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ANALYSIS OF THE SINGLE FUEL CONCEPT WITHIN THE EUCOM AREA OF RESPONSIBILITY

by

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Currently, U.S. Navy ships, with the exception of CVNs and submarines, utilize F-76 as their main fuel source and utilize JP-5 for aviation and support equipment. When planning for replenishment at sea, ships must plan to receive both F-76 and JP-5. Ships must also utilize separate storage and testing of the two fuels. The replenishment ships, which refuel the warships, are constrained by how much of each fuel type they can store. Being able to utilize a single fuel could simplify replenishment schedules.

This research effort analyzes fuel supply and distribution capabilities during Phase II operations in the European theater when operating under the single fuel concept. This effort builds on two prior works: an unclassified study focused on the logistics benefit provided by the single fuel concept in the Pacific and a classified study (sanitized for this thesis) that explored the current logistics capability and capability gaps surrounding petroleum, oil and lubricant (POL) distribution. This work determines the potential impacts of switching to a single type of fuel (JP-5) and examines what kinds of policy changes and/or asset procurements may be needed to close those gaps. This study uses the NPS-developed Fuel Usage Study Extended Demonstration (FUSED) model to evaluate our capabilities to move fuel in theater using currently available assets operating under a single fuel concept (JP-5) and compares it with the performance with two fuels: JP-5 and F-76.

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ANALYSIS OF THE SINGLE FUEL CONCEPT WITHIN THE EUCOM AREA OF RESPONSIBILITY

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATION

AOR	Area of operational responsibility
ARG	amphibious readiness group
bbl	barrel of fuel (42 U.S. gallons)
CG	Ticonderoga-class guided-missile cruiser
CLF	Combat Logistics Force
CSG	Carrier Strike Group
CVN	Nimitz-class nuclear aircraft carrier
DDG	Arleigh Burke-class guided-missile destroyer
DF-2	Military Diesel Fuel NATO designation code F-65
DFM	Diesel Fuel Marine
DFSP	Defense Fuel Support Point
DLA	Defense Logistics Agency
DOD	U.S. Department of Defense
F-76	NATO designation for naval distillate fuel, complying with MIL-DTL-16884N for the U.S. Navy
FSII	Fuel Systems Icing Inhibitor
FUSED	Fuel Usage Study Extended Demonstration
FY	fiscal year
GAMS	General Algebraic Modeling Language
JP-4	Aviation fuel composed of kerosene and gasoline NATO designation code F-40
JP-5	Aviation turbine fuel (high flashpoint) complying with MIL-DTL-5624W. NATO designation code F-44
JP-8	military equivalent of Jet A-1 fuel with corrosion inhibitors and anti-icing additives complying with MIL-DTL-83133J. NATO designation code F-34
LCS	littoral combat ship (United States Navy hull classification)
LHD	landing helicopter dock ship (United States Navy hull classification)
LPD	San Antonio-class landing platform dock
LSD	landing ship, dock (United States Navy hull classification)
MSC	Military Sealift Command

NATO	North Atlantic Treaty Organization
OTTER	Optimized Transit Tool and Easy Reference
POSEIDON	Pacific operational energy survey, exploration, investigation, and development to meet operational needs
RAS	replenishment at sea
RASP	replenishment at sea planner
SFC	Single Fuel Concept
T-AKE	auxiliary cargo and ammunition ship
T-AO	fleet replenishment oiler ship
TFP	Transit Fuel Planner
UNREP	underway replenishment
USAWC	United States Army War College
USEUCOM	Unites States European Command
USINDOPACOM	United States Indo-Pacific Command
USNS	United States Naval Ship
USS	United States Ship
VBA	Visual Basic for Applications

EXECUTIVE SUMMARY

The United States (U.S.) European Command (EUCOM) area of operational responsibility (AOR) is dynamic and very different in challenges than the U.S. Indo-Pacific Command (INDOPACOM) AOR. The challenge is not a time or distance challenge to get ships to missions, but a resource competition challenge. There are not many dedicated U.S. warships to the region, and being flexible enough to alter missions on a moment's notice is required. One way to enable the fleet to effectively tackle this resource sparseness is to lengthen individual and groups of ships' operational legs. This thesis examines the possibility of utilizing the single maritime fuel concept of exclusively utilizing aviation fuel for the fleet to extend the operational capability of warfighting vessels. This will encompass switching the replenishment fleet and storage facilities to all aviation fuel as well.

Before exploring possible scenarios to see if single fuel could be beneficial for the U.S. Navy in the EUCOM AOR, a literature review of previous single fuel studies was conducted. In this review, it was found that jet propulsion 5 (JP-5) is compatible with Navy vessel engines and it is feasible to switch to all JP-5 for vessels and aircraft and not negatively impact the engines and generators of the fleet (Guimond 2007). Two possible downsides to switching to all jet fuel were a slight increase in cost per gallon and a slight reduction in efficiency with compared to naval distillate fuel (Giannini et al. 2002).

In order to determine whether switching to a single fuel is beneficial for the U.S. Navy, different EUCOM transits of 2 ship groups with varying operations were compared for both single and dual fuel. Additionally, different platforms for each of the 2 groups were rotated through 2 carrier strike groups (CSG), 2 amphibious readiness groups (ARG), and 1 ARG and 1 CSG. For more realism, a JP-5 efficiency modifier was also incorporated for varying propulsion and generator percentages of 97%, 98%, 99% and 100%. The base model utilized for analysis was the Fuel Usage Study Extended Demonstration (FUSED) created by Naylor (2015). FUSED was extended for this thesis to incorporate the JP-5 efficiency modifier, the single/dual fuel option and the fuel burn of aircraft. A total of 216 iterations were run in FUSED and for each iteration the following items were tracked: the

total gallons burned, total time spent refueling, total fuel delivered by the combat logistic force (CLF), total number of replenishments at sea (RASs) and total number of CLF trips to port. These totals were compared for single and dual fuel, at each JP-5 efficiency modifier for each group of 2 ships.

The results showed that single fuel burned more fuel but extended the time between RASs and CLF trips to port. Additionally, fewer CLF trips to port and RASs were required to travel the same distance with the same operations for single fuel. The results suggest that it is potentially beneficial for EUCOM to explore the use of a single maritime fuel concept to increase the flexibility of the fleet. Additionally, cost savings could be incurred by the less frequent CLF trips to port, which could offset the $0.01 increase in cost per gallon of jet fuel. The results were in line with a previous INDOPACOM single fuel thesis which found the total number of CLF and warfare assets could increase their operational range by switching to a single maritime fuel (Jimenez et al. 2020).

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I. INTRODUCTION

This thesis examines the potential benefits of switching to aviation turbine fuel (JP-5) as the single maritime fuel for aviation and surface assets in the United States European Command (USEUCOM) area of operational responsibility. This is based on the single fuel concept (SFC), which has been encouraged by all branches of the Military. The base model utilized for analysis was the Fuel Usage Study Extended Demonstration (FUSED; Naylor 2015). FUSED originated from a fleet fuel efficiency study and allows the user to calculate the estimated gallons of fuel burned for a specific transit (Crawford 2014). Note that the output of FUSED is in gallons, rather than barrels (bbls). In FUSED, ships, drills, ports, speed and engine configurations can all be modified via user inputs to create realistic scenarios. We extended FUSED so that JP-5 and/or naval distillate fuel (F-76) can be used, and we compared time on station and total refueling required for group movements when single or dual fuel types were used. We also added the ability to track the consumption of air resources' fuel to obtain a more realistic fleet fuel consumption model. The goal of the thesis is to determine whether pooling fuel resources (JP-5 and F-76 tanks) allows for more schedule flexibility.

The baseline scenario for this thesis is a transit from Souda Bay, Greece, to Loch Striven, Scotland. Figure 1 shows a map of the route. Three different ship configurations were considered to compare results: 2 Carrier Strike Groups (CSGs), 2 Amphibious Readiness Groups (ARGs) and 1 CSG and 1 ARG. For each ship configuration, the transit was modified multiple times with different operational requirements. All three configurations were run using the same model parameters otherwise, to show the potential benefits and drawbacks of using a single maritime fuel for varying ship platforms.

Our analysis demonstrates that using JP-5 only, instead of both JP-5 and F-76, has a pooling effect that allows for more time between replenishments. Moreover, the replenishment ships were able to increase the number of operational days between ports. In short, using a single maritime fuel appears to give more flexibility for both USEUCOM warships and replenishment ships. The downside for this increased flexibility is a higher overall fuel cost to the fleet; this depends on the efficiency of JP-5 relative to F-76.

However, improving technology and the tuning of engines to jet fuel can diminish this added cost over time.

Figure 1. USEUCOM Route of Warships from Souda Bay, Greece to Loch Striven, Scotland. Adapted from Wikimedia Commons (2008)

The U.S. Navy currently operates under a dual fuel concept. Airplanes are fueled with Aviation turbine fuel complying with MIL-DTL-5624 (Department of Defense [DOD] (2016), North Atlantic Treaty Organization (NATO) designation F-44 (JP-5) and ships are fueled with NATO designation for naval distillate fuel, complying with MIL-DTL-16884 (Department of Defense [DOD] (2014) for the U.S. Navy (F-76). They use separate tanks, receipt mechanisms, inventory procedures and testing procedures. The single fuel concept (SFC) proposes utilizing JP-5 for both aviation and shipboard fuel. This can add more flexibility and endurance to the fleet by allowing all sources requiring fuel to access all tanks on a vessel. The resulting increased fuel endurance can allow for fewer replenishments at sea (RAS). Another potential benefit of using a single fuel is reduced testing and maintenance times for personnel onboard ships, due to the ability to conduct all testing at once. These outcomes would allow the warfighter more time to conduct missions and more time to be available on station for additional requirements.

JP-5 is currently \$3.11 per gallon and F-76 is \$3.10 per gallon, according to the Defense Logistics Agency (DLA) standard price list for fiscal year (FY) 2022. At a one cent price differential, the overall price change would be nominal. The specifications for JP-5 are more stringent due to the high flashpoint[1] and additive requirements for naval aviation fuel. U.S. Navy aircraft cannot operate with low flashpoint fuel because of the safety risks associated with it. It was previously found that diesel-powered marine systems can utilize JP-5 without any significant issues (Sermarini 2000). The commitment and necessity of the U.S. Navy to minimize the total number of fuel types utilized has been addressed since 2002 (Giannini et al. 2002). While JP-5 has a lower energy density compared to F-76 (Giannini et al. 2002), the difference is small.

At U.S. Air Force bases around the world, a single fuel is primarily in use for aviation. This fuel is the military equivalent of Jet A-1 (JP-8, NATO designation code F-34) with corrosion inhibitors and anti-icing additives complying with MIL-T-83133 (Department of Defense [DOD] (2015). Because of the relatively low flashpoint of JP-8 (100° Fahrenheit) it cannot be utilized for the maritime fuel (DOD 2015). However, JP-5

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[1] Flashpoint is the temperature at which the fuel is able to ignite.

meets the minimum flashpoint requirements and can be utilized to fuel both ships and aircraft. Following the shore model of a single fuel, a single maritime fuel is obtainable and available by switching the engines and pumps to a configuration that supports JP-5.

The proponents of the SFC argue that it can lead to increased fleet flexibility. In this thesis, we investigate this claim in the USEUCOM area of responsibility. Specifically, we consider the following research questions:

1. Does a CSG or ARG gain more flexibility in operations by switching to a single fuel?
2. Is the overall refueling time on station lower for a single fuel than dual fuel?
3. Is the lower energy efficiency of JP-5 a negative item when proposing the conversion to a single maritime fuel?

II. BACKGROUND

A. INTRODUCTION TO USEUCOM AOR

The United States European Command (USEUCOM) area of responsibility (AOR) is unique in that it requires the cooperation of many countries while being much less vast than the United States Indo-Pacific Command (USINDOPACOM) AOR. The current commander's priorities listed in the EUCOM posture statement are to be able to tackle the difficulties posed by the Russian Federation and the People's Republic of China. (U.S. European Command 2022). While distance is the main issue for refueling the fleet in the USINDOPACOM AOR, competing concurrent operations with limited resources is the main concern in the USEUCOM AOR.

B. HISTORICAL DUAL FUEL USAGE

The U.S. Navy currently operates with F-76 for its ships, and with JP-5 for its aircraft. There has been resistance to moving towards a single fuel because the existing processes, equipment and facilities are set up to accommodate the dual fuel concept. A prior concern to switching to a single fuel was the price differential between JP-5 and F-76. However, the price differential is currently only $.01 per gallon. Another concern was the reduction in efficiency in running the ships' generators and engines on JP-5. A prior study found that the current reduction is only estimated at 2.6% (Giannini et al. 2002). This is due to a slightly lower energy density of JP-5 compared to F-76. With improved technology and the use of additives, this energy density differential can potentially be reduced (Giannini et al. 2002).

For this thesis, SFC studies and prior theses from 1996 onwards were examined. The SFC is not a new concept, but as of today it has not been able to gain sufficient visibility or backing in the U.S. Navy.

C. FUEL TYPES AND CHARACTERISTICS

1. JP-5 (Aviation Turbine Fuel; Naval Jet Fuel)

This thesis focuses on the single fuel concept where Jet Propellant 5, or JP-5 (NATO designation code F44), is used for both ships and aircraft. JP-5 is an aviation fuel that has a flashpoint of 140° Fahrenheit. The main distinction between JP-5 from JP-8 is that JP-8 has a flashpoint of only 100° Fahrenheit (DOD 2016). JP-5 additives include a Fuel Systems Icing Inhibitor (FSII), a lubricity improver and a corrosion inhibitor. The FSII helps to prevent ice crystals from forming. Ice crystals are a problem because they can block lines or melt and subsequently cause water contamination in the fuel. JP-5 is the standard fuel for Naval Aviation.

2. F-76 (NATO Designation for Naval Distillate Fuel; Diesel Fuel Marine)

The other fuel considered in this thesis is F-76, also known as Diesel Fuel Marine (DFM). Like JP-5, it has a relatively high flashpoint of 140° Fahrenheit (DOD 2014). This is another safety requirement that only the Navy has due to at-sea operations. To produce F-76, crude oil is first distilled into light and heavy portions. Then, F-76 is made from distillates and stability additives are added to allow for long term storage. The additives and sourcing of fuel are how it differs from commercial diesels. Commercial fuels often use chemical processes to create different fuel types. The way F-76 is produced results in a more stable and reliable product. F-76 is the standard fuel for Navy Surface Assets.

III. LITERATURE REVIEW

A. SINGLE NAVAL FUEL AT SEA

The 2002 Naval Air Systems Command Fuels and Lubricants Division study found that there was enough JP-5 to fuel maritime and aviation Navy and Marine assets (Giannini et al. 2002). An implication of switching to this single fuel type is an increased fuel purchasing cost compared to the current dual fuel system, due to the loss of efficiency associated with using JP-5 in place of F-76. Specifically, it has been estimated that using JP-5 instead of F-76 results in an approximately 2.6% reduction in range (Giannini et al. 2002). At the same time, it was found that cost savings could be obtained from decreased shipboard maintenance and infrastructure costs because of the reduced number of tanks and associated equipment that would be required with a single fuel in the fleet (Giannini et al. 2002). The study also found that there may be increased flexibility in planning underway replenishments.

B. JP-5: THE POTENTIAL UNIVERSAL FUEL AT SEA

Sermarini (2000) explored the limitations and benefits of using a single fuel at sea. The author found that one key point was that the U.S. Army Ground Material Operating on Aviation Kerosene Fuel did not find a statistically significant difference in average fuel consumption when comparing engines run on JP-8 and military diesel fuel F-65 (DF-2). He noted that while JP-8 is not JP-5 and DF-2 is not F-76, this is a similar comparison of running engines on jet versus diesel fuel.

Additionally, this study also found that using one fuel simplifies logistics and improves demand predictability. Sermarini determined that a single fuel might also provide options for reducing the number of tankers and oilers needed to support the Fleet (2000).

C. SINGLE FUEL CONCEPT FOR MARITIME OPERATIONS: EFFECTS ON TACTICAL AND OPERATIONAL READINESS

Guimond (2007) reviewed 100,000 Navy corrective maintenance records from 1995–2003 and found the JP-5 did not negatively affect ship diesel engines. Additionally, the study did not find any indications of increased part replacement when switching from F-76 to JP-5 fuel. Furthermore, except for the prime mover engines of Westerbeke, all of the engines sold to the Navy have been tested with JP-5 (Guimond 2007). Lastly, the study found that while utilizing JP-5 did not interfere with the engines' capability to achieve full power, fuel consumption increased by 4.6% per gallon when compared to F-76.

However, Guimond (2007) points out that JP-5 does not currently have a specification to meet a minimum cetane rating of 40. This minimum cetane specification would allow for more reliability in ignition and engine starting and acceleration. The study also found that using JP-5 could lead to increased fuel consumption due to a minor power loss associated with utilizing JP-5.

D. STRATEGIC IMPLICATIONS FOR A SINGLE-FUEL CONCEPT

The United States Army War College (USAWC) research project discusses the Department of Defense's (DOD's) desire to convert all military forces to a single fuel (Weir 1996). This project considered the infeasibility for the Navy to utilize JP-8 as a universal fuel, due to its lower flashpoint and the safety concerns that this poses in maritime environments. Weir (1996) determined that the Navy would need to utilize JP-5 and aviation fuel NATO code F-40 (JP-4) in cold weather conditions.

Weir (1996) also discusses the need to design future equipment that can utilize JP-8 as fuel. The study suggests that a single fuel across all ground forces will allow for more streamlined logistics.

E. POSEIDON

This 2019 USINDOPACOM study explored operational challenges for the AOR, and made recommendations for future investments. One area of concern was operational energy. The survey recommended camouflaging and concealing bulk fuel, creating more mobile Defense Fuel Supply Points (DFSPs) and synthetic fuel manufacturing.

This study ties to this thesis in that the positioning and security of fuel facilities and refueling assets will need to be taken into account for the USEUCOM AOR.

F. ALTERNATIVE PRACTICES TO IMPROVE SURFACE FLEET FUEL EFFICIENCY

Crawford (2014) utilized the Transit Fuel Planner (TFP) to encourage fuel conservation and efficiency to allow for costs savings for the fleet and Military Sealift Command (MSC). It was found that by reducing the fuel safety level by 10%, MSC ships could save $18.5M per year. The thesis also found that by encouraging drift operations and single-generator operations, the fleet could save upwards of $60M per year. Recommended follow-on work included researching techniques that could allow ships to stay on station longer (Crawford 2014).

G. OTTER: AN OPTIMIZED TRANSIT TOOL AND EASY REFERENCE

Blackburn (2016) discusses the use of OTTER, which is the successor to the Transit Fuel Planner, to achieve fuel savings throughout the fleet. OTTER allows for drills and evolutions to be added into a schedule and for the output to include optimal speed combinations for fuel savings (Blackburn 2016). The savings to the Navy was shown to come primarily from the guided missile cruiser (CG), destroyer (DDG), and littoral combat ship (LCS) classes (Blackburn 2016).

H. SINGLE FUEL CONCEPT FOR MARITIME OPERATIONS: OPERATIONAL BENEFITS

Jimenez, Walters and Lessner (2020) surveyed the operational benefits that switching to a single maritime fuel would provide. Using a USINDOPACOM scenario, it was found that switching to all JP-5 fuel would allow for the surface fleet to be refueled by fewer MSC ships (Jimenez et al. 2020). This thesis found that the auxiliary cargo and ammunition ship (T-AKE) refueling capacity was increased by 20% and fleet replenishment oiler ship (T-AO) refueling capacity was increased by 12% by switching to a single fuel. Jimenez, Walters and Lessner (2020) determined that the number of MSC port visits could be reduced by switching to a single fuel. Additionally, warfare assets were able to increase their operational range (Jimenez et al. 2020).

I. SINGLE FUEL CONCEPT FOR THE NAVY'S SURFACE FLEET: AN ANALYSIS OF LONG-TERM SOLUTIONS

Kinser and Kube (2021) explored the potential cost savings and supply chain simplifications associated with switching to a single maritime fuel. This thesis proposed rolling out the SFC in 3 phases to allow for increased production of JP-5 and for ships to be slowly modified to use JP-5. The thesis predicted that nearly $100M over the next decade could be saved by switching to JP-5.

J. FUEL SHARING IN EXPEDITIONARY OPERATIONS

This article uses historical data to show the potential benefits of fuel sharing, which include decreasing mission and logistics risk (Doerr et al. 2019). The Ardennes campaign was used to show that the Germans' ability to succeed increased by 34% if they had enough fuel (Doerr et al. 2019). Tacticians can underestimate the value of streamlined logistics, and this article shows that logistics can influence the outcome of a battle.

K. COMBAT LOGISTICS FORCE PLANNER

The combat logistic force (CLF) fleet conducts underway replenishments (UNREP) to replenish warships and this article explores optimizing the CLF fleet schedule through the CLF planner tool (Brown and Carlyle 2008, p.800). Additionally, the CLF planner can be utilized to advise on which future CLF ships the Navy should invest in (Brown and Carlyle 2008). The article discusses CLF composition, CLF customers, scenarios, logistics planning factors and sea routes. An integer linear program was utilized to model the best composition and schedule of CLF ships to service the customer by minimizing penalties incurred from shortages of commodities (Brown and Carlyle 2008, p. 803). The CLF planner utilizes General Algebraic Modeling Language (GAMS) to solve the scenario inputted by the user (Brown and Carlyle 2008, p. 807). The CLF planner allows the user to see if and how naval operations can be logistically supported (Brown and Carlyle 2008, p. 809).

L. REPLENISHMENT AT SEA PLANNER

The Replenishment at Sea Planner (RASP) is the follow-on tool to the CLF planner and optimizes CLF fuel consumption (Brown et al. 2018, p.4). RASP does this by solving an integer linear optimization problem to minimize total costs (Brown et al. 2018, p.10). When RASP was tested out in 5th Fleet in 2010, it encountered road blocks to being utilized by replenishment planners through network non-integration and overall distrust in the software (Brown et al. 2018, p.10). However, in 2013 5th Fleet adopted RASP as its daily scheduling tool (Brown et al. 2018, p.11). While working on implementing RASP in 7th Fleet in 2013, it was found the most valuable item for the schedulers was time savings and not cost savings in fuel (Brown et al. 2018, p.12). Modelers incorporated a quick solve option into RASP that allows for time reduction for solution by solving much faster than the full solve option (Brown et al. 2018, p.13). This article also found that RASP has allowed schedulers to plan further out than before since schedules can be generated quickly and that there is a possibility for better cross-fleet planning.

M. SUMMARY

All the literature reviewed showed potential benefits from adopting a single maritime fuel. There are some potential drawbacks, including the reduced energy density of JP-5 compared to F-76. Also, the current cost of JP-5 is usually higher (within 1% difference), so there would be an associated cost increase by changing to all JP-5. However, all the studies showed increased operational flexibility and increased MSC flexibility. In particular, the work on TFP and OTTER showed that by adapting smarter engine configurations, fuel can be saved. This potential savings of fuel through other measures can help offset the increase in fuel needed to operate exclusively with JP-5.

In the current Navy with a smaller overall number of ships, increased flexibility is important. Also, with technology continually advancing, the energy density differential between JP-5 and F-76 will likely be reduced over time.

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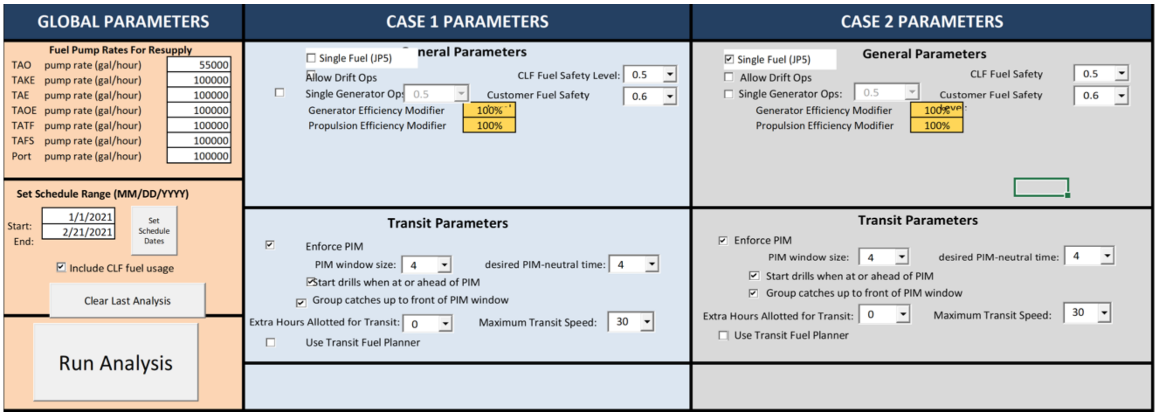
IV. MODEL AND METHODOLOGY

A. MODEL: FUSED

The base model utilized for this thesis was the Fuel Usage Study Extended Demonstration (FUSED) developed by Naylor in 2015. FUSED is a Visual Basic for Applications (VBA) modeling tool that allows the user to calculate the estimated gallons of fuel burned for up to ten battle groups conducting missions in a particular theater. The ship operating parameters, drills, ports, movement speed and engine configurations can be modified via user inputs to create realistic scenarios. See Figure 2 for an overview of the FUSED user interface. The inputs to FUSED include the fuel curves for each ship class, which are used to estimate the amount of fuel burned when carrying out a user-defined mission.



Fuel Pump Rates For Resupply

TAO	pump rate (gal/hour)	55000
TAKE	pump rate (gal/hour)	100000
TAE	pump rate (gal/hour)	100000
TAOE	pump rate (gal/hour)	100000
TATF	pump rate (gal/hour)	100000
TAFS	pump rate (gal/hour)	100000
Port	pump rate (gal/hour)	100000

Set Schedule Range (MM/DD/YYYY)
Start: 1/1/2021
End: 2/21/2021
☑ Include CLF fuel usage

CASE 1 PARAMETERS

General Parameters
☐ Single Fuel (JP5)
☐ Allow Drift Ops
☐ Single Generator Ops: 0.5
CLF Fuel Safety Level: 0.5
Customer Fuel Safety: 0.6
Generator Efficiency Modifier: 100%
Propulsion Efficiency Modifier: 100%

Transit Parameters
☑ Enforce PIM
PIM window size: 4
desired PIM-neutral time: 4
☑ Start drills when at or ahead of PIM
☑ Group catches up to front of PIM window
Extra Hours Allotted for Transit: 0
Maximum Transit Speed: 30
☐ Use Transit Fuel Planner

CASE 2 PARAMETERS

General Parameters
☑ Single Fuel (JP5)
☐ Allow Drift Ops
☐ Single Generator Ops: 0.5
CLF Fuel Safety: 0.5
Customer Fuel Safety Level: 0.6
Generator Efficiency Modifier: 100%
Propulsion Efficiency Modifier: 100%

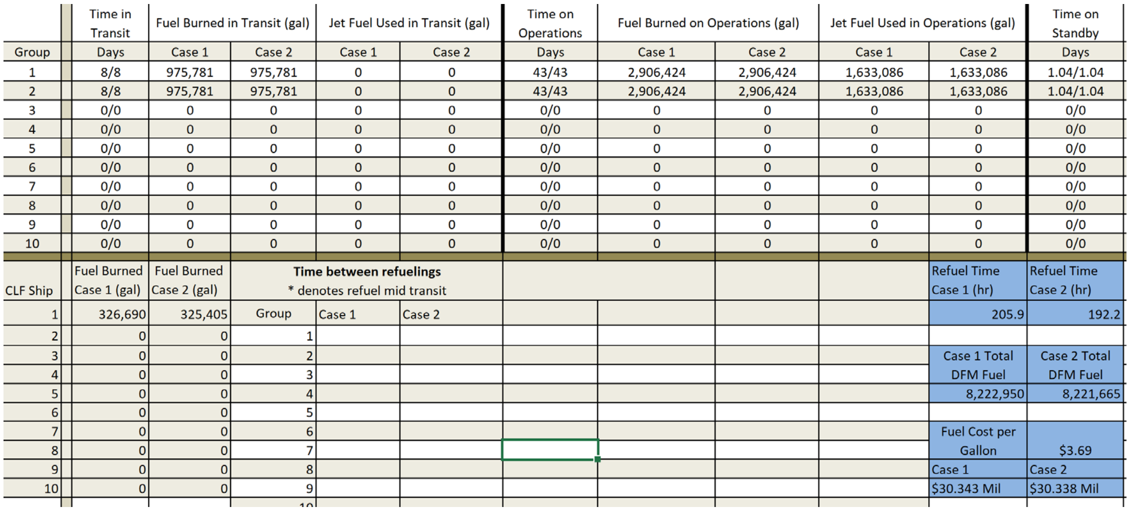
Transit Parameters
☑ Enforce PIM
PIM window size: 4
desired PIM-neutral time: 4
☑ Start drills when at or ahead of PIM
☑ Group catches up to front of PIM window
Extra Hours Allotted for Transit: 0
Maximum Transit Speed: 30
☐ Use Transit Fuel Planner

Case 1 was utilized for dual fuel in this study and Case 2 for single fuel (JP-5 only). All other parameters were the same between the two cases, except for modifying the Generator and Propulsion efficiency to account for the fact that JP-5 is less energy dense than F-76

Figure 2. FUSED User Interface. Source: Naylor (2015).

FUSED calculates fuel consumption on an hour-by-hour basis, and its outputs show the fuel consumed by the combatant ships and Combat Logistics Force (CLF) ships. The customer ships in each battlegroup and CLF ships in theater must be specified. The mission schedule of the battlegroups and the timing of operations is inputted by the user before running the FUSED model. In addition to the fuel consumed, it shows the fuel delivered to the customer ships by the CLF ships. See Table 1 for an example of the results generated by FUSED. The number of times fuel is delivered, RAS locations, specific fuel quantities and the dates of delivery are tracked. The fuel delivery by CLF ships is triggered by any ship in a battlegroup reaching a user-specified fuel safety level. See Table 2 for an example of the RAS requirements generated by FUSED. For this thesis, this safety level can be triggered by either JP-5 or F-76 and was set at 60%. Additionally, the entire battlegroup is refueled together. If the DDG falls below the safety level, the CG and nuclear aircraft carrier (CVN) will also receive fuel.

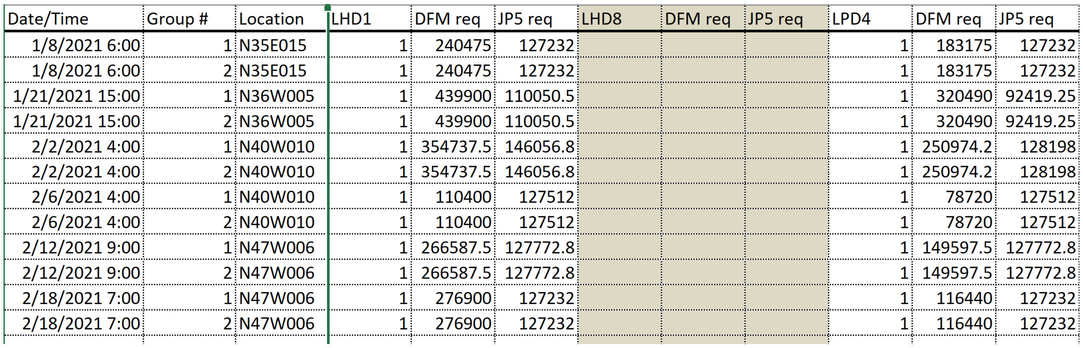
Table 1. FUSED Results Tab. Source: Naylor (2015).



	Time in Transit	Fuel Burned in Transit (gal)		Jet Fuel Used in Transit (gal)		Time on Operations	Fuel Burned on Operations (gal)		Jet Fuel Used in Operations (gal)		Time on Standby
Group	Days	Case 1	Case 2	Case 1	Case 2	Days	Case 1	Case 2	Case 1	Case 2	Days
1	8/8	975,781	975,781	0	0	43/43	2,906,424	2,906,424	1,633,086	1,633,086	1.04/1.04
2	8/8	975,781	975,781	0	0	43/43	2,906,424	2,906,424	1,633,086	1,633,086	1.04/1.04
3	0/0	0	0	0	0	0/0	0	0	0	0	0/0
4	0/0	0	0	0	0	0/0	0	0	0	0	0/0
5	0/0	0	0	0	0	0/0	0	0	0	0	0/0
6	0/0	0	0	0	0	0/0	0	0	0	0	0/0
7	0/0	0	0	0	0	0/0	0	0	0	0	0/0
8	0/0	0	0	0	0	0/0	0	0	0	0	0/0
9	0/0	0	0	0	0	0/0	0	0	0	0	0/0
10	0/0	0	0	0	0	0/0	0	0	0	0	0/0
CLF Ship	Fuel Burned Case 1 (gal)	Fuel Burned Case 2 (gal)	**Time between refuelings** * denotes refuel mid transit							Refuel Time Case 1 (hr)	Refuel Time Case 2 (hr)
1	326,690	325,405	Group	Case 1	Case 2					205.9	192.2
2	0	0	1								
3	0	0	2							Case 1 Total DFM Fuel	Case 2 Total DFM Fuel
4	0	0	3								
5	0	0	4							8,222,950	8,221,665
6	0	0	5								
7	0	0	6							Fuel Cost per Gallon	
8	0	0	7								$3.69
9	0	0	8							Case 1	Case 2
10	0	0	9							$30.343 Mil	$30.338 Mil

Fuel burned in transit, during operations, and on standby. It also gives total hours of refueling. Case 1 in this study is dual fuel and Case 2 is single fuel.

Table 2. FUSED RAS Results. Source: Naylor (2015).



Date/Time	Group #	Location	LHD1	DFM req	JP5 req	LHD8	DFM req	JP5 req	LPD4	DFM req	JP5 req
1/8/2021 6:00	1	N35E015	1	240475	127232				1	183175	127232
1/8/2021 6:00	2	N35E015	1	240475	127232				1	183175	127232
1/21/2021 15:00	1	N36W005	1	439900	110050.5				1	320490	92419.25
1/21/2021 15:00	2	N36W005	1	439900	110050.5				1	320490	92419.25
2/2/2021 4:00	1	N40W010	1	354737.5	146056.8				1	250974.2	128198
2/2/2021 4:00	2	N40W010	1	354737.5	146056.8				1	250974.2	128198
2/6/2021 4:00	1	N40W010	1	110400	127512				1	78720	127512
2/6/2021 4:00	2	N40W010	1	110400	127512				1	78720	127512
2/12/2021 9:00	1	N47W006	1	266587.5	127772.8				1	149597.5	127772.8
2/12/2021 9:00	2	N47W006	1	266587.5	127772.8				1	149597.5	127772.8
2/18/2021 7:00	1	N47W006	1	276900	127232				1	116440	127232
2/18/2021 7:00	2	N47W006	1	276900	127232				1	116440	127232

The refueling requirements are broken down by Group 1 and Group 2. The time and location are listed as well.

For the purpose of our USEUCOM study, it was assumed that the MSC fuel pump rate was 55,000 gallons per hour and that the fuel burn rates for the navy warfare ships complied with the 2021 Logistics Support in Contested Environment tables. Additionally, it was assumed that there would be an approximate setup and breakaway time of 15 minutes per refueling evolution. It was also assumed that for the SFC case all tanks (both JP-5 and F-76) would be accessible to both the ships engines and generators and aircraft without limitations. Lastly, the speed of the transit for the ships was set between 14.7 and 15.2 knots to give a realistic transit speed.

B. MODEL: FUSED WITH DUAL FUEL CAPABILITY AND DYNAMIC INPUTS

We took FUSED's initial setup and added the ability to utilize all JP-5 or dual fuel. Because fuel consumption might increase using JP-5, we also added the ability to track the consumption of air resources' fuel and added a generator and engine propulsion efficiency modifier. This was used to model different JP-5 efficiency percentages (97%, 98%, 99% and 100%). These efficiency percentages were based on the 2.6% reduced efficiency in the Single Naval Fuel at Sea Study. Additionally, a feature to log how many times the CLF ships returned to port was added to help track CLF tasking.

C. SCENARIO

The scenario utilized for this thesis was the movement of ships from Souda Bay, Greece to Loch Striven, Scotland with varying operations. The ships' arrival time to Loch Striven, Scotland depended on the duration of operations. Figure 1 shows the path of the ships. The ships were programmed to stop at way points near major ports for four different operations. These different points were off the coast of Augusta Bay, Rota, Lisbon, and Brest. The way points for operations are shown in Figure 3.

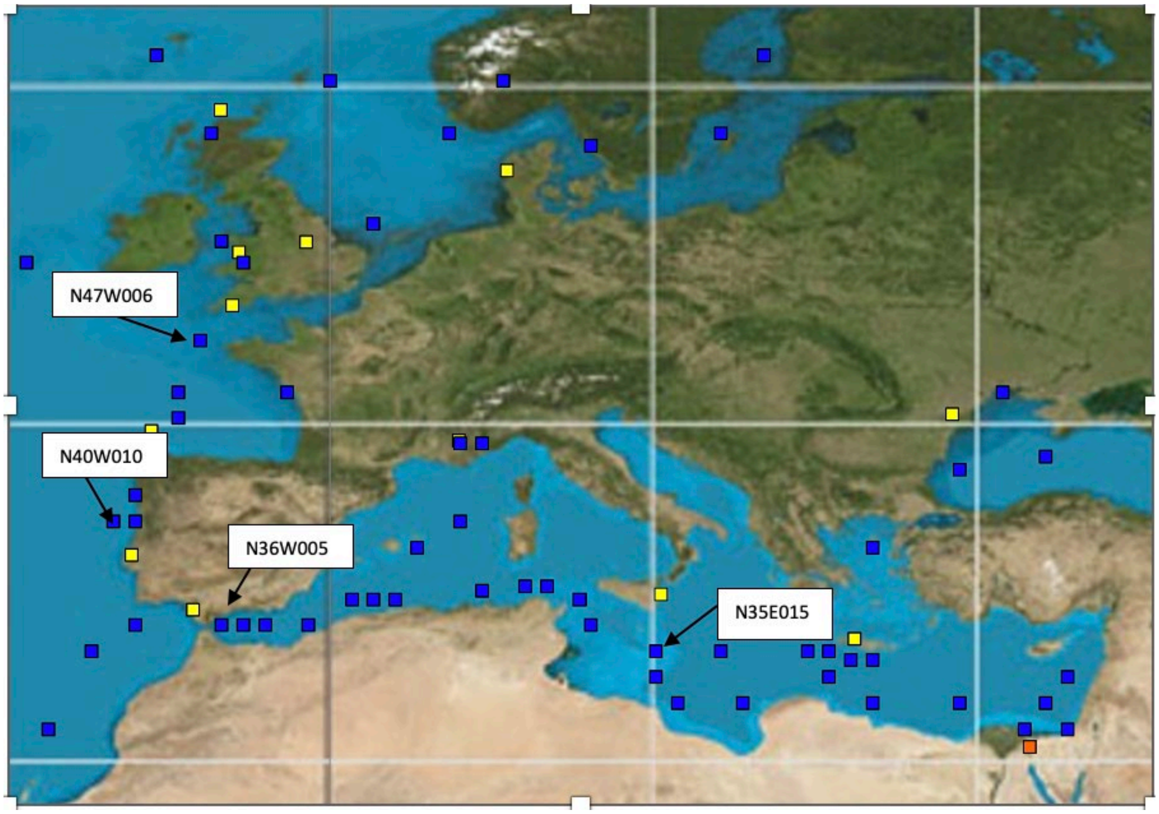


Figure 3. FUSED Map of AOR with labeled way points where operations take place along the transit. Source: Naylor (2015).

The four different operations considered were: flight operations, pre-assault operations, assault operations, and sustainment operations. The base timeline for each of the four operations was 10 Days. The duration for each operation was modified to also show the results for 7 days and 13 days one iteration at a time (Table 3). Additionally, all the iterations were run with different ship configurations and all iterations were run with both single and dual fuel. The three different ship configurations were 2 ARGS, 2 CSGS and 1CSG, and 1 ARG (Table 4). It was assumed that an ARG was made up of 1 landing helicopter dock ship (LHD), 1 landing platform dock (LPD), and 1 landing ship dock (LSD) ship. Each CSG consisted of 1 CVN, 1 CG and 2 DDGs. The number of MSC ships was limited to one TAO per ship configuration. That is, only one TAO could service 2 CSGs or 2 ARGs, or 1 CSG and 1 ARG.

Table 3. The 9 Different Scenarios with Varying Days of Operations.

	9 SCENARIOS			
DAYS	**PRE-ASSAULT (PA)**	**ASSAULT (AST)**	**FLIGHT OPERATIONS (FO)**	**SUSTAINMENT (SUS)**
10 Days ALL	10 days	10 days	10 days	10 days
7 DAY FO	10 days	10 days	7 days	10 days
7 DAY PA	7 days	10 days	10 days	10 days
7 DAY SUS	10 days	10 days	10 days	7 days
7 DAY AST	10 days	7 days	10 days	10 days
13 DAY FO	10 days	10 days	13 days	10 days
13 DAY PA	13 days	10 days	10 days	10 days
13 DAY SUS	10 days	10 days	10 days	13 days
13 DAY AST	10 days	13 days	10 days	10 days

All scenarios were run in FUSED for both single and dual fuel at each JP-5 fuel efficiency of 97%, 98%, 99% and 100% for each ship configuration.

Table 4. The 3 Different Ship Configurations Utilized (2 CSGs, 2 ARGs, 1 CSG 1 ARG)

3 SHIP CONFIGURATIONS			
SHIPS	**2 CSG's**	**2 ARG's**	**1 CSG and 1 ARG**
CVN	2		1
CG	2		1
DDG	4		2
LHD		2	1
LPD		2	1
LSD		2	1

The aviation fuel burn rate for each platform was estimated from the 2021 Logistics Support in Contested Environment tables. Each iteration for operation and ship type was run at varying JP-5 fuel efficiency. The different fuel efficiencies utilized were 97%, 98%, 99% and 100% (Table 5). The range of these values was based on the estimated 2.6% decrease for JP-5 from the (Giannini et al. 2002). The different iterations for the scenario led to a total of 72 iterations per ship configuration for a total of 216 iterations.

Table 5. The 4 different JP-5 Efficiencies Utilized in Comparison to F-76.

JP-5 ENERGY COMPARISON TO F-76		
PER GALLON	**JP-5**	**F-76**
Efficiencies:	97%	100%
	98%	100%
	99%	100%
	100%	100%

Each gallon of JP-5 produced the energy density % of 97–100% of each gallon of F-76 for engine and generator use.

The performance of the 10-day all operations scenario is shown in Table 6. The ships are divided into Group 1: first ship group (CSG or ARG) and Group 2: Second ship group (CSG or ARG) and are assumed to be transiting between operations towards the final location of Loch Striven, Scotland. As shown in Figure 3, the coordinates N35E015 correspond to a location off the shore of Augusta Bay, N36W005 is off the shore of Rota, N40W010 is off the coast of Lisbon, and N47W006 is off the coast of Brest. The purpose of running each iteration of the scenario for both single and dual fuel was to be able to compare the differences. Additionally, running each iteration for the four different JP-5 fuel efficiencies allowed the user to see the differences in results for each energy density of JP-5 compared to the F-76 and JP-5 model.

Table 6. 10-Day All Operations Scenario Schedule Produced from the Tables Tab in FUSED Source: Naylor (2015)

Group 1 Schedule					
Op Type	start time	end time	Nav Start	Nav End	Power (KW)
Transit	1/1/21 0:00	1/2/21 6:00	SOUDA	N35E015	1500
FltOps	1/2/21 6:00	1/12/21 6:00	N35E015	N35E015	
Transit	1/12/21 6:00	1/15/21 2:00	N35E015	N36W005	1500
pre assault	1/15/21 2:00	1/25/21 2:00	N36W005	N36W005	
Transit	1/25/21 2:00	1/26/21 5:00	N36W005	N40W010	1500
assault	1/26/21 5:00	2/5/21 5:00	N40W010	N40W010	
Transit	2/5/21 5:00	2/6/21 12:00	N40W010	N47W006	1500
Sustain	2/6/21 12:00	2/16/21 12:00	N47W006	N47W006	
Transit	2/16/21 12:00	2/18/21 0:00	N47W006	LOCHST	1500

Group 2 Schedule					
Op Type	start time	end time	Nav Start	Nav End	Power (KW)
Transit	1/1/21 0:00	1/2/21 6:00	SOUDA	N35E015	1500
FltOps	1/2/21 6:00	1/12/21 6:00	N35E015	N35E015	
Transit	1/12/21 6:00	1/15/21 2:00	N35E015	N36W005	1500
pre assault	1/15/21 2:00	1/25/21 2:00	N36W005	N36W005	
Transit	1/25/21 2:00	1/26/21 5:00	N36W005	N40W010	1500
assault	1/26/21 5:00	2/5/21 5:00	N40W010	N40W010	
Transit	2/5/21 5:00	2/6/21 12:00	N40W010	N47W006	1500
Sustain	2/6/21 12:00	2/16/21 12:00	N47W006	N47W006	
Transit	2/16/21 12:00	2/18/21 0:00	N47W006	LOCHST	1500

Group 1 is the first group of ships (either CSG, ARG) Group 2 is the second group composed of CSG or an ARG. Both groups have identical schedules and lengths of operations.

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V. RESULTS

A. DATA

A total of 216 iterations (3 ship configurations x 4 energy efficiencies x 9 operational scenarios x 2 fueling modes) were conducted with FUSED in order to explore the effects that different factors had on refueling time, fuel burned, fuel delivered, number of RAS events, and number of CLF trips to port. Each FUSED iteration was run for both single and dual fuel to compare results.

For ease of comparison, the dual fuel outputs for hours refueled, total fuel burned, and total fuel delivered were used as the denominator for the varying efficiencies of JP-5. Dual fuel was used as the baseline value and all single fuel values were compared to dual fuel, using dual fuel as the denominator value. This gave relative values for single fuel compared to dual fuel. Thus, the results are provided as ratios of single compared to dual fuel. This allowed for the plots of all efficiencies to be shown on one graphic for hours refueled, total fuel burned, and total fuel delivered. The number of CLF trips to port and number of RAS events were left as actual observed values.

B. MODEL OUTPUTS

1. Two CSGs: 10 Days All Results

Figures 4 shows the results for 2 CSGs and 10 Days of all stages of operations: flight operations, pre-assault, assault, and sustainment. Figure 4 (left) shows the results for single fuel at efficiencies 97%, 98%, 99%, and 100% compared to dual fuel for total hours refueling, total fuel delivered by CLF ships and total fuel burned. As the efficiency of JP-5 increased, the total hours spent refueling and total fuel burned decreased. The overall fuel delivered remains steady throughout the JP-5 efficiencies. Figure 4 (right) shows that dual fuel requires more CLF trips to port to refuel and reload than single fuel for all JP-5 efficiencies. In this scenario, the switch to single fuel resulted in one less trip that the CLF must make. However, the number of RASs remained the same under both single and dual fuels.

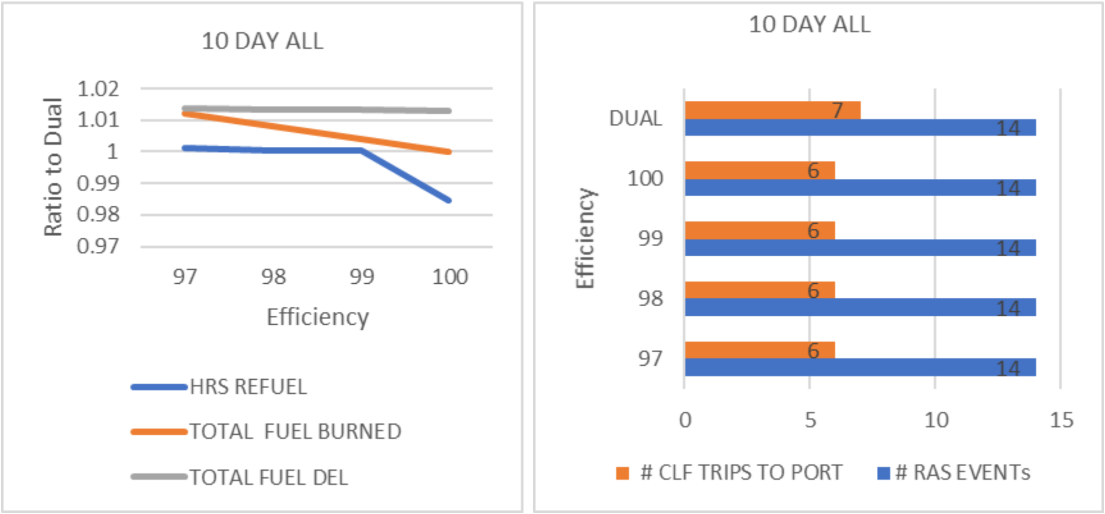

Figure 4. CSGs 10 Days All (left); CSGs 10 Days CLFs RASs (right)

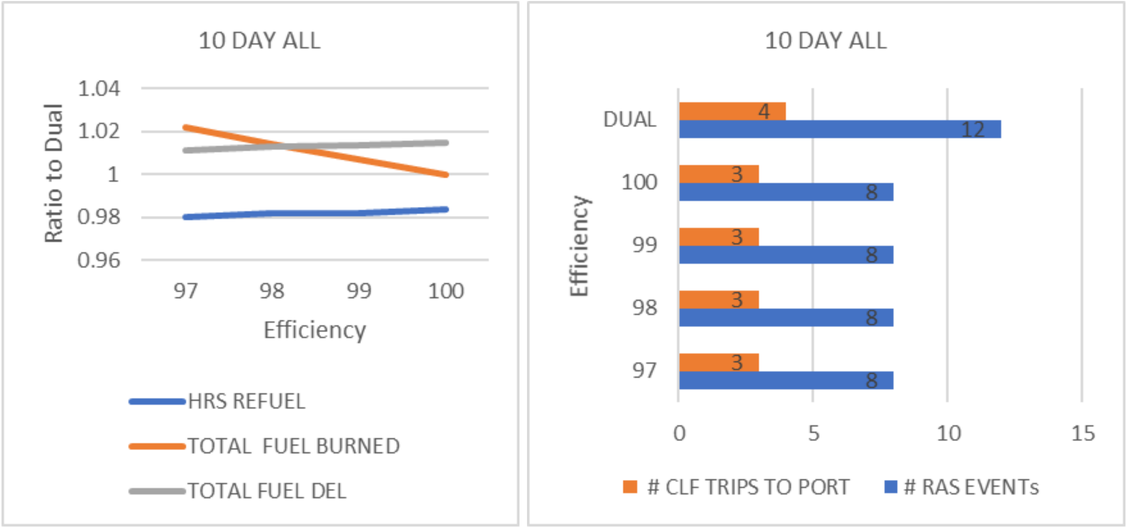

Figure 5. ARGs 10 Days All (left); ARGs 10 Days CLFs and RASs (right)

2. Two ARGs 10 Days All Results:

Figure 5 shows the results for 2 ARGs and 10 Days of all stages of operations: flight operations, pre-assault, assault, and sustainment. Contrary to the dual CSG configuration, Figure 5 (left) shows the total hours refueled increases slightly with increased JP-5 efficiency. However, more fuel is delivered with increased efficiency. It is shown that the total fuel burned decreases as efficiency increases. Figure 5 (right) displays that with dual fuel, the CLF ship will require an additional trip to shore to replenish its stores when compared to the single fuel construct. Additionally, the number of RASs for the all JP-5 configuration is reduced by 4 allowing more time for operations.

3. One CSG and One ARG 10 Days All Results:

Figure 6 shows the results for 1 CSG and 1 ARG and 10 Days of all stages of operations (flight operations, pre-assault, assault, and sustainment). Figure 6 (left) shows that as efficiency increases, the total fuel burned decreases while the total fuel delivered and total hours spent refueling remain relatively steady. Figure 6 (right) shows that the total number of CLF trips to port is increased for dual fuel while all efficiencies of the single fuel have one less CLF trip to port. Additionally, Figure 6 (right) shows that the total number of RASs is reduced by 2 when utilizing JP-5 only.

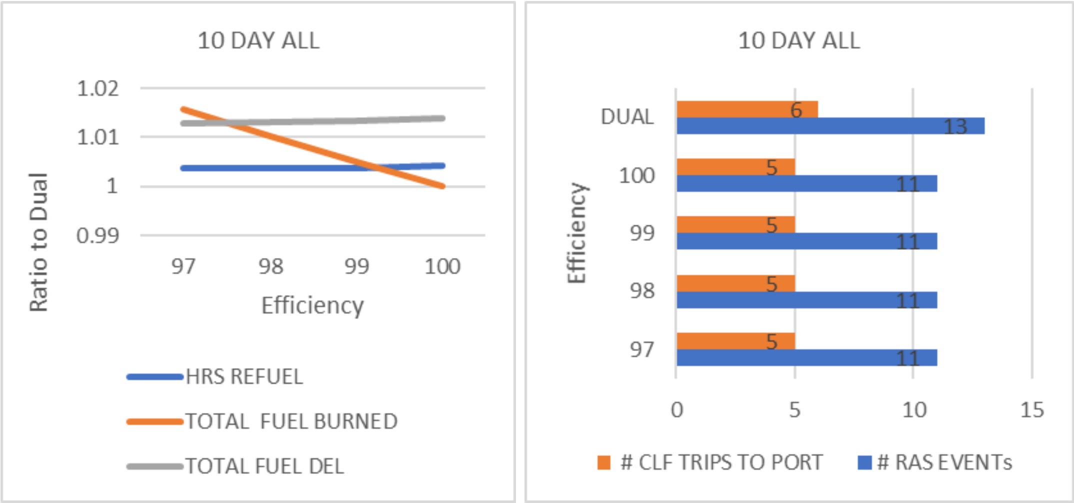

Figure 6. CSG 1 ARG 10 Days All (left); CSG 1 ARG 10 Days CLFs RASs (right)

4. Two CSGs 7 Day Operations Results

Figures 7 and 8 display the different number of CLF trips and RAS events required for 2 CSGs when one of the operations is 7 days instead of 10 Days. Figure 7 (left) shows that when flight operations are 7 days, and all other operations are 10 days, the number of CLF trips to port and RASs are reduced by 2 for all single fuel efficiency configurations. Figure 6 (right) shows that when pre-assault operations are 7 days, and all other operations are 10 days, the number of CLF trips to port and RASs are reduced by 2 for all single fuel efficiency configurations. Figure 7 (left) shows that when sustainment operations are 7 days and pre-assault, assault, and flight operations remain at 10 days the CLF trips to port is reduced by 1 for single fuel at all efficiency levels. Figure 8 (left) shows that for 7-day sustainment operations no reduction in total number of RASs is observed. Figure 8 (right) shows that the number of CLF trips to port is reduced by 1 for single fuel efficiency, and no total reduction in RASs is observed.

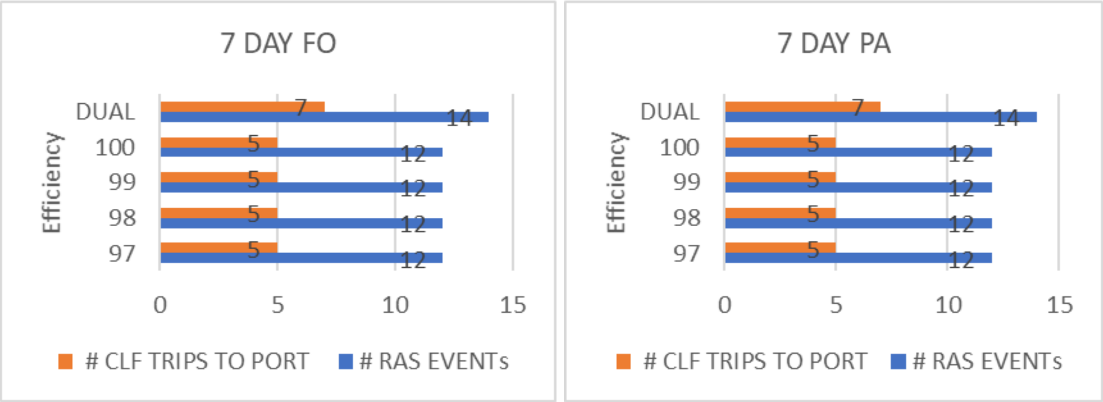

Figure 7. CSGs 7 Day Flight Ops CLFs RASs (left); CSGs 7 Day Pre-Assault CLFs RASs (right)

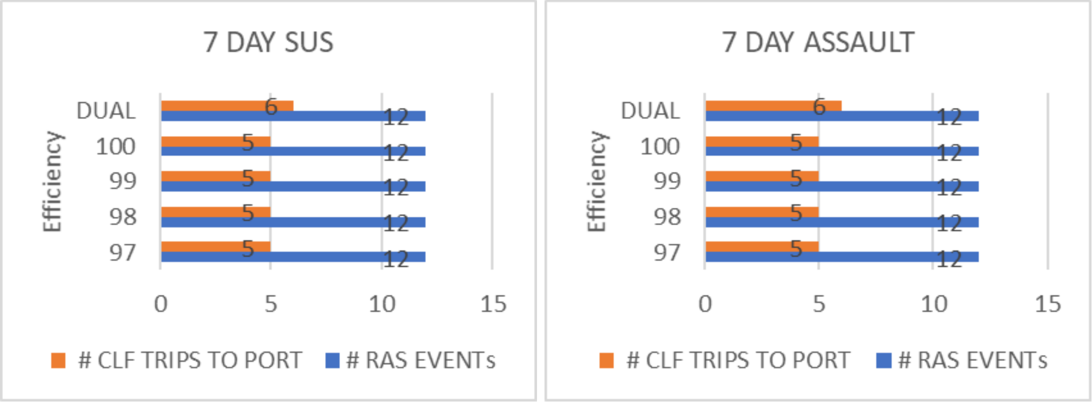

Figure 8. CSGs 7 Sustainment CLFs RASs (left); CSGs 7 Assault CLFs RASs (right)

Figures 9 and 10 display comparisons of single fuel at efficiencies 97% , 98% , 99%, and 100 % compared to dual fuel for total hours refueling, total fuel delivered by CLF ships, and total fuel burned. Figure 9 (left) shows that when flight operations are 7 days and sustainment, pre-assault, and assault remain at 10 days, the total hours spent refueling and total fuel delivered increase slightly with increased JP-5 efficiency. The total fuel burned decreases with increased efficiency. Figure 9 (right) shows that when 7 days are spent on pre-assault operations and all others remain at 10 days, the total fuel burned decreases with increased JP-5 efficiency and the total hours spent refueling and total fuel delivered increase slightly with increased efficiency. Figure 10 (left) shows that when sustainment has 7 days and all others 10 days, the total fuel delivered and hours spent refueling increases with efficiency but the overall fuel burned decreases with efficiency. Figure 10 (right) shows that for 7-day assault and all other operations 10 days, the total fuel burned decreases with increased efficiency and the total fuel delivered and time spent refueling increases with increased efficiency.

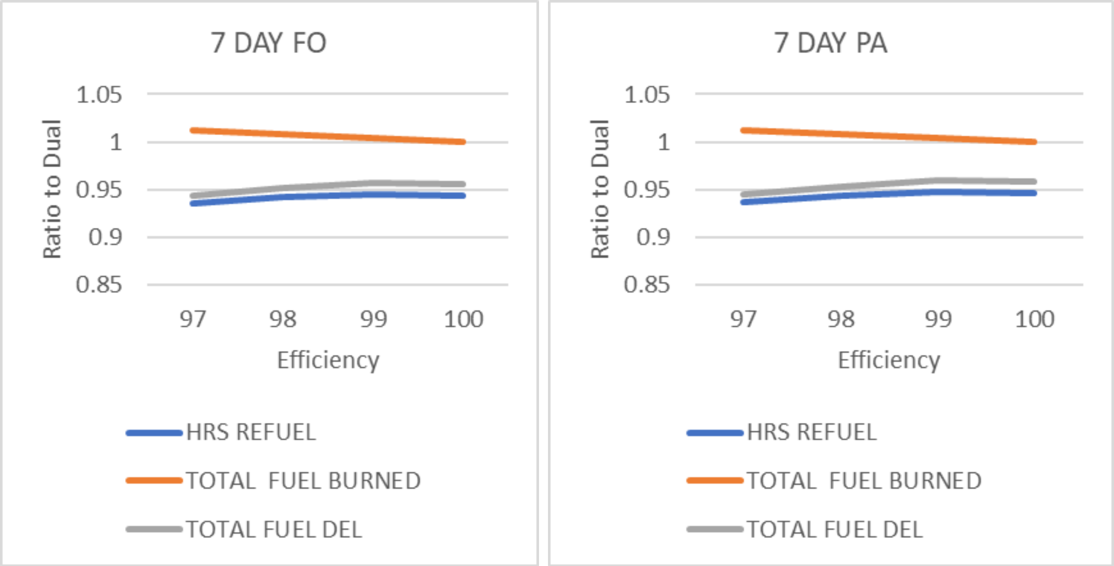

Figure 9. CSGs 7 Day Flight Ops (left); CSGs 7 Day Pre-Assault (right)

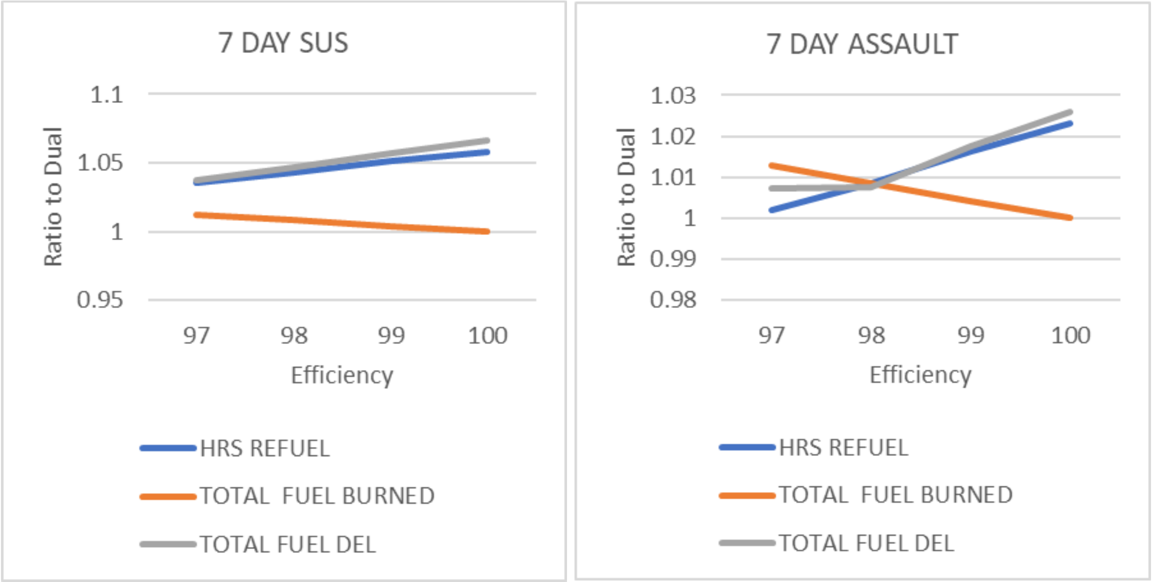

Figure 10. CSGs 7 Day Sustainment (left); CSGs 7 Day Assault (right)

5. Two ARGs 7 Day Operations Results

Figures 11 and 12 show the total number of CLF trips to ports and RASs at different single fuel efficiencies for the 2 ARG configuration. Figure 11 (left) shows the benefit of single fuel for 7-day flight operations. At 97% and 98% JP-5 efficiency, the total number of RASs is reduced by 4. At 99% and 100% JP-5 efficiency and 7-day flight operations, the total number of RASs is reduced by 6 and the total CLF trips to port is reduced by 2. Figure 11 (right) shows the results of 7 days of pre-assault operations and 10 Days of all other operations. For single fuel the total number of CLF trips to port is reduced by 1 and the total number of RASs is reduced by 4. Figure 12 (left) shows the results of 7 days of sustainment operations in the 2 ARG configuration. At 97% and 98% JP-5 efficiency, the total number of RASs is reduced by 2 and the total number of CLF trips to port increases by 1. At 99% and 100% JP-5 efficiency, the total number of RASs is reduced by 4 and the total number of CLF trips to port is reduced by 1. Figure 12 (right) shows the results of 7 days of assault operations with 2 ARGs and for all efficiencies the total number of RASs is reduced by 4 and total number of CLF trips to port is reduced by 2.

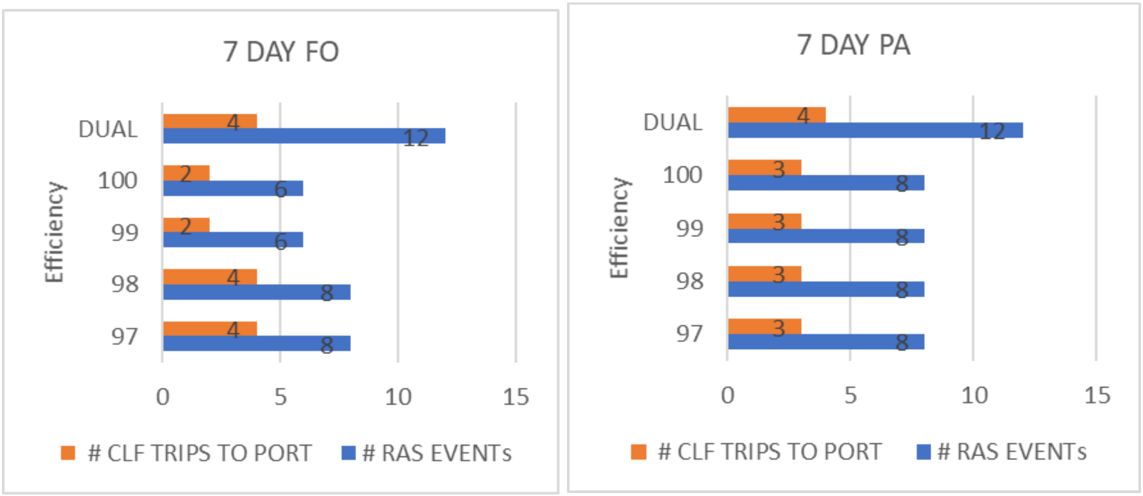

Figure 11. ARGs 7 Day Flight Ops CLFs RASs (left); ARGs 7 Day Pre-Assault CLFs RASs (right)

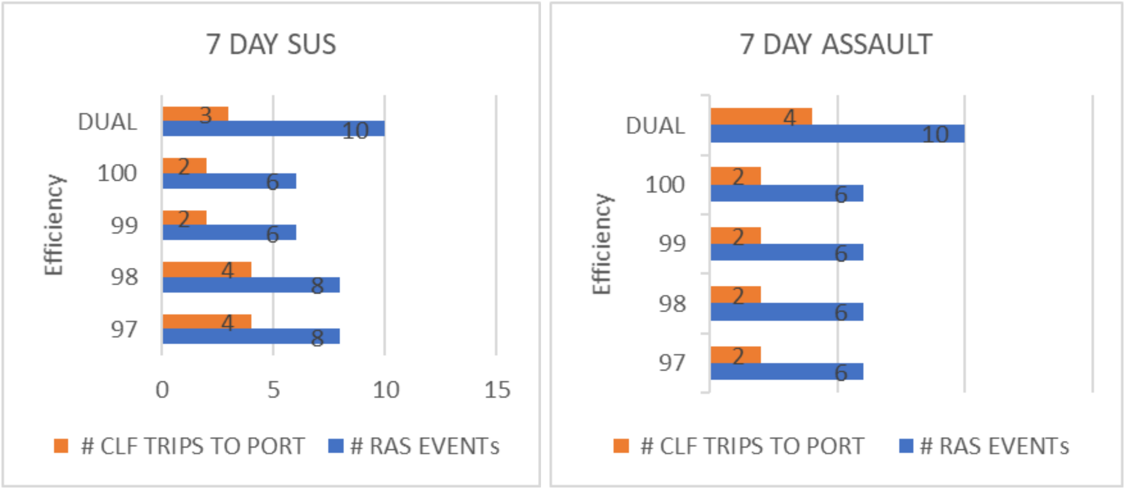

Figure 12. ARGs 7 Sustainment CLFs RASs (left); ARGs 7 Assault CLFs RASs (right)

Figures 13 and 14 show the results of 2 ARGs and varying 7-day operations. When flight operations are 7 days and sustainment, assault and pre-assault remain at 10 days as in Figure 13 (left), the hours spent refueling and total fuel delivered decrease with increased JP-5 efficiency while the total fuel burned remains steady. Figure 13 (right) shows that with 7 days of pre-assault operations, the total fuel burned decreases with increased JP-5 efficiency and the total hours spent refueling and total fuel delivered remain relatively steady. Figure 14 (left) with 7 days of sustainment operations shows a reduction in total fuel delivered and time spent refueling with increased JP-5 efficiency. Figure 14 (right) with 7 days of assault operations shows a marginal decrease in total fuel burned with an increase in JP-5 efficiency.

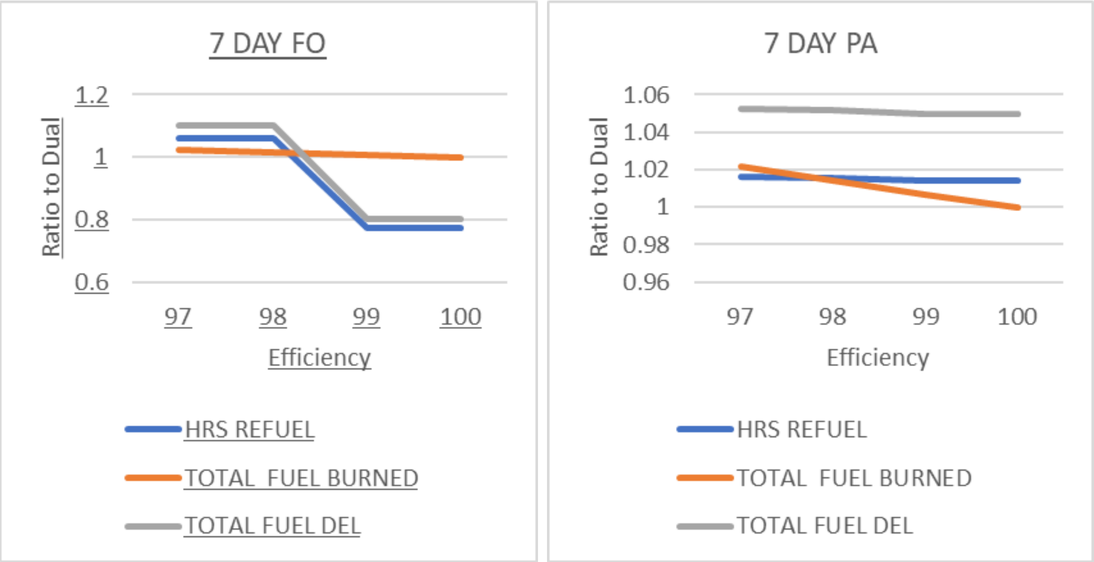

Figure 13. Figure 13. ARGs 7 Day Flight Ops (left); ARGs 7 Day Pre-Assault (right)

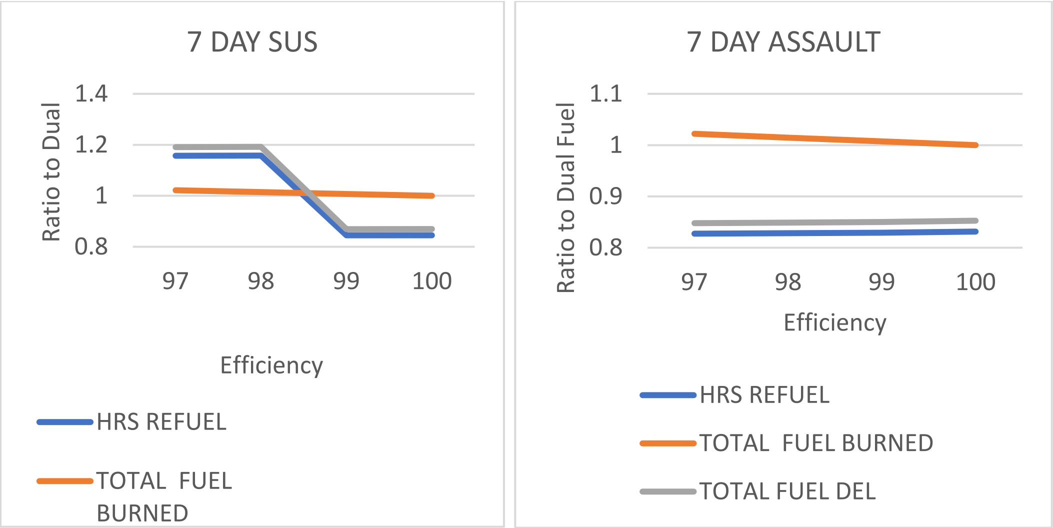

Figure 14. ARGs 7 Day Sustainment (left); ARGs 7 Day Assault (right)

6. One CSG and One ARG 7 Day Operations Results

Figures 15 and 16 show the effect of varying operations days total with 1 CSG and 1 ARG on the number of CLF trips to port and number of RASs. Figure 15 (left) shows that with 7 days of flight operations and 10 days of sustainment, pre-assault and assault, the JP-5 only has a benefit of 1 reduced CLF trip to port. Additionally, for 97% and 98% JP-5 efficiency the number of RASs is reduced by 3 and for 99% and 100% JP-5 efficiency number of RASs is reduced by 4. Figure 15 (right) shows that for 7 days of pre-assault operations with 1 CSG and 1 ARG the number of CLF trips to port is only reduced by 1 at 99% and 100% JP-5 efficiency. Additionally, for all JP-5 efficiencies the total number of RASs is reduced by 3. Figure 16 (left) shows that for 7 days of sustainment operations the number of CLF trips to port is only reduced by 1 at 99% and 100% JP-5 efficiency. Additionally, at 97% and 98% JP-5 efficiency total RASs is reduced by 1 and at 99% and 100% JP-5 efficiency total RASs is reduced by 2. Figure 16 (right) displays that for 7-day assault operations all JP-5 efficiencies reduce the total number of CLF trips by 1 and total number of RASs by 2.

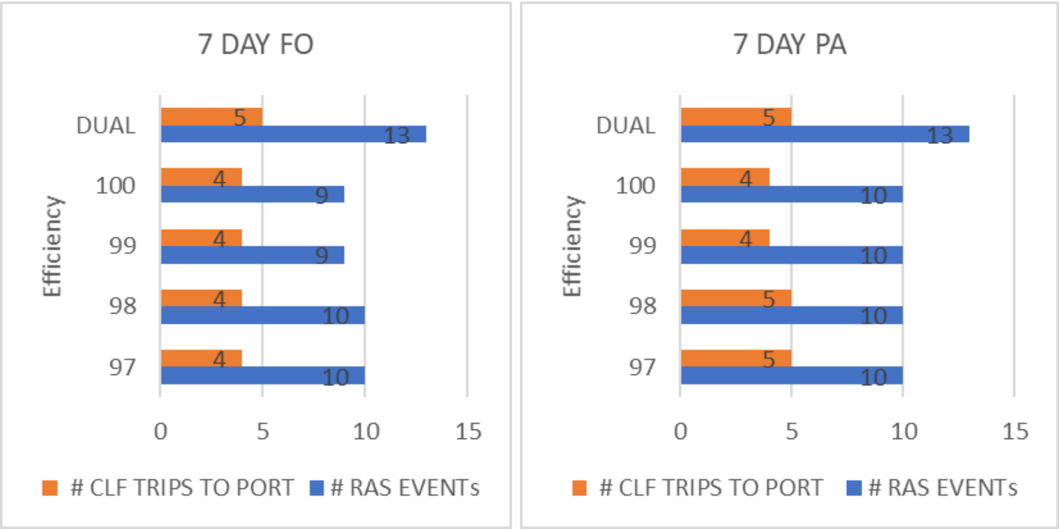

Figure 15. CSG ARG 7 Flight Ops CLFs RASs (left); CSG ARG 7 Pre-Assault CLFs RASs (right)

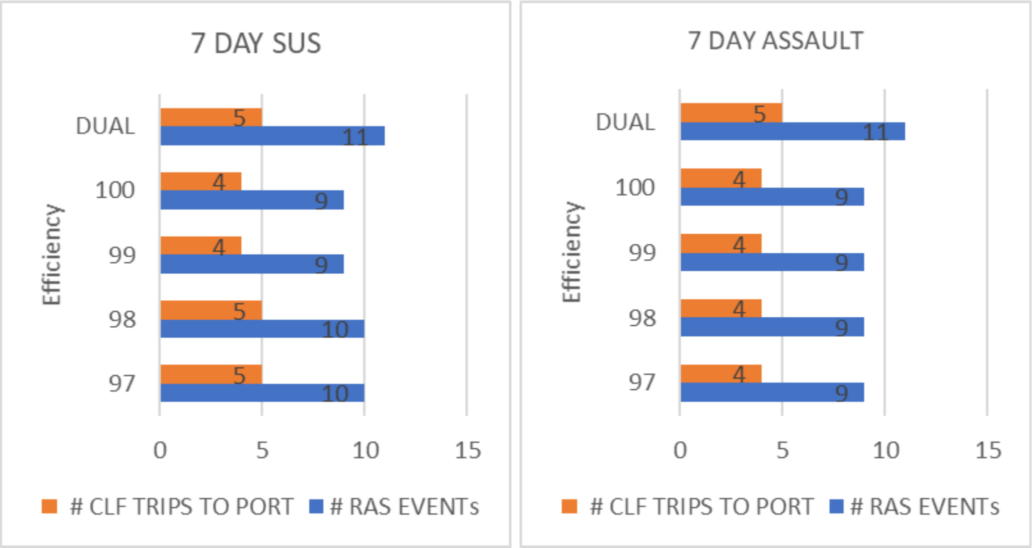

Figure 16. CSG ARG 7 Sustainment CLFs RASs (left); CSG ARG 7 Assault CLFs RASs (right)

Figures 17 and 18 show comparisons of single fuel at efficiencies 97%, 98% , 99%, and 100 % compared to dual fuel for total hours refueling, total fuel delivered by CLF ships and total fuel burned. Figure 17 (left) shows that for 7-day flight operations with 1 CSG and 1 ARG as fuel efficiency increases so does total hours spent refueling, total fuel burned, and total fuel delivered. Figure 17 (right) shows that for 7 days of pre-assault operations as JP-5 efficiency increases so does hours spent refueling and total fuel delivered, while total fuel burned decreases. Figure 18 (left) shows for 7 days of sustainment operations as JP-5 efficiency increases total fuel delivered, total time spent refueling and total fuel burned decrease. Figure 18 (right) shows that for 7 days of assault operations as JP-5 efficiency increases total fuel delivered and total hours spent refueling increase and total fuel burned decreases.

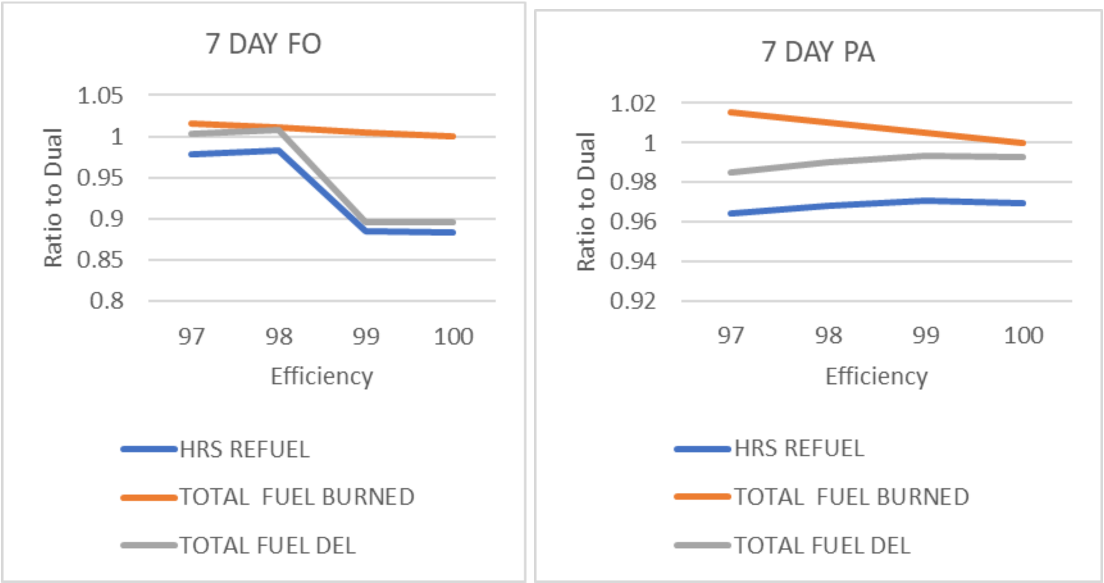

Figure 17. CSG ARG 7 Day Flight Ops (left); CSG ARG 7 Day Pre-Assault (right)

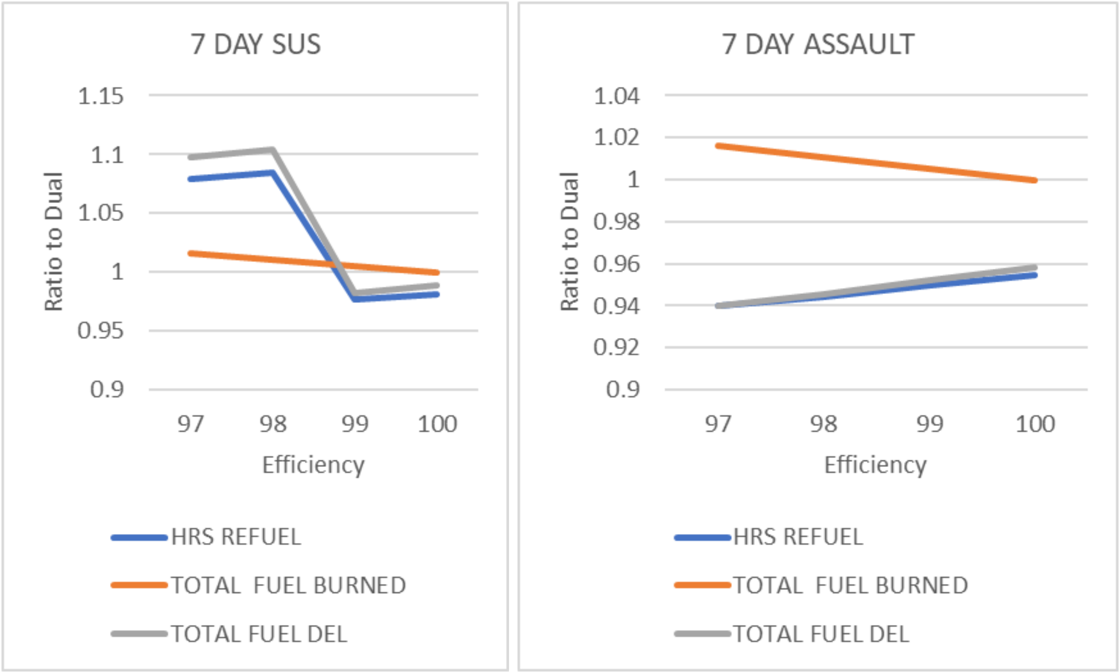

Figure 18. CSG ARG 7 Day Sustainment (left); CSG ARG 7 Day Assault (right)

7. Two CSGs 13 Day Operations Results

Figures 19 and 20 show the refueling time, fuel burned, and fuel delivered to 2 CSGs with one of the four operations at 13 days and the rest at 10 days. Figure 19 (left) portrays that with 13 day of flight operations and 10 days of pre-assault, sustainment and assault as JP-5 efficiency increases the total time spent refueling and total fuel delivered increases and the total fuel burned decreases. Figure 19 (right) shows that for 13 days of pre-assault operations as JP-5 efficiency increases total fuel burned decreases and total fuel delivered and total hours spent refueling increases. Figure 20 (left) shows that for 13 days of sustainment as JP-5 efficiency increases total time refueling and total fuel delivered increases and total fuel burned decreases. Figure 20 (right) shows that for 13 days of assault operations, as JP-5 efficiency increases total fuel burned decreases and total hours refueling and total fuel delivered increases.

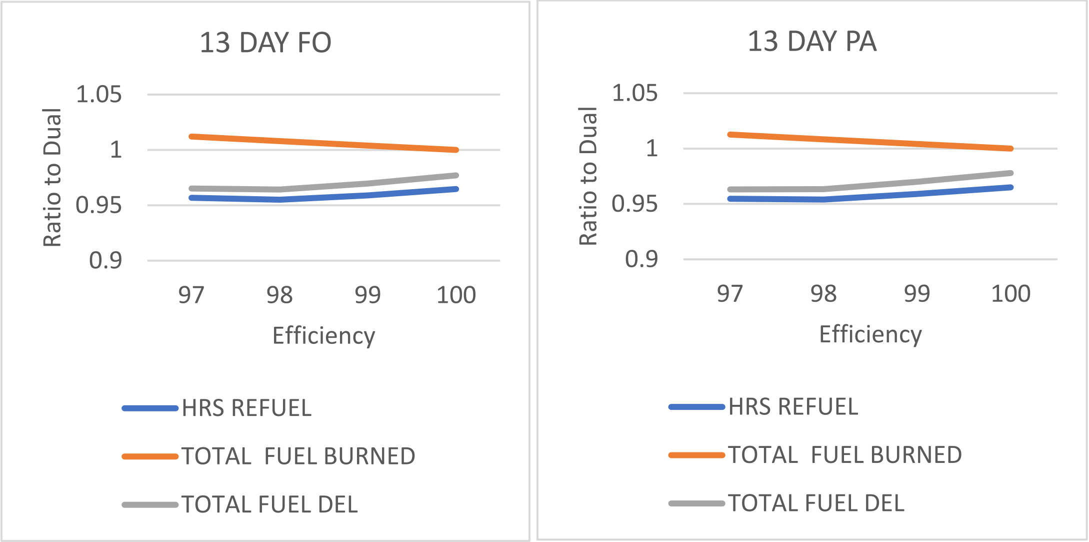

Figure 19. CSGs 13 Day Flight Ops (left); CSGs 13 Day Pre-Assault (right)

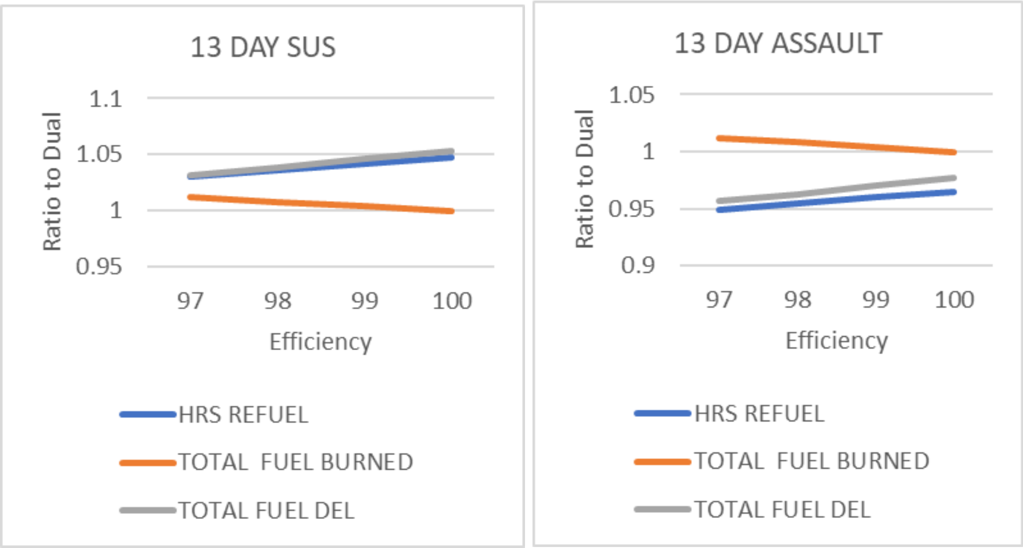

Figure 20. CSGs 13 Day Sustainment (left); CSGs 13 Day Assault (right)

Figures 21 and 22 show the total number of CLF trips to ports and RASs at different single fuel efficiencies with rotating 13-day operations. Figure 21 (left) portrays that for 13-day flight operations and 10-day sustainment, pre-assault and assault the total number of CLF trips and number of RASs is reduced by 2 each for all single fuel efficiencies. Figure 21 (right) shows that for 13 days of pre-assault operations with 2 CSGs the total number of CLF trips and number of RASs is reduced by 2 each for all single fuel efficiencies. Figure 22 (left) portrays that for 13 days of sustainment operations the total number of CLF trips to port is reduced by 1 for all fuel efficiencies and the total number of RASs is the same as dual fuel. Figure 22 (right) shows that for 13 days of assault operations the total number of CLF trips and number of RASs is reduced by 2 each for all single fuel efficiencies.

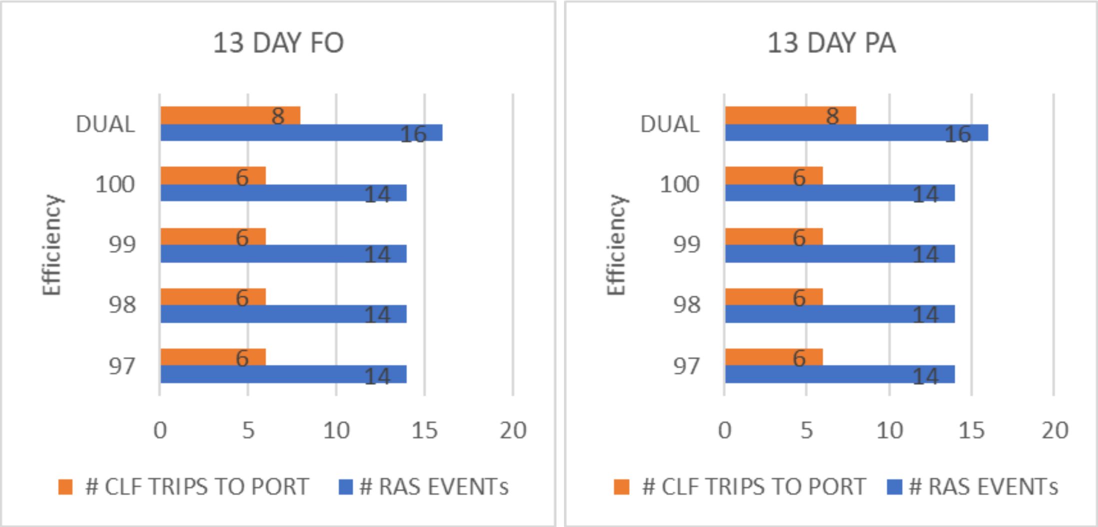

Figure 21. CSGs 13 Flight Ops CLFs RASs (left); CSGs 13 Pre-Assault CLFs RASs (right)

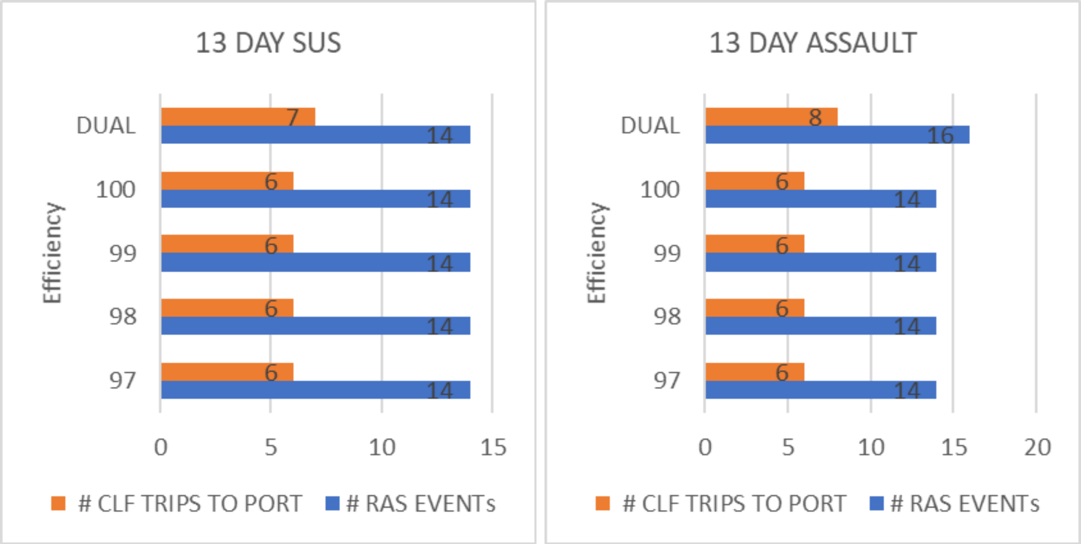

Figure 22. CSGs 13 Sustainment CLFs RASs (left); CSGs 13 Assault CLFs RASs (right)

8. Two ARGs 13 Day Operations Results

Figures 23 and 24 show the refueling time, fuel burned, and fuel delivered to 2 ARGs with one of the four operations at 13 days and the rest at 10 Days. Figure 23 (left) portrays that for 13 days of flight operations the total hours refueling, total fuel burned, and total fuel delivered decrease slightly with increased JP-5 fuel efficiency. Figure 23 (right) shows for 13 days of pre-assault operations with 2 ARGs with increased JP-5 fuel efficiency the total fuel delivered increases while the total fuel burned decreases. No major change in hours spent refueling is seen. Figure 24 (left) shows for 13 days of sustainment operations with increased JP-5 fuel efficiency that the total fuel delivered, and time spent refueling, increase and total fuel burned decreases. Figure 24 (right) portrays that for 13 days of assault operations with 2 ARGs with increased JP-5 fuel efficiency the total fuel delivered, and time spent refueling, increase and total fuel burned decreases.

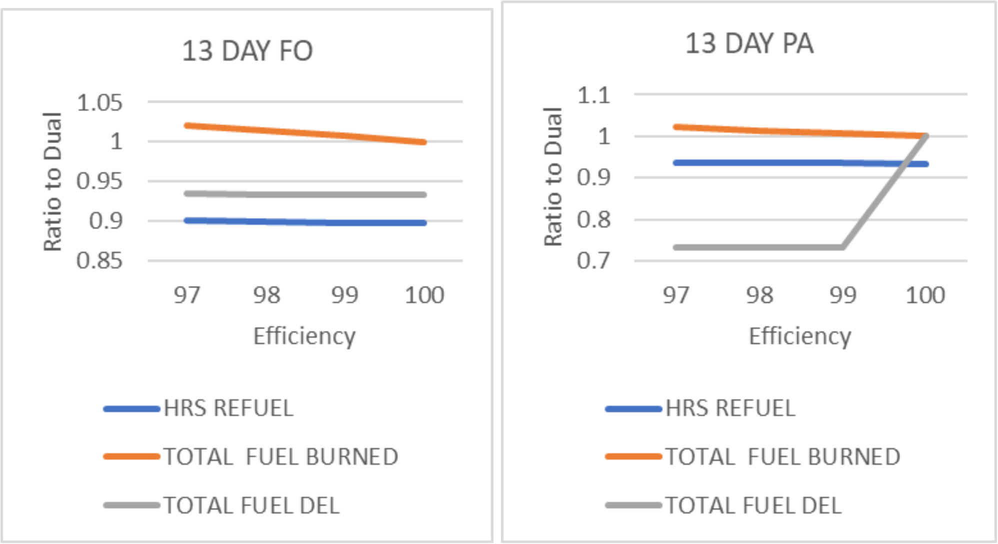

Figure 23. ARGs 13 Day Flight Ops (left); ARGs 13 Day Pre-Assault (right)

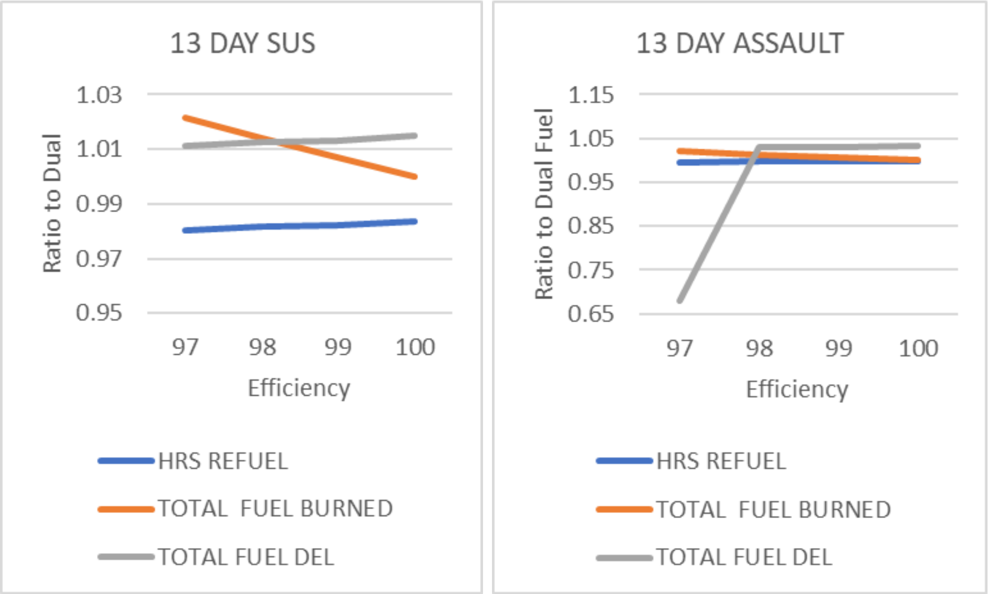

Figure 24. ARGs 13 Day Sustainment (left); ARGs 13 Day Assault (right)

Figures 25 and 26 portray the total number of CLF trips to ports and RASs at different single fuel efficiencies with rotating 13-day operations and 2 ARGs. Figure 25 (left) shows that for 13 days of flight operations with 2 ARGs single fuel reduces the total number of CLF trips by 2 and the total number of RASs by 6. Figure 25 (right) displays that for 13 days of pre-assault operations with 2 ARGs single fuel reduces the total number of RASs by 4 and total number of CLF trips by 1. Figure 26 (left) shows that for 13 days of assault operations with 2 ARGs single fuel reduces the total number of RASs by 4 and total CLF trips by 1. Figure 26 (right) shows that for 13 days of sustainment operations in 2 ARGs single fuel reduces total RASs by 4 and CLF trips by 1.

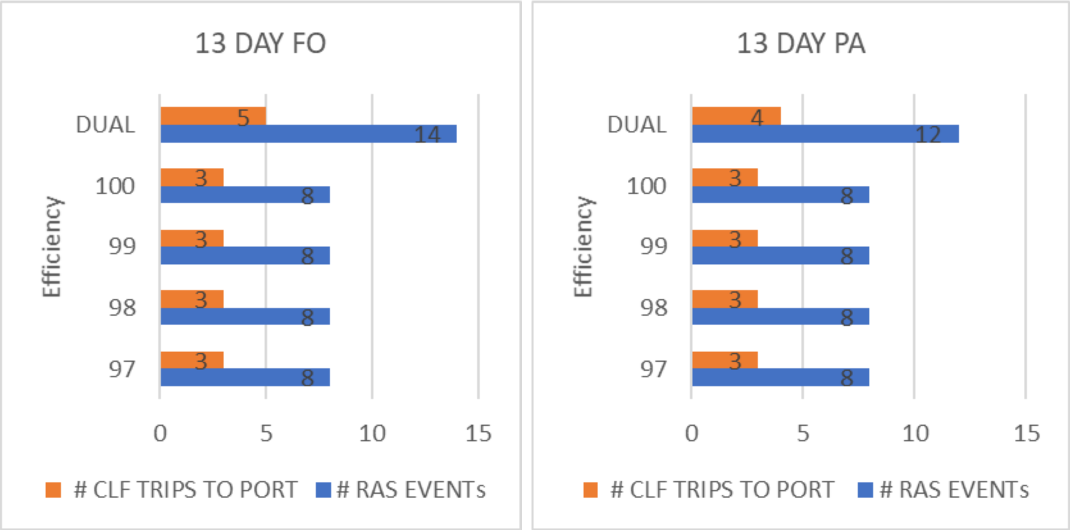

Figure 25. ARGs 13 Flight Ops CLFs RASs (left); ARGs 13 Pre-Assault CLFs RASs (right)

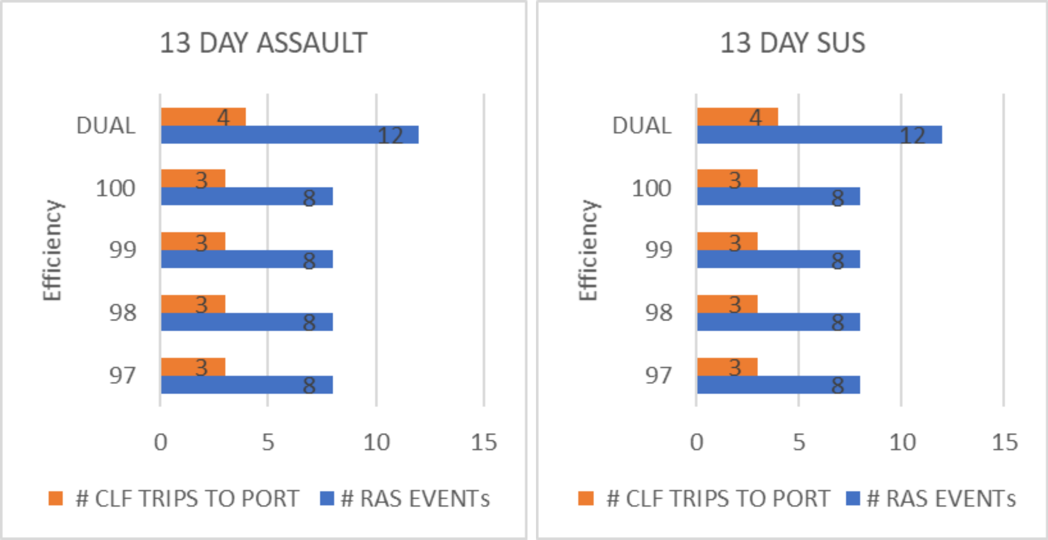

Figure 26. ARGs 13 Assault CLFs RASs (left); ARGs 13 Sustainment CLFs RASs (right)

9. One CSG and One ARG 13 Day Operations Results

Figures 27 and 28 display the refueling time, fuel burned, and fuel delivered to 1 ARG and 1 CSG with one of the four operations at 13 days and the rest at 10 Days. Figure 27 (left) shows that for 13 days of flight operations with 1 CSG and 1 ARG that as JP-5 efficiency increases total fuel burned decreases and total hours refueling and total fuel delivered increase. Figure 27 (right) shows that for 13 days of pre-assault operations with 1 CSG and 1 ARG as JP-5 efficiency increases total fuel burned decreases and total hours refueling and total fuel delivered increase. Figure 28 (left) shows that for 13 days of sustainment operations with 1 CSG and 1 ARG as JP-5 efficiency increases total fuel burned decreases and total hours refueling and total fuel delivered increase. Figure 28 (right) shows that for 1 CSG and 1 ARG and 13 days of assault operations as JP-5 efficiency increases total fuel burned decreases and total hours refueling and total fuel delivered increase. All these results are similar for 1 CSG and 1 ARG.

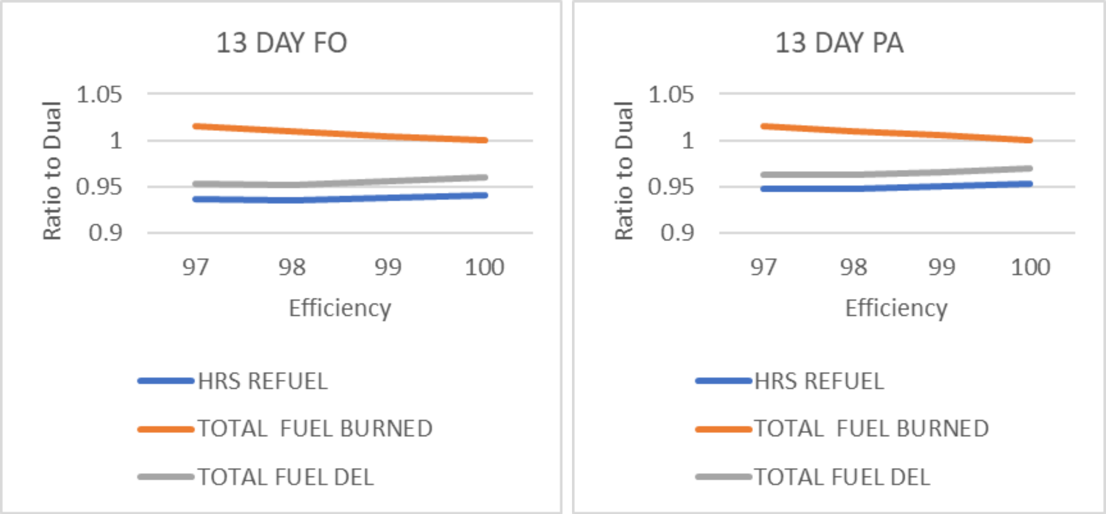

Figure 27. CSG and ARG 13 Day Flight Ops (left); CSG and ARG 13 Day Pre-Assault (right)

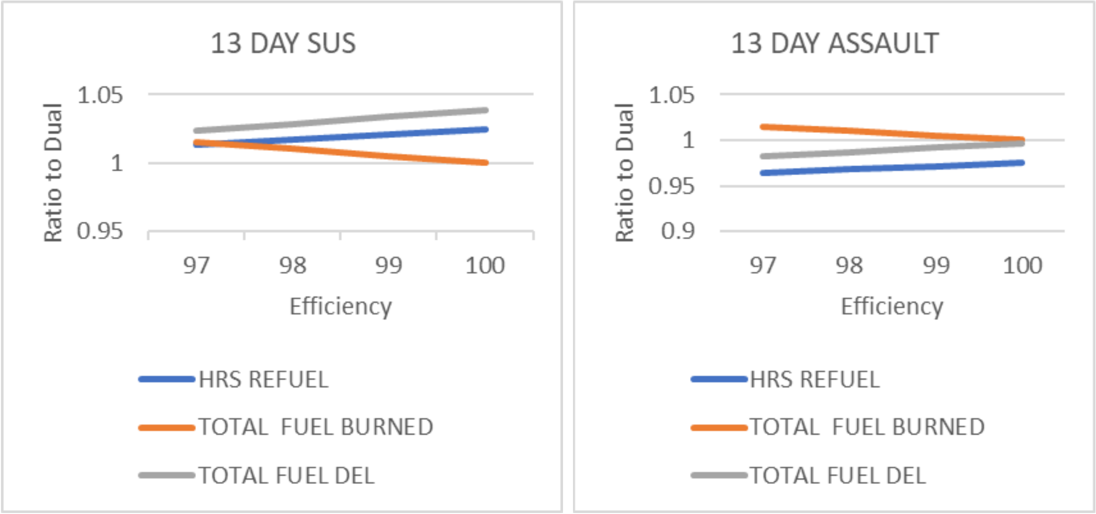

Figure 28. CSG ARG 13 Sustainment (left); CSG ARG 13 Assault (right)

Figures 29 and 30 portray the total number of CLF trips to ports and RASs at different single fuel efficiencies with rotating 13-day operations and 1 ARG and 1 CSG. Figure 29 (left) shows that for 13 days of flight operations and 10 Days of sustainment, pre-assault and assault operations with 1 CSG and 1 ARG the total number of CLF trips to port is reduced by 1 and the total number of RASs is reduced by 4 for single fuel. Figure 29 (right) shows that for 13 days of pre-assault operations with 1 CSG and 1 ARG the total CLF trips to port is reduced by 1 and total RASs is reduced by 3 for all single fuel efficiencies. Figure 30 (left) shows for 13 days of sustainment operations the total CLF trips to port is reduced by 1 and total RASs is reduced by 2 for single fuel. Figure 30 (right) shows that for 13 days of assault operations with 1 CSG and 1 ARG the total CLF trips to port is reduced by 1 and total RASs is reduced by 3 for single fuel.

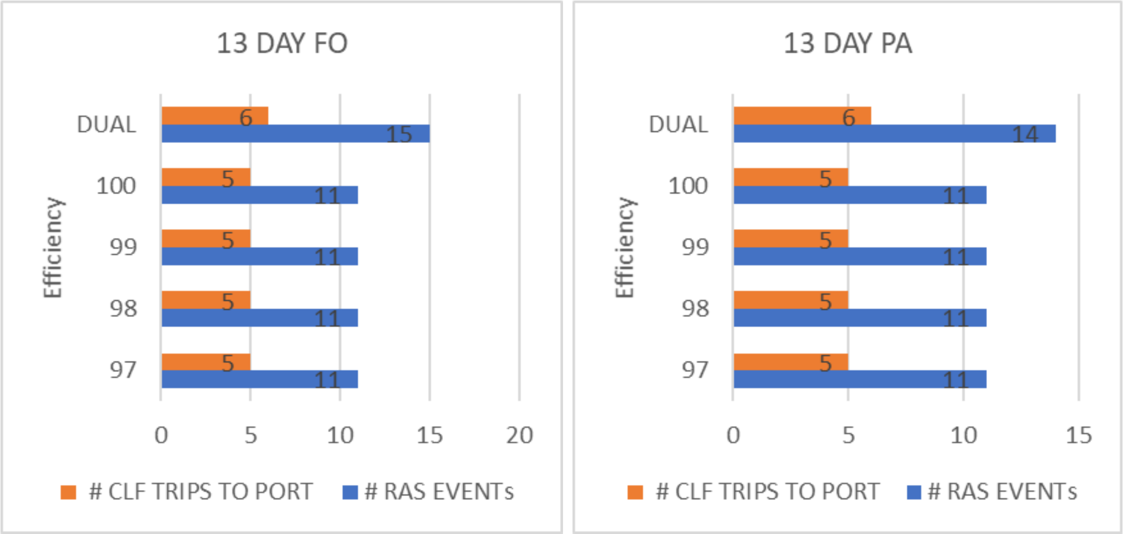

Figure 29. CSG ARG 13 Flight Ops CLFs RASs (left); CSG ARG 13 Pre-Assault CLFs RASs (right)

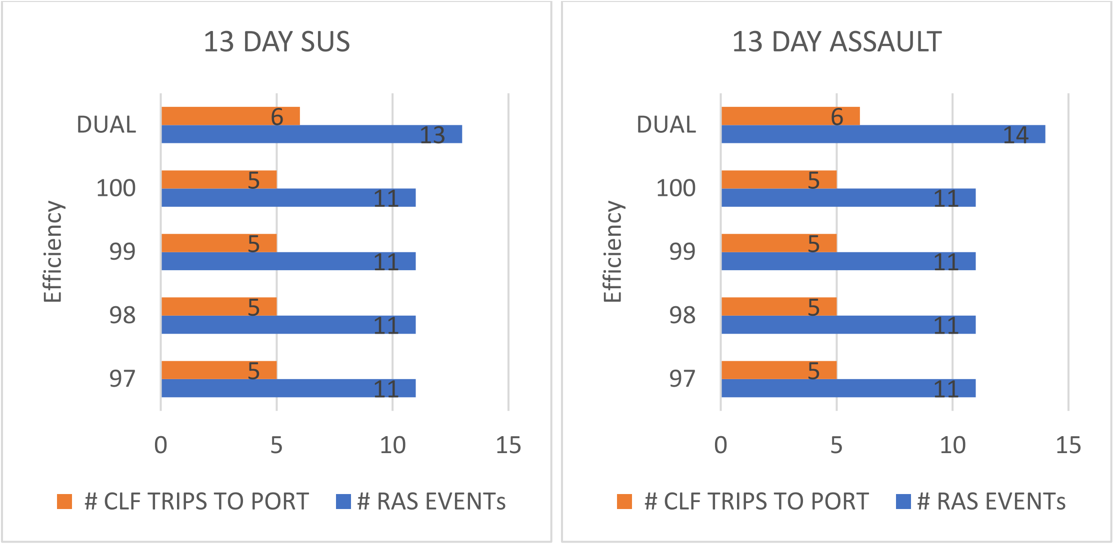

Figure 30. CSG ARG 13 Sustainment CLFs RASs (left); CSG ARG 13 Assault CLFs RASs (right)

C. SINGLE VS. DUAL FUEL RESULTS

For all but two of the scenarios with single fuel (2 ARGs with 7-day sustainment operations at 97 and 98% JP-5 efficiency) single fuel either maintained or reduced the number of CLF trips to port, compared to dual fuel. For all scenarios, single fuel retained or reduced the number of RASs required. In most cases the total number of CLF trips to port and total number of RASs was reduced. This result confirms the intuition that pooling all tanks to carry a single fuel, JP-5, increases endurance and flexibility.

Additionally, reducing the effectiveness of JP-5 by 2–3% did not significantly impact operations. In general, it increased the amount of fuel required for the transit but did not have a negative impact on total number of RASs.

For operations that burn more JP-5 and for platforms that hold more JP-5, the benefit of pooling is more readily seen. This is shown by the 2 ARG results and the 13-day flight operations and 13-day assault operations configurations.

Conversely, there was no benefit observed by maintaining the dual fuel model. The single fuel model allowed the ships to operate longer before replenishing fuel stores because they did not hit their safety threshold as quickly. For the dual fuel model, during heavy air or surface operations either JP-5 or F-76 inventories would hit their required safety percentage prior to the combined tanks of the single fuel model.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results of this thesis indicate that the SFC may be beneficial for the EUCOM AOR. Our analysis showed a consistent reduction in the required number of RASs and CLF trips to port at all JP-5 energy efficiencies in the scenarios evaluated. The added flexibility gained from fewer RASs and CLF trips to port allows for groups of ships to remain at operations and on standby for longer periods of time. Among the benefits of fewer RASs and CLF trips to port is a cost savings to the Navy; water, sewage and power costs are incurred whenever a ship goes to port. These reduced periods in port could help offset the minor cost increase in utilizing JP-5 instead of F-76 to power the ships.

The overall trend in refueling results for single fuel was that the groups received more fuel from the CLF ships and spent more time refueling as the JP-5 efficiency increased. These two events are tied together, as it is expected to spend more time refueling if you receive more fuel. However, as JP-5 efficiency increased, a smaller amount of fuel was burned overall. To overcome the possible increase in time refueling, it is proposed that the overall safety level for USS ships be reduced to allow for even more time between replenishments.

The hesitancy in moving towards SFC should not continue. There may be some initial setbacks in converting the fleet’s engineering network and establishing the supply chain on the shore side. However, as shown with past dealings with DLA, if there is a requirement, they will find a way to provide. Additionally, JP-8 as a single fuel for the Air Force has already been enacted and has not encountered major difficulties. The technical studies of the effect of jet fuel on engines and generators has shown no significant degradation of equipment. The only current downside is the small price differential per gallon and the slight energy density reduction. With increased research on running JP-5 in surface engines and generators, this energy reduction can be minimized.

B. FUSED CONSIDERATIONS

In the existing FUSED model, the fuel tank levels of the USS ships are not visible. We recommend that this feature be added in a future version of FUSED, or to at least conglomerate F-76 and JP-5 percentages. This can be calculated indirectly by how much fuel is burned and how much fuel is delivered but seeing the overall fuel levels would be an added benefit for users of FUSED.

The assumptions for the scenario (14.7-15.2 kt transit speed, 55,000 gallons per hour refueling rate for T-AOs, 97–100% energy efficiency per gallon of JP-5 to F-76, easy access to all tanks) are not realistic for all platforms or fleet scenarios. In general, the CVNs can receive fuel at a much faster rate than the LHD, and the LHD can receive fuel quicker than the LPD, LSD, CG and DDG. Adding all these intricacies for each platform would cause the model to be too complex.

Additionally, it is assumed that the oiler will be present and readily available to replenish the groups when required. This is not a realistic representation of CLF behavior. In contrast, RASP is a robust CLF planning tool that has operational details which are not considered in FUSED (Brown et al. 2018). To achieve more realistic and detailed results inclusive of CLF movement, the linking of FUSED with RASP was explored. However, currently the two tools do not have a congruent set-up and linking the two would entail re-formatting and extensive code modification for one or both tools.

C. FUTURE WORK

We recommend that a future thesis or research project linking FUSED with RASP be undertaken, in order to get a more detailed and realistic refueling schedule. This would allow users to obtain more realistic warship and oiler movements and requirements in order to save the most fuel and/or reduce the number of required replenishments. Additionally, it would be beneficial to experiment with different scenarios in varying AORs to see if the benefits of SFC are still present. On the engineering side, exploring upgrades or developments to increasing the energy density of JP-5, or altering the engine and generator configurations to best run JP-5, would be helpful. On the supply side, exploring the timeline required to convert Navy storage facilities and DLA contracts to all JP-5 would be advantageous.

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