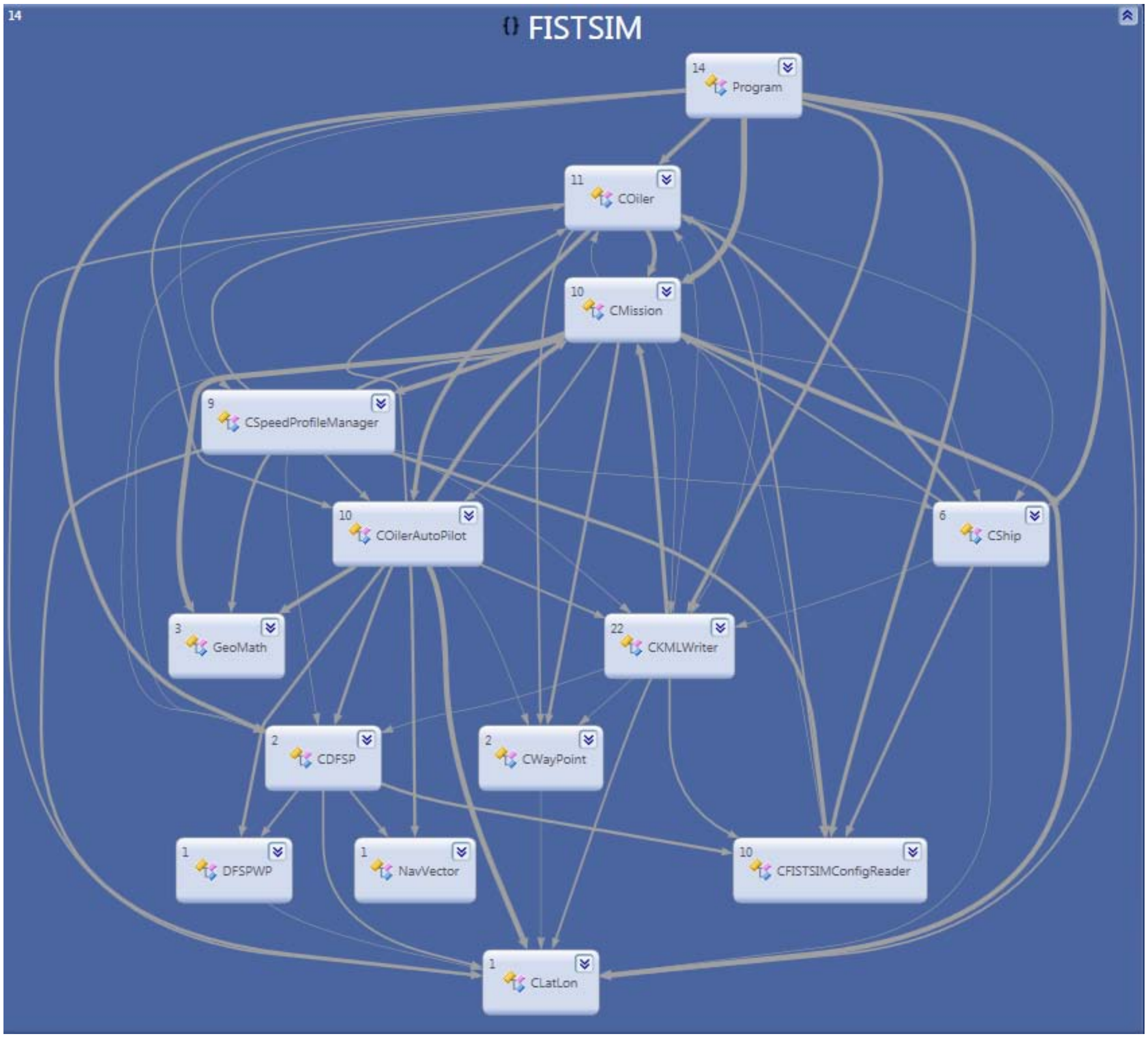


Figure 68. FISTSIM Main Objects and Dependencies

This figure displays the interconnections of the major programming objects comprising FISTSIM.

Table 20. FISTSIM Objects

This table provides a listing of the objects in FISTSIM and an overview of their function.

Object	**Purpose**
Program	Generates all the FISTSIM objects and starts the execution of the simulation.
COiler	A class that models the GSG's escort oiler. The oiler is an instantiated instance of COiler class.
CMission	A class that models the reference mission.
CSpeedProfileManager	A class that manages the speed profile for the GSG
COilerAutoPilot	A class that handles navigating the oiler whenever it is separated from the GSG.
GeoMath	An object that formats data and makes calls to the WGS-84 routines in Gavaghan.Geodesy open-source library.
CDFSP	A class that models a DFSP. Each DFSP in an instantiated instance of the CDFSP class.
CKMLWriter	A class responsible for generated the FISTSIM.KML files used by Google Earth for graphically displaying mission data.
CShip	A class that models GSG ships. Each ship in the GSG is an instantiated instance of the CShip class.
CFISTSIMConfigReader	A class that reads data from the FISTSIMConfig.txt file for configuring the various objects in FISTSIM.

2. Simulation Rules

To understand the detailed behaviors of the GSG during the execution of a mission, it is necessary to understand the various rules implemented in FISTSIM. Words in *italics* are parameters in the FISTSIMConfig.txt file. Table 21 shows a listing of FISTSIM rules.

Table 21. FISTSIM Rules

This table provides a listing of the major rules and rulesets implemented in the FISTSIM model.

Rule ID	**Description**
SPM-1	While refueling ships, the GSG maintains current speed even if the Speed Profile Manager (SPM) wants to change speed based on the expiration of current SPM timer. Speed in updated as soon as the oiler is detached from the refueling ships.
SPM-2	If any of the ship's fuel levels drop to *"Ships slow down for oiler at level"* the GSG slows to

	the speed specified by *"Max Speed Moving Away From Oiler"*
SPM-3	If the GSG is moving away from a DFSP that the oiler is using to refuel and the active segment is a distance based segment, the GSG reduces speed to *"Max Speed Moving Away From Oiler"*. This helps prevent the GSG from traveling too far from the oiler given its limited maximum speed.
SPM-4	If *"Randomize Speed Profile"* is set to 'Y', the SPM selects a speed/time value from the available speed profile entries for the active segment when the SPM clock for the current speed/time selection expires.
SPM-5	If *"Randomize Speed Profile"* is set to 'N', the SPM selects the next speed/time value from the available speed profile entries for the active segment when the SPM clock for the current speed/time selection expires. Once the last entry is selected, the SPM selects the first entry from the active segment.
SPM-6	If *"Use Normal Distribution for Speed Profile"* is set to 'Y', the SPM will use a normal distribution with the mean and standard deviation provided in the speed profile table to pick a new speed and time value otherwise the mean for speed and time is used.
SPM-7	As soon as a new segment becomes active (GSG has arrived at the last waypoint of a segment), a new speed/time selection is made for the new segment.
SPM-8	If by chance a speed <0 is selected based on the normal distribution, the speed is truncated to zero knots.
SPM-9	If by chance a time <0.1hrs is selected based on the normal distribution, a new time value is randomly selected from normal distribution.
SPM-10	Speeds are always rounded to whole integer values.
SPM-11	If by chance a speed is selected from the normal distribution that is greater than *"Fleet Max Speed"*, the speed is truncated to *"Fleet Max Speed"*.
M-1	At the current speed, if the GSG will arrive at a waypoint in less than 1 hour, the simulation clock is increment by the amount of time required for the GSG to arrive at the active waypoint.
M-2	Once the GSG arrives at the last waypoint of the last segment, the simulation run is complete.
M-3	Once the GSG arrives at the last waypoint of a segment, the next segment becomes active and waypoint 0 of the new segment becomes the active waypoint.
M-4	If the segment is a time based segment (vice distance) waypoints are randomly generated with

	a rectangular box defined by the segment’s 4 waypoints. A randomly selected waypoint must be least 1 hour away at the current speed otherwise another random waypoint is chosen.
M-5	When a new waypoint becomes active, the waypoint is checked for special instruction codes to signal the oiler to detach for fuel or for the GSG ships to top-off their tanks.
M-6	While the GSG is patrolling a time based area (Operation Areas) and the oiler is detached for a fuel run, when it comes time to select a new random waypoint, up to 10 attempts are performed to randomly select a waypoint that closes the distance between the GSG and the selected DFSP. This has the effect of causing the GSG to migrate towards the region of the operational area closer to the DFSP. This would be natural tendency by human operators to reduce the time to the next refueling opportunity.
O-1	The oiler can support refueling of up to 2 ships simultaneously.
O-2	If the active waypoint special instruction codes contain an ‘X’, the oiler does not accept ships for refueling.
O-3	If the GSG is operating at speeds faster than the oiler’s maximum speed, refueling operations are not allowed.
O-4	If the oiler is not physically alongside the GSG (the GSG has sped away from the oiler), refueling operations are not allowed.
O-5	If the oiler’s fuel level is <= *“Absolute Min Level (gal)”*, refueling is not allowed.
O-6	The oiler will not detach from the GSG if the active waypoint has a special instruction code of ‘Z’.
O-7	The oiler will transfer up to *”Refuel Rate (gph)”* of fuel (per hour) to an ship alongside for refueling. Refueling will stop when the receiving ship’s tanks are filled to *“Max Fill Level”*.
O-8	Whenever the oiler needs to detach to bring on fuel, the oiler will broadcast a “last call” to the GSG. Any GSG ship that currently has a fuel level less than 90% full will queue up and come alongside to top off their tanks.
O-9	The oiler will determine a refueling trip to a DFSP is needed whenever the current onboard fuel level minus the amount of fuel required to top off the GSG ships drops to the value specified by *“Oiler Min Fuel Level”*.
O-10	The oiler will bring on fuel from a DFSP at the rate of the host’s DFSP *“Transfer Rate (gph)”*. Once oiler’s fuel level reaches *“Oiler Max Fill Level”* the oiler will depart the DFSP and head

	back to the GSG.
OAP-1	The oiler's autopilot engages whenever the oiler is operating independent of the GSG (heading to/from a DFSP or when the GSG outruns the oiler).
OAP-2	When the oiler detaches for a fuel run, the oiler measures the distance to all the available DFSPs and selects the closest DFSP. The oiler includes the travel distance of the defined approach vectors for the DFSP.
OAP-3	For an approach to a DFSP, the oiler selects the closest approach vector's waypoint that is within the "visibility" of the oiler. Visibility is defined by a cone from the waypoint to a region defined by start and end arcs and distance. This is used to help the oiler approach a DFSP without cutting through a land mass.
OAP-4	If there are not any "visible" DFSP approach vector waypoints, the oiler increases speed to the oiler's maximum speed and proceeds along the reference mission path until a DFSP approach vector comes into view. This is necessary to prevent non-sensible paths by the oiler.
OAP-5	When the oiler leaves a DFSP to return the GSG, the oiler examines all the available approach vectors (now used as departure vectors) to identify the optimal path for leaving the DFSP. The autopilot plots a course to the end of the approach vector at which point it plots an intercept course for the GSG.
OAP-6	If while the oiler is following an approach vector (while departing a DFSP) and it detects that the GSG is within 150nm, the oiler abandons following the approach vectors and plots an intercept course for the GSG.
OAP -7	Once the oiler intercepts the GSG, the autopilot is disengaged and the oiler follows the route of the GSG.
S-1	If the ship's fuel level drops <= *"Ships Refuel at Level"* or the oiler broadcasts a "last call" and the ship's fuel level is < 90% capacity, the ship will request to come alongside the oiler for refueling.
S-2	Once the ship has received permission to come alongside, the ship will spend *"Refuel Setup Time (hr)"* time coming alongside in preparation to bring on fuel.
S-3	A refueling ship will bring on fuel until a fuel level of *"Max Fill Level"* is reached or the oiler's fuel level drops to *"Absolute Min Level (gal)"*.

3. Contact Information

For additional information and access to FISTSIM source code, please contact the FISTSIM developer:

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theodore.schinder@navy.mil
(757) 492-7295

CDSA Dam Neck
1922 Regulus Ave
Virginia Beach, VA

E. VALIDATION

The FISTSIM model's fuel calculations were verified against FIST's "Fuel Estimation.xlsx" spreadsheet and the fuel estimation process described in Navy Warfare Publication Sustainment at Sea NWP 4-01.2.

1. Comparison to FIST Fuel Estimation.xlsx

FISTSIM is designed to emulate the behaviors of humans operating the GSG for maximum performance of the fleet and in compliance with the reference mission, including the desired speed profiles, while taking necessary steps to prevent running out of fuel during times when the fueling system is under stress. For example, if the GSG operates at speeds faster than the oiler and the GSG ship's fuel levels drop too low, then the fleet will slow down. This allows the oiler to catch up and refuel the ships. Similarly, while the oiler is detached from the GSG performing a fuel run, the GSG will slow down to conserve fuel should fuel levels drop too low. The slow speeds will remain in use until the oiler rejoins the fleet.

a. Simulation Initial Conditions

To facilitate an apples-to-apples comparison of the fuel burn calculations between FISTSIM and the previous spreadsheet model "Fuel Estimation.xlsx", the initial conditions of FISTSIM were artificially configured as follows:

- DDGs and CGs fuel tank capacities were set such that they would not require a single refueling during the entire six month deployment. This was necessary to prevent FISTSIM from slowing the fleet due to fuel level restrictions.
- The oiler's maximum speed was set equal to the fleet's maximum speed. This allowed the oiler to keep up with the GSG at all times during the mission.
- Randomizations of the speed profile were disabled to ensure FISTSIM operated the GSG at the same speeds and times as entered into the "Fuel Estimation.xlsx" spreadsheet.
- Using normal distributions for the speed profile was disabled. Again this ensures FISTSIM uses the exact same speed profile speed and time data as entered in the "Fuel Estimation.xlsx".

Due to the design of "Fuel Estimation.xlsx", each segment's speed profile in the spreadsheet must be normalized to a 24 hour period. Accordingly the speed profile of " Fuel Estimation.xlsx" was set to produce identical speed and time behaviors to those used in FISTSIM.

b. **Comparison Results**

Fuel consumption was calculated using both FISTSIM and the "Fuel Estimation.xlsx" spreadsheet. The results are shown in Table 22.

Table 22. Comparison of FISTSIM to "Fuel Estimation.xlsx"

This table lists some of the differences in the calculations between FISTSIM and the initial "Fuel Estimation.xlsx" spreadsheet model used by FIST

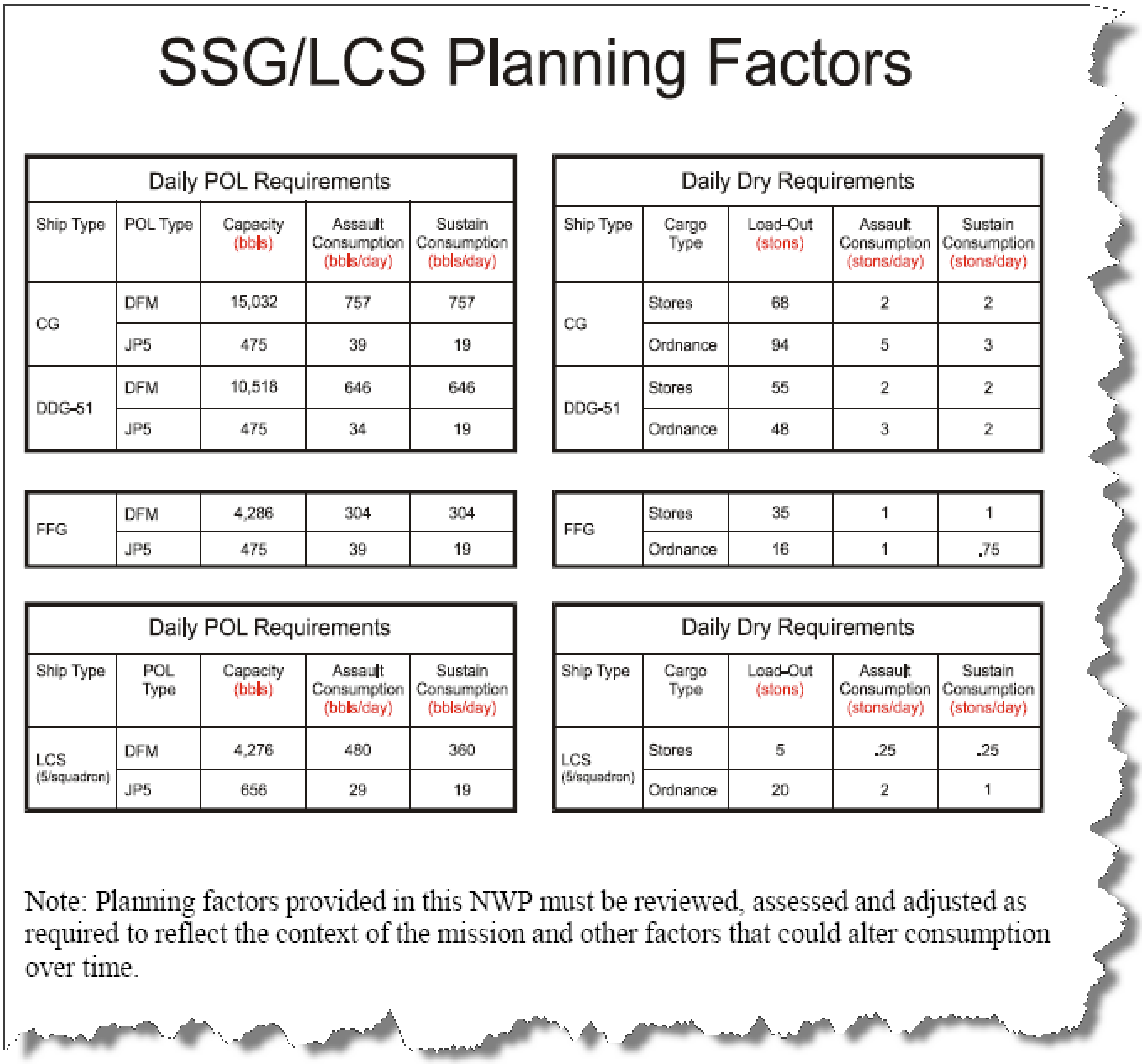
	Fuel Estimation.xlsx	**FISTSIM**	**Difference**
Total Fuel Burned (bbls)	640,140	644,366.9 ± 2,332.2	0.66%
Total Distance Traveled (nm)	46,058	46,203.4 ± 145.1	0.32%
Underway Time (days)	164.54	163.7 ± 0.3	-0.54%

FISTSIM generates random waypoints within the operational areas while the GSG is patrolling Operational Area 1 and Operational Area 2. This has the result of adding run-to-run variation in the distance, time and hence fuel consumption especially for the transit from Op Area 2 to the Suez Canal. This run-to-run variation is reflected in the standard deviation values shown in Table 22. Even with the randomization of the waypoints in the operational areas, it can be seen that FISTSIM's calculations of time, distance, and fuel agrees with the less sophisticated "Fuel Estimation.xlsx".

It is important to remember that artificial (non-realistic conditions) were imposed on the GSG in FISTSIM to create this comparison for the purposes of comparing calculations. Using FISTSIM with realistic constraints such as the need for refueling ships, maintaining sufficient fuel levels, limited oiler speeds, etc. is necessary to properly model the behavior of the actual GSG.

2. Comparison to NWP 4-01.2 Fuel Estimation

Appendix A of NWP 4-01.2 provides tables for estimating strike group fuel requirements. NWP 4-01.2 Table A-2.3. SSG/LCS Planning Factors (see Figure 69) provides estimated daily fuel consumption for CG 47 and DDG 51 class ships. As annotated by Table A-2.3's note: "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."



SSG/LCS Planning Factors

Daily POL Requirements				
Ship Type	POL Type	Capacity (bbls)	Assault Consumption (bbls/day)	Sustain Consumption (bbls/day)
CG	DFM	15,032	757	757
	JP5	475	39	19
DDG-51	DFM	10,518	646	646
	JP5	475	34	19
FFG	DFM	4,286	304	304
	JP5	475	39	19

Daily Dry Requirements				
Ship Type	Cargo Type	Load-Out (stons)	Assault Consumption (stons/day)	Sustain Consumption (stons/day)
CG	Stores	68	2	2
	Ordnance	94	5	3
DDG-51	Stores	55	2	2
	Ordnance	48	3	2
FFG	Stores	35	1	1
	Ordnance	16	1	.75

Daily POL Requirements				
Ship Type	POL Type	Capacity (bbls)	Assault Consumption (bbls/day)	Sustain Consumption (bbls/day)
LCS (5/squadron)	DFM	4,276	480	360
	JP5	656	29	19

Daily Dry Requirements				
Ship Type	Cargo Type	Load-Out (stons)	Assault Consumption (stons/day)	Sustain Consumption (stons/day)
LCS (5/squadron)	Stores	5	.25	.25
	Ordnance	20	2	1

Note: 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.

Figure 69. SSG/LCS Planning Factors

This figure shows some of the planning factors used in modeling SSG and LCS shipsin NWP 4-01.2

FISTSIM fuel consumptions vary with initial conditions provided to the model. Specifically FIST investigated the minimum infrastructure requirements to support the GSG for a 2016 deployment. For the purposes of comparing the NWP 4-01.2 fuel estimation and FISTSIM, a 1000 run simulation using three DFSPs was used for the comparison. NWP 4-01.2's fuel requirements were found by multiplying the number of underway days by the daily ship's requirements times the number of ships times the energy conversion factor between S-5 and F-76. The total fuel burned as indicated by

NWP 4-01.2 was 690,867 barrels. FISTSIM predicted a usage of 655.287 ± 17,594.2. Thus, the difference between NWP and FISTSIM is only 5.15%.

The close agreement between NWP 4-01.2's fuel estimate and FISTSIM indicates both that FISTSIM is generating reasonable fuel consumption calculations, and the initial conditions used for FISTSIM are reasonable. Specifically, the speed profile's time and speed entries are consistent with typical strike group deployment operational tempos.

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APPENDIX C: FUEL QUALITY TESTING

A. INTRODUCTION

As the Navy moves towards introduction of an alternative fuel to F-76 marine diesel, quality testing and control must be factored into the system solution. As detailed in the fuel study (Chapter II), there are differences between Fischer-Tropsch-derived S-5 (FT S-5) and crude-distilled F-76. The standard testing methodology currently in Navy use for surface platforms is geared strictly towards F-76. If S-5 is introduced into the supply chain, effects on the current fuel paradigm must be analyzed. Multiple fuels in concurrent use are not uncommon for the military. Gasoline was used across all branches of the military in the recent past, and the Navy still maintains separate specifications for JP-5 and F-76. In this regard, S-5 is not expected to have a large cultural impact on fuel handlers or their procedures.

The details of S-5 production is technical, complicated, and as a result is probably considered intellectual property by the companies familiar with its production. Furthermore, there are always inherent compatibility unknowns when introducing a new component. Despite this lack of detail, the overlying process and bounds that are part of FT S-5 production permit making some inferences as to the impact of integrating FT S-5 into the standard F-76 testing regime.

Based on MIL-DTL-16884L, there are 21 specific properties that are part of the typical testing suite for F-76. There are one or more methods of testing for each of these properties, and the limits or criteria for testing may be found in MIL-STD-3004B. For these properties, each typically fit into one of three groups:

1. Criteria that should remain unchanged despite any fuel differences
2. Criteria that need to be measured against each fuel, however the value of the criteria needs to be changed or adjusted for each fuel in turn
3. Criteria for F-76 that may not be necessary for FT S-5

A list of these measures is located in Table 23.

Table 23. Fuel Properties

A List of fuel properties broken down by general category

Unchanged measures	Measures that vary between fuels	Unnecessary F-76 measures for S-5 fuel
Pour point	Carbon content	Sulfur
Cloud point	Nitrogen Content	Trace elements
Particulate contamination	Hydrogen content	Storage stability
Cetane rating	Flash point	
Sediment	Carbon residue	
Copper corrosiveness	Ash residue	
Cold Filter / Plugging	Free water	
	Acidity	
	Density / Specific gravity	
	Color	
	Viscosity	

B. UNCHANGED MEASURES FOR DIFFERENT FUELS

A subset of the measures must remain constant across all fuels. This is because they determine effects that are important regardless of the fuel, or are not a direct measure of the fuel. Some measure a general effect found in any fuel (not just F-76 or FT S-5). They measure a property that can be imparted on the system by or through use of the fuel. For instance, particulates and sediments have no bearing on the fuel's molecular formula at all as they can be found in any liquid. These measures must be kept low to prevent fuel filters, pumps and lines from clogging with debris. The cloud, pour, and cold filtering measures are all temperature related and can have similar effects to particulates and sediment when critical temperatures are reached. Conversely, the cetane rating and copper corrosion are highly dependent on the chemical formula of the fuel. However, these measures are related to generalized effects of the fuel on specific (copper, brass, or bronze containing) areas of engine, pump, or infrastructure operation and maintenance. Thus, these measures cannot be deviated from their required value ranges without increasing the probabilistic risk of abnormal operation or failures.

C. MEASURES THAT NEED TO BE EVALUATED AT DIFFERENT VALUES FOR DIFFERENT FUELS.

Certain measures are critical to determining fuel quality. When the fuel type is changed, these critical values must be adjusted to accommodate the new type of fuel. Therefore these measures will have different values than those of F-76. Despite these differences, however, FIST expects the fuel infrastructure to be compatible except where noted in this document.

- Carbon, Nitrogen, and Hydrogen content – Diesel is not composed of a single molecule type. It is made up of a range of molecules that vary depending on time of year, producer, and a host of other variables. This composition variance can cause performance variance for the fuel under combustion. This variance will likely affect both FT S-5 and F-76. F-76, like all petroleum distillate fuels, comes from catalytic cracking of crude oil into lighter (less molecular weight) hydrocarbons. This process produces many types (a blend) of lighter hydrocarbons, not just one specific kind. The same should be true of the Fischer-Tropsch process (FT). Based on FT's basic process of upgrading carbon-containing syn-gas into longer chain molecules, it should encounter the same problem—it should not necessarily build up to one specific molecule, but a range of compounds in the same general neighborhood of molecular weight.

- Due to these molecular differences, the amount of specific atoms contained in a given amount of fuel sample (and their ratio to each other) should be different. This is reflected in other performance criteria such as the different energy densities of FT S-5 and F-76. For this reason, these are still useful measures for fuel quality within a specific type of fuel, but the values will vary between differing fuel types.

- Flash point – The flash point is a specific property of a given solution of liquids related to the partial vapor pressures of the component liquids. It will vary depending on the constituents of the fuel sample. This value will thus be different between fuel types. It will also be different depending on the percent makeup of constituents—even if the actual molecules represented between two samples are the same. This is helpful in determining if a fuel sample contains a heavier percent of lighter (and more volatile) or heavier, less volatile components. Given this analytical insight, along with requirements for minimum flash point of fuel (as discussed in the Fuel Study), this is still an important measure for fuel quality.

- Carbon and Ash residue – These measures are related to predictions of the amount of residual carbon and ash deposits expected when the fuel is burned. It would be expected this values may shift somewhat due to differences in what exactly an engine is combusting. These tests are listed here as a precautionary item. Further research on FT S-5 may reveal that the chemical production method and/or carbon source leads to enough stability in the delivered fuel composition that these measures may not be relevant or may be wasteful. Due to possible issues with incomplete combustion or other limitations and effects that may lie outside the fuel's chemical envelope, this cannot be definitively stated for these measures.

- Free water – The amount of water that can be both dissolved and (more so) contained in suspension in a fuel is a function of multiple chemical properties of the fuel. Water inhibits the combustion process. Additionally, acids can be dissolved in water. Fundamental differences in a fuel type's ability to retain water and/or acids will probably differ and require further study to define accurate criteria for quality judgments.

- Density, color, and viscosity – All three of these values are inherent properties of any liquid and determined by its chemical makeup (when keeping all other environmental factors constant). As a result, these measures should have different threshold values for different fuel types. Their use as a factor of fuel quality inside a specified fuel type is still legitimate and should continue to be used. It should be noted that both density and viscosity were utilized as alternative fuel evaluation criteria in the fuel study.

D. MEASURES THAT ARE NOT APPLICABLE TO FT S-5 FUEL FROM F-76 FUEL

F-76 and FT S-5 are produced in very different ways. As mentioned before, F-76 is produced through the catalytic cracking of crude oil from a geological source. As a result of its geological source, various mineral contaminants from the Earth's crust will inevitably be included in crude oil and require active separation to remove. As with any process, separations cannot be done to 100% and the expense required to remove smaller and smaller amount of one chemical from another increase asymptotically (similar to a cost benefit analysis pursuing maximum performance regardless of cost). Thus, contaminants are still present in some amount.

Fischer-Tropsch fuels like S-5 come from a very different process. As mentioned before, a base feedstock can utilize a wide range of carbon sources to be reduced into syn-gas. Using feedstock selections that are inherently limited in specific types of contaminants can be drastically reduced, controlled, or even outright eliminated.

That being said, some feed stocks may introduce these contaminants back into the fuel. The primary concern here is coal, which is both a FT carbon feedstock and derived from the same geological sources as petroleum and contains the same contaminants.

E. EXTRA FT S-5 TESTING

Invariably there will be new properties in FT S-5 that have not been fully explored or recognized. This should be expected given the lower TRL of FT derived fuels as compared to F-76. It will be important to recognize that new and unanticipated fuel quality issues will probably be discovered as deployment and operational support with FT S-5 matures. It is recommended to keep close tabs on fuel quality and to have research programs developed to analyze the fuel for storage, handling, production, and usage conditions and variances that may impact its usability in Naval systems. An inherent part of this effort will be to determine if additional, FT S-5-specific measures require formulating, standardizing, and monitoring.

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