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ANALYSIS OF EA-18G GROWLER ENGINE MAINTENANCE AT NAVAL AIR STATION WHIDBEY ISLAND, WA

By: Edward U. Hood,
Zulfiqar A. Khan, and
Brian C. Story

June 2013

Advisors: Keebom Kang and
Ken Doerr

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The purpose of this research is to conduct a cost-benefit analysis of the repair of EA-18G aircraft engines at Naval Air Station (NAS) Whidbey Island, WA. Currently, Fleet Readiness Center West (FRCW) at NAS Lemoore, CA, provides engine repair to all squadrons flying F/A-18E/F Super Hornet and EA-18G Growler aircraft. The F/A-18E/F Super Hornets use the F414-GE-400 engine; the same engine/propulsion system/module used in the EA-18G Growler. The introduction of EA-18G Growlers to the Navy and replacement of aging F/A-18C aircraft with Super Hornets has increased the demand of repair at FRCW. Over 1,000 miles separates the Growlers at Whidbey Island and the repair facility at NAS Lemoore, which affects readiness levels. This research builds on the findings and recommendations of a previous thesis project at the Naval Postgraduate School, *Forecasting the Demand of the F414-GE-400 Engine at NAS Lemoore*, which concluded that FRCW is working at 100% utilization. The present project focuses on the practices both NAS Whidbey Island and NAS Lemoore use and creates a scenario that duplicates the test cell for the Growler engine and relevant equipment at NAS Whidbey Island. The goal of this project is to identify if the Growler's readiness would be increased by adding the capability to test the F414-GE-400 engine at NAS Whidbey Island as well as any additional benefits that might be gained.

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ANALYSIS OF EA-18G GROWLER ENGINE MAINTENANCE AT NAVAL AIR STATION WHIDBEY ISLAND, WA

Edward U. Hood, Lieutenant, United States Navy,
Zulfiqar A. Khan, Lieutenant Commander, Pakistan Navy, and
Brian C. Story, Lieutenant Commander, United States Navy

Submitted in partial fulfillment of the requirements for the degree of

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June 2013

Authors: ______________________________
Edward U. Hood

____
Zulfiqar A. Khan

____
Brian C. Story

Approved by: ______________________________
Keebom Kang, PhD

____
Ken Doerr, PhD

____
William R. Gates, Dean
Graduate School of Business and Public Policy

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ANALYSIS OF EA-18G GROWLER ENGINE MAINTENANCE AT NAVAL AIR STATION WHIDBEY ISLAND, WA

ABSTRACT

The purpose of this research is to conduct a cost-benefit analysis of the repair of EA-18G aircraft engines at Naval Air Station (NAS) Whidbey Island, WA. Currently, Fleet Readiness Center West (FRCW) at NAS Lemoore, CA, provides engine repair to all squadrons flying F/A-18E/F Super Hornet and EA-18G Growler aircraft. The F/A-18E/F Super Hornets use the F414-GE-400 engine; the same engine/propulsion system/module used in the EA-18G Growler. The introduction of EA-18G Growlers to the Navy and replacement of aging F/A-18C aircraft with Super Hornets has increased the demand of repair at FRCW. Over 1,000 miles separates the Growlers at Whidbey Island and the repair facility at NAS Lemoore, which affects readiness levels. This research builds on the findings and recommendations of a previous thesis project at the Naval Postgraduate School, *Forecasting the Demand of the F414-GE-400 Engine at NAS Lemoore*, which concluded that FRCW is working at 100% utilization. The present project focuses on the practices both NAS Whidbey Island and NAS Lemoore use and creates a scenario that duplicates the test cell for the Growler engine and relevant equipment at NAS Whidbey Island. The goal of this project is to identify whether the Growler's readiness would be increased by adding the capability to test the F414-GE-400 engine at NAS Whidbey Island, as well as any additional benefits that might be gained.

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TABLE OF CONTENTS

I. INTRODUCTION....1
A. BACKGROUND....1
B. TWO NAVAL AIR STATIONS....1
C. RESEARCH OBJECTIVE....3
D. RESEARCH QUESTIONS....3
E. METHODOLOGY....3
F. REPORT ORGANIZATION....4

II. BACKGROUND....5
A. NAVAL AVIATION MAINTENANCE PROGRAM....5
1. Levels of Maintenance....5
a. Organizational-level Maintenance....6
b. Intermediate-level Maintenance....6
c. Depot-level Maintenance....7
B. FLEET READINESS CENTER....7
1. Engine Repairs....8
2. Fleet Readiness Center Northwest (Whidbey Island, WA) Power Plants Division....11
C. PLANNED MAINTENANCE SYSTEM....11

III. LITERATURE REVIEW....13

IV. METHODOLOGY AND REFERENCE DATA....23
A. ANALYSIS TECHNIQUES....23
1. Cost–and–Benefit Analysis....23
2. Life–Cycle Cost....24
3. Areas of Focus With Regard to Current Operations....24
a. Reliability....24
b. Mean Time between Failures....25
c. Operational Availability....25
d. Calculating the Probability of Failure....26
e. Spare Parts Quantity Determination....27
f. Logistics Cycle Time Reduction....28
g. Inventory Carrying Cost....28
h. Data Sources....29

V. ANALYSIS....31
A. ASSUMPTIONS....31
B. CALCULATING THE ENGINE A_o IN PRESENT SCENARIO....32
C. CALCULATING THE PRESENT MEAN TIME BETWEEN FAILURES AT WHIDBEY ISLAND....33
D. CALCULATING THE AVERAGE NUMBER OF ENGINE FAILURES BY USING FLEET MEAN TIME BETWEEN FAILURES....33
E. CALCULATING THE ENGINE TRANSPORTATION COSTS IN THE PRESENT SCENARIO....34

F. CALCULATING THE ENGINE TRANSPORTATION COSTS USING FLEET MEAN TIME BETWEEN FAILURE....35
G. IMPACTS OF TRANSPORTATION TIME UPON THE SPARE ENGINE POOL....35
1. Calculating the Number of Spare Engines for 46 Aircraft with a Four Days Transportation Time....35
2. Calculating the Number of Spare Engines for 114 Aircraft with a Six Days Transportation Time....36
H. IMPACT OF PROTECTION LEVEL UPON THE SPARE ENGINE POOL....36
1. Calculating the Number of Spare Engines for 46 Aircraft with an 85% Protection Level....36
2. Calculating the Number of Spare Engines for 46 Aircraft with a 90% Protection Level....37
3. Calculating the Number of Spare Engines for 114 Aircraft with an 85% Protection Level....38
4. Calculating the Number of Spare Engines with 114 Aircraft with a 90% Protection Level....38
I. EFFECTS OF LIMITED REPAIR CAPABILITY AND UPGRADING ENGINE TEST CELL UPON ENGINE SPARE POOL....39
1. Calculating the $\lambda_{effective}$ of AB Module....39
2. Calculating the Probability that Only AB Module Will Need to Be Replaced....40
3. Calculating the Frequency of AB Failures with 46 and 114 Aircraft....41
a. Excel Poisson Distribution Function....41
b. Building the Probability Chart....41
4. Calculating Average Number of Engine Failures Due to Spray Bars in the AB Module....43
5. Calculating the Cost of Transportation for Engines Having AB Module (Main Spray Bar) Defects....44
6. Calculating the Cost of Upgrading FRCNW's Engine Test Cell...45
J. LIFE-CYCLE COST AND EFFECTS ON OPERATIONAL AVAILABILITY OF THE GROWLER AFTER MODIFYING FRCNW'S ENGINE TEST CELL....46

VI. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS....53
A. RESULTS....53
1. Calculating the Number of Engine Failures Due to Spray Bar Issue in the AB Module....53
2. Calculating the Number of Spare Engines....53
3. Calculating the Transportation Costs....54
4. Calculating the Life-Cycle Costs of Upgrading FRCNW's Engine Test Cell and Providing Limited F414 Engine Repair Capability....54

5. Probability of Afterburner Failures and Effects on FRCNW's Spare Engine Pool 55
B. CONCLUSIONS AND RECOMMENDATIONS 55
1. Additional Operating Costs versus Engine Carrying Avoidance ..55
2. Effect on the Number of Spare Engines Required 55
3. Concept of Fleet Readiness Center/Center of Excellence and Centralized versus Decentralized Facilities 56
C. AREAS OF FURTHER RESEARCH 56
1. Bottleneck at FRC Southeast Located at NAS Jacksonville, FL ...57
2. Re-examination of This Study Following Delivery of the 114th Growler 58
D. SUMMARY 58
REFERENCES 61
INITIAL DISTRIBUTION LIST 65

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LIST OF FIGURES

Figure 1. Over 1,000 Miles Between the Two Repair Sites 2
Figure 2. Fleet Readiness Center Chain of Command 8
Figure 3. F414-GE-400 Engine 9
Figure 4. Six Sections of the F414-GE-400 Engine 10
Figure 5. Fleet Readiness Center Northwest Power Plants Division Chain of Command 10

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LIST OF TABLES

Table 1. Average Number of Engine Failures Using Fleet Mean Time Between Failures for 46 Aircraft 34
Table 2. Average Number of Engine Failures Using Fleet Mean Time Between Failures for 114 Aircraft 34
Table 3. Number of Spare Engines for 46 Aircraft with a Four Days Transportation Time 36
Table 4. Number of Spare Engines for 114 Aircraft with a Six Days Transportation Time 36
Table 5. Number of Spare Engines for 46 Aircraft with an 85% Protection Level 37
Table 6. Number of Spare Engines for 46 Aircraft with a 90% Protection Level 38
Table 7. Number of Spare Engines for 114 Aircraft with an 85% Protection Level 38
Table 8. Number of Spare Engines for 114 Aircraft with a 90% Protection Level 39
Table 9. Scheduled Maintenance Interval and Window for F414 Engine Modules 40
Table 10. Frequency of AB Failures for 46 Aircraft....42
Table 11. Frequency of AB Failures for 114 Aircraft....42
Table 12. Average Number of Engine Failures Due to AB Module for 46 Aircraft 43
Table 13. Average Number of Engine Failures Due to Spray Bars for 46 Aircraft....44
Table 14. Average Number of Engine Failures Due to Spray Bars for 114 Aircraft....44
Table 15. F414 Test Cell Operator Annual Allowances and Costs 45
Table 16. F414 Test Cell Equipment Costs 45
Table 17. Engine Carrying Avoidance....47
Table 18. Annual F414 AB Spray Bar Failures 48
Table 19. Life-Cycle Costs at an Engine Carrying Rate of 10% 49
Table 20. Life-Cycle Costs at an Engine Carrying Rate of 15% 51

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LIST OF ACRONYMS AND ABBREVIATIONS

AB	Afterburner
AIMD	Aircraft Intermediate Maintenance Detachment/Department
A_o	Operational Availability
APB	Acquisition Program Baseline
AWP	Awaiting Parts
CLS	Contractor Logistics Support
CMC	Commandant of the Marine Corps
COMNAVAIRFOR	Commander, Naval Air Forces
D-Level	Depot Level
DoD	Department of Defense
FRC	Fleet Readiness Center
FRCNW	Fleet Readiness Center Northwest
FRCW	Fleet Readiness Center West
FRP	Full-Rate Production
FY	Fiscal Year
GAO	Government Accountability Office
IECMS	In-Flight Engine Condition Monitoring System
I-Level	Intermediate Level
IMA	Intermediate Maintenance Activity
LCC	Life-Cycle Cost
MEI	Major Engine Inspection
MTBF	Mean Time Between Failures
NAE	Naval Aviation Enterprise
NAS	Naval Air Station
NASWI	Naval Air Station Whidbey Island
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMP	Naval Aviation Maintenance Program
NPS	Naval Postgraduate School

NPV	Net Present Value
OEM	Original Equipment Manufacturer
O-Level	Organizational Level
PMS	Planned Maintenance System
RBA	Ready Basic Aircraft
RFI	Ready for Issue
RFT	Ready for Tasking
RTAT	Repair Turn Around Time
TAT	Turnaround Time

I. INTRODUCTION

A. BACKGROUND

The EA-6B Prowler electronic suppression aircraft started its operational duties in 1971. The Navy and Marine Corps employ the EA-6B Prowler as a shield of protection over its strike aircraft, ground troops, and ships by jamming the enemy's radar, electronic data links, and communications. In 2003, Boeing was awarded a developmental contract for the EA-18 Growler to replace the 40-year-old EA-6B Prowler. However, it was not until "November 2010 [that] the first EA-18G Growler squadron started their maiden deployment to the Central Command located at Al Asad Air Base, Iraq" (Plecki, 2011, para. 1). This deployment marked the beginning of the phasing out of the EA-6B Prowler. Both Prowler and Growler aircraft are home-based out of Naval Air Station (NAS) Whidbey Island, WA, where Prowlers are repaired; however, the repair facility for the Growler is at NAS Lemoore, CA. As the Growler continues to replace the Prowler, the question arises: Should Whidbey Island have limited capability to repair Growler components?

B. TWO NAVAL AIR STATIONS

According to NAS Lemoore's website, its "principal mission is to support Strike-Fighter Wing, U.S. Pacific Fleet and its mission to train, man, and equip the west coast Strike-Fighter squadrons" (Naval Air Station Lemoore, 2012). NAS Lemoore is also the home of Fleet Readiness Center West (FRCW), which "provides the highest quality Intermediate and Depot Level aviation maintenance, component repair, and logistics support to the fleet both locally and around the world, in the fastest, safest, most cost efficient manner possible" (FRC West, 2012). In an MBA project titled *Forecasting the Demand of the F414-GE-400 Engine at NAS Lemoore,* Hersey, Rowlett, and Thompson (2008) stated that most of the Super Hornet/Growler engines are repaired at FRCW. They concluded that the repair capability of F414-GE-400 engines at FRCW was near 100% capacity, given manpower levels at that time. As the Growler replaces the Prowler and operational wear and tear occurs to the Growler, the question arises of how the current repair cycle will keep up with the operational demand, both for the F/A-18E/F and EA-18G.

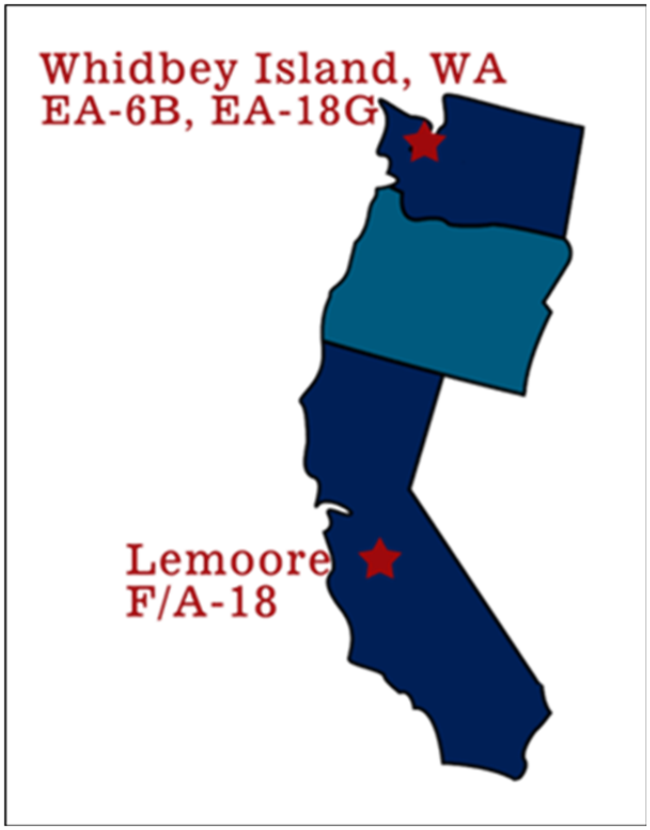

Figure 1. Over 1,000 Miles Between the Two Repair Sites

According to NAS Whidbey Island's (NASWI) website,

> [NASWI] is the premier naval aviation installation in the Pacific Northwest and home of all Navy tactical electronic attack squadrons flying the EA-6B Prowler and EA-18G Growler. Adding to the depth and capability of the air station are four P-3 Orion Maritime Patrol squadrons and two Fleet Reconnaissance squadrons flying the EP-3E Aries. (Naval Air Station Whidbey Island, 2012)

Whidbey Island, WA, is also the home of Fleet Readiness Center Northwest (FRCNW). According to its website,

> Fleet Readiness Center Northwest, previously known as Aircraft Intermediate Maintenance Detachment (AIMD), was established in 1959

> and developed into the premier Intermediate and Depot Maintenance Facility in the Pacific Fleet. Over 1,100 Sailors, Marines, civilians, contractors and depot maintenance level personnel at FRCNW provide aviation maintenance and logistics support to 13 EA-6B squadrons, six P-3/EP-3 squadrons, 12 aircraft carriers, one C-9 squadron, the station Search and Rescue component and various Northwest Region activities. (Fleet Readiness Northwest, 2012)

As the Navy phases out the Prowler, the demand for repairing its engine will also decrease.

C. RESEARCH OBJECTIVE

In this project, we focus on the feasibility of adding limited repair capability for the Growler engine at FRCNW. We also examine practices followed at both FRCW and FRCNW and simulate a scenario in which Whidbey Island has limited repair capability for the Growler engine. By analyzing this scenario, we hope to identify whether the readiness of the Growler would be increased, as well as any additional benefits that might be gained.

D. RESEARCH QUESTIONS

Our primary question is, Should FRCNW gain limited repair capability for the F414-GE-400 engine, including updating the existing test cell? To assist in answering this question, we assess the demand for engine repair during calendar year 2012 and the current forecasting method used to estimate engine demand.

E. METHODOLOGY

Our investigation for this paper encompassed a lengthy literature review and data analysis. The concepts applied are from Logistic Engineering, Operational Management, Supply Chain Management, and Simulation Modeling for Management Decision Making courses we completed at the Naval Postgraduate School (NPS). Additionally, we used maintenance practices that are outlined in the Naval Aviation Maintenance Program (NAMP; Commander, Naval Air Forces [COMNAVAIRFOR], 2012) instruction.

To create the estimate, we utilized the fleet's 2012 data pertaining to the Growler engine, primarily gathered from PMA-265, Electronic Attack Wing and FRCW. Although this data captured only one year of flight operations, we believe it represents the Growlers through various deployments.

F. REPORT ORGANIZATION

In Chapter I, we provide a general awareness about the research project and background information for the situation, research objective, research question, and methodology. In Chapter II, we provide background information on the NAMP. In Chapter III, we review the various studies, government and acquisition reports, and websites, including those published by the original equipment manufacturer (OEM). In Chapter IV, we explore various logistic engineering concepts used to develop our cost benefit analysis. In Chapter V, we discuss the analysis of the spare engine and how protection level can affect it. In Chapter VI, we present our results, conclusions, and recommendations.

II. BACKGROUND

In this chapter, we define the concepts necessary to understanding the dynamics of naval aviation maintenance. First, we explain the NAMP instruction (COMNAVAIRFOR, 2012) and how it defines different levels of maintenance. Second, we describe FRCs, including how they have evolved, and what their position in the Naval Aviation Enterprise (NAE) is. Third, we present an overview of FRCNW's Power Plants Division structure. Finally, we explain the Planned Maintenance System (PMS) and how it relates to engine maintenance.

A. NAVAL AVIATION MAINTENANCE PROGRAM

The aviation maintenance community considers the NAMP its bible. "The NAMP applies to all organizations operating or supporting Navy and Marine Corps manned and unmanned aircraft and related equipment" (COMNAVAIRFOR, 2012, p. 1). It also standardizes the policies and procedures for the management of all Navy and Marine Corps aviation maintenance activities. The objective of the NAMP instruction is as follows:

> to achieve and continually improve aviation material readiness and safety standards established by Chief of Naval Operations /Commander Naval Air Forces (COMNAVAIRFOR), with coordination from the Commandant of the Marine Corps (CMC), with optimum use of manpower, material, facilities, and funds. (COMNAVAIRFOR, 2012, p. 1–4)

The NAMP separates maintenance into three levels—organizational, intermediate, and depot—to maximize readiness of aircraft and equipment and allow the Navy to manage personnel and material more efficiently. Ultimately, this instruction documents the main doctrine of naval aviation maintenance and takes precedence over all other aviation maintenance documents, unless otherwise directed within it.

1. Levels of Maintenance

The three levels of maintenance can be considered as a pyramidal hierarchy because the higher levels build upon capabilities and functions provided by the lower levels. Task complexity, space requirements, skill level of assigned personnel, and scope of support responsibility are the basis for the separation of tasks. Although the intermediate and depot levels are more specialized, their main focus is to support their primary customer: the organization level.

a. Organizational-level Maintenance

Organizational-level (O-level) maintenance is work performed on aeronautical equipment owned by the operational command. "The O-level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission capable status while continually improving the local maintenance process" (COMNAVAIRFOR, 2012, p. 3–1). This level of maintenance is the closest to the warfighter in terms of ensuring that the aircraft are operational and able to fly when scheduled. Blanchard (1992) described the O-level as follows:

> Organizational-level personnel are usually involved with the operation and use of equipment, and have minimum time available for detailed system maintenance. Maintenance at this level normally is limited to periodic checks of equipment performance, visual inspections, cleaning of equipment, some servicing, external adjustments, and the removal and replacement of some *components*. Personnel assigned to this level generally do not repair the removed components, but forward them to the intermediate level. From the maintenance standpoint, the least skilled personnel are assigned to this function. (p. 115)

b. Intermediate-level Maintenance

Intermediate-level (I-level) maintenance consists of more specialized maintenance in removal, repair, and replacement of assemblies, modules, or piece parts. "The I-level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the lowest practical resource expenditure" (COMNAVAIRFOR, 2012, p. 3–2). At the I-level, test equipment assists Sailors or Marines in identifying faulty components and the repairs needed to return an item to a ready for issue condition. Blanchard (1992) described the I-level as follows:

> At this level, end items may be repaired by the removal and replacement of major modules, assemblies, or piece parts. Scheduled maintenance

> requiring equipment disassembly may also be accomplished. Available maintenance personnel are usually more skilled and better equipped than those at the organizational level and are responsible for performing more detail maintenance. Maintenance tasks that cannot be performed by the lower levels due to limited personnel skills and test equipment are performed here. High personnel skills, additional test and support equipment, more spares, and better facilities often enable equipment repair to the module and piece part level. (pp. 115–116)

c. Depot-level Maintenance

Depot-level (D-Level) maintenance is the most in-depth maintenance within naval aviation and is performed at the FRCs. "D-level maintenance is also performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items" (COMNAVAIRFOR, 2012, p. 3–2). The FRCs assist both the organizational and intermediate maintenance levels by providing engineering assistance and performing maintenance that is beyond the ability of the lowest level unit. This repair capability is the furthest from the warfighter, but it gives the NAE the ability to get components in nearly new condition. Blanchard (1992) stated,

> The depot level constitutes the highest type of maintenance, and supports the accomplishment of tasks above and beyond the capabilities available at the intermediate level. The depot level of maintenance includes the complete overhauling, rebuilding, and calibration of equipment as well as the performance of highly complex maintenance actions. (p. 116)

B. FLEET READINESS CENTER

On February 13, 2006, the NAE's board of directors accepted the FRC concept, one of the most dramatic transformations in the 50 years of naval aviation maintenance. Naval Air Systems Command developed the FRC concept because of the recommendation of the 2005 Base Realignment and Closure Committee. This concept integrated the ashore Intermediate Maintenance Activity (IMA) and the depot as one repair facility, creating the Center of Excellence Repair Facilities, with a mission "to produce quality airframes, engines, components, [support equipment] SE, and [to] provide services that meet the NAE's aircraft [ready-for-tasking] RFT goals with improved effectiveness and efficiency" (COMNAVAIRFOR, 2012, p. 12–1). Additionally, the FRCs provide integrated off-flight line repair, in-service industrial scheduled inspections/mods, and deployable Sea Operational Detachment personnel that augment the afloat Aircraft Intermediate Maintenance Detachment/Departments (AIMDs).

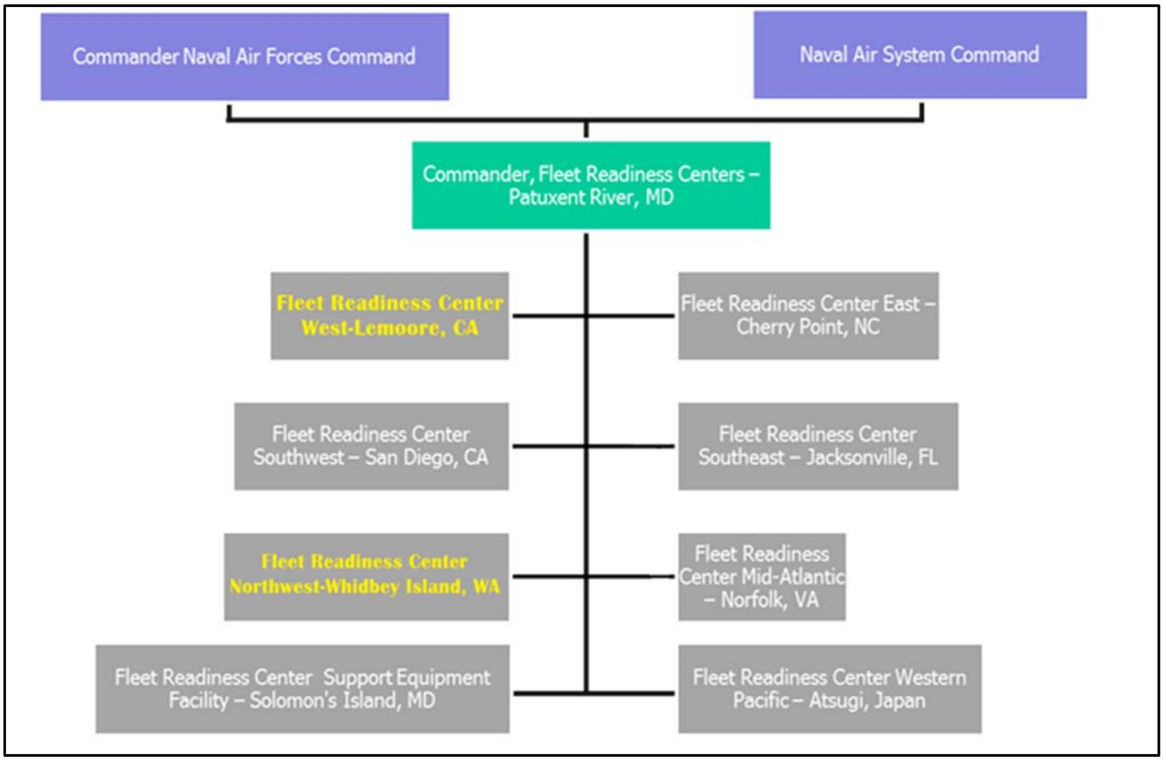

Figure 2. Fleet Readiness Center Chain of Command

1. Engine Repairs

FRCs contain many divisions that repair a variety of aeronautical components. For example, the Power Plants Division is responsible for engine repairs. Their levels of repair capability are first-, second-, or third-degree repair. *Repair* is defined as "necessary preparation, fault correction, disassembly, inspection, replacement of parts, adjustment, reassembly, calibration, or tests accomplished in restoring items to serviceable status" (COMNAVAIRFOR, 2012, p. A-65). The NAMP (COMNAVAIRFOR, 2012) defined the degrees of repair as follows:

> FIRST-DEGREE REPAIR - The repair of gas turbine engines to a depth which includes and goes beyond that repair authorized for second- and third-degree IMAs. It includes compressor rotor replacement and

disassembly to a degree that the compressor rotor is removed. Any degree of repair which requires compressor rotor removal constitutes first-degree repair. Only those activities specifically designated as first-degree repair activities and included in NAVAIR NOTE 4700 will be outfitted to accomplish repair of that magnitude. (COMNAVAIRFOR, 2012, p. A-28)

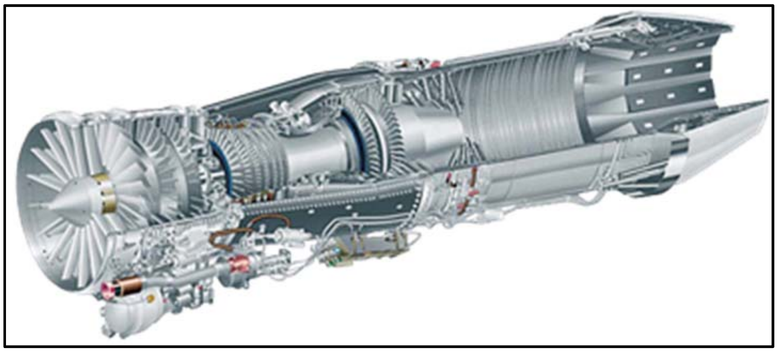

Figure 3. F414-GE-400 Engine

SECOND-DEGREE REPAIR - The repair of a damaged or non-operating gas turbine engine, its accessories, or components to an acceptable operating condition. As used in this instruction, repair by designated IMAs includes the repair/replacement of turbine rotors and combustion sections, including afterburners. Also authorized are replacing externally damaged, deteriorated, or time-limited components, gear boxes, or accessories, and conducting engine inspections. In addition, minor repair to the compressor section is authorized, for example, dressing nicks in compressor vanes and blades within limits of the operating and service instructions. Further, the repair or replacement of reduction gearboxes and torque shafts of turbo shaft engines and compressor fans of turbofan engines which are considered repairable within the limits of the approved intermediate maintenance manuals shall be done by second-degree repair activities. COMNAVAIRFOR, 2012, p. A-70)

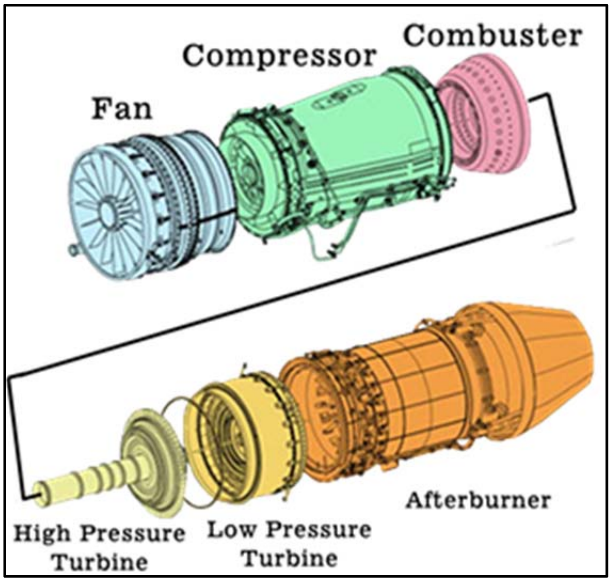

Figure 4. Six Sections of the F414-GE-400 Engine

> THIRD-DEGREE REPAIR - Encompasses the same gas turbine engine repair capability as the second-degree repair except that certain functions which require high maintenance man-hours and are of low incident rate are excluded. (COMNAVAIRFOR, 2012, p. A-78)

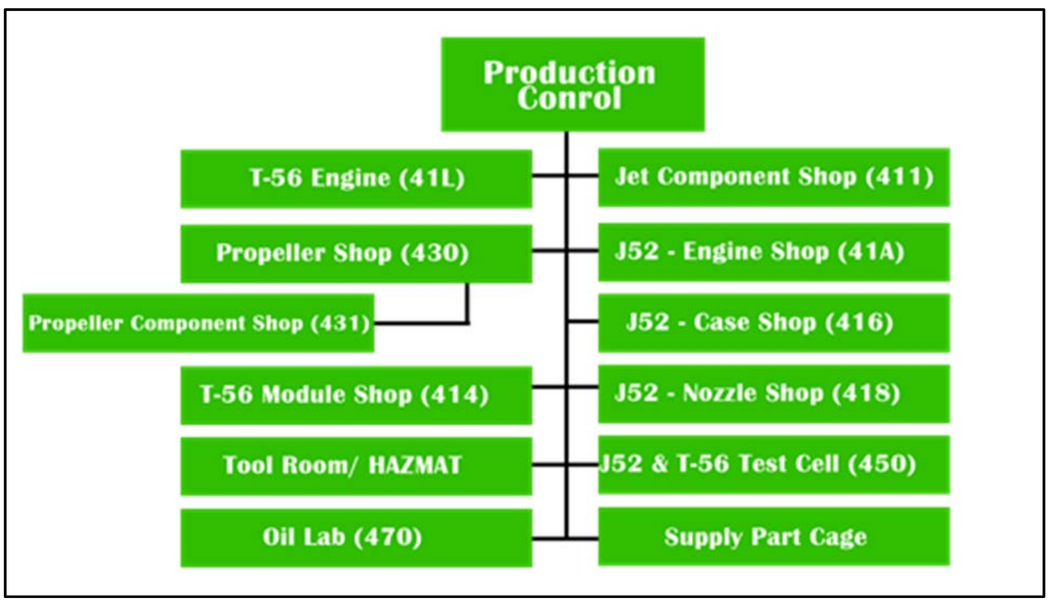

Figure 5. Fleet Readiness Center Northwest Power Plants Division Chain of Command

2. Fleet Readiness Center Northwest (Whidbey Island, WA) Power Plants Division

FRCNW's Power Plants Division qualifies as a second-degree repair activity site for the J-52 and T-56 engines; it can inspect, repair, and test the engines for the Prowler (J-52 engine) and the P-3C (T-56 engine). Power Plants inspect for verification of all applicable technical directives, for high-time components, and for a history of discrepancies. However, Power Plants does not have any repair capability for the F414-GE-400 engine, leaving it able only to preserve or de-preserve engines for Growler squadrons.

C. PLANNED MAINTENANCE SYSTEM

The PMS is a program that ensures that aircraft and aeronautical equipment are maintained throughout their service life. Naval Aviation Logistics Command Management Information System (NALCOMIS) is the computer database that tracks maintenance actions. NALCOMIS can track scheduled inspections that are performed at particular intervals (e.g., hourly, calendar, event driven). The hourly inspections can be performed within a 10% deviation of the standard. The calendar inspections can be performed with a deviation of plus or minus three days. Event driven inspections are performed as needed, such as following a hard landing. Because aircraft engines are tracked by operational hours, the 10% deviation can be applied to engine inspections. To illustrate, the Growler's engine has a 200-hour inspection that can be accomplished between 180 hours and 220 hours of operation.

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III. LITERATURE REVIEW

There have been several studies that have explained and analyzed the F414-GE-400 engine and its repair cycle. Some of those studies suggested areas of further research, which served as a point of reference and guidance for our methodology in this research. We utilized lessons learned from the courses of Operations Management, Supply Chain Management, Business Modeling and Analysis, and Simulation Modeling for Management Decision Making, all completed at NPS. The concepts we learned were of great significance in helping us analyze the current repair cycle for the Growler engines and in providing useful recommendations for improving aircraft readiness.

Stearns (1998) presented a simulation metamodel used to determine initial rotatable pool inventories for F404-GE-400 engine modules onboard a deployed aircraft carrier. Stearns' study looked at the AIMD afloat, their pool of F404 engines, and their repair cycle. He claimed that millions of dollars could be saved annually by following the metamodel recommendations for changes and reduction in inventories, while the operational availability (A_o) of the squadron could also be maximized. In his study, Stearns (1998) developed the simulation model from real maintenance and usage data and provided a detailed and accurate representation of the repair cycle. By using regression analysis, he claimed that the Navy could achieve annual savings of over $1.16 million by lowering the inventory quantities of F404 engine modules onboard aircraft carriers. Stearns (1998) also recommended that the simulation factors be updated once a year with current data and that the metamodel be re-computed to determine shifts in significance among the modules. Moreover, he claimed that the squadron's A_o would benefit from adjusting inventory levels to reflect the changes.

Bartlett and Braun (1993) provided a feasibility study and cost- benefit analysis to determine what generic D-level capabilities are require to be shifted to certain AIMDs to reduce costs and improve fleet support of F404-GE-400/402 turbofan engine. Their study examined the cost analysis of engine maintenance between two maintenance facilities: AIMDs at NAS Cecil Field and NAS Lemoore. Bartlett and Braun (1993) used a simulation of both the repair facilities to determine whether either expanding the repair capacity or keeping the status quo was more beneficial. With the help of their simulation model, they concluded that there are strong indications that expanding the repair capabilities of the AIMDs is feasible and cost effective. Moreover, they claimed that transferring welding and spin balance capability from the depot at Jacksonville, FL, to the AIMDs at NAS Cecil Field and NAS Lemoore would reduce turnaround time with only a minimal increase to work-in-process time. Their study also calculated the net savings of manpower costs depending on whether Navy or civilian personnel are used to augment spin balance and welding work centers and whether new or existing equipment is utilized in these work centers. The projected maintenance cost savings over a 10-year period claimed by Bartlett and Braun (1993) was $4.9 million, assuming civilian augmentation and new equipment, whereas with the existing equipment and naval personnel, the savings over a 10-year period was $5.9 million.

Hersey et al. (2008) forecasted the repair demand of the F414-GE-400 engine and determined whether FRC West would be able to meet increased demand in the near future. Their study collected current history of I-level repair for the F414 engine and estimated its increase based on the arrival of additional engines procured by the Navy. The researchers built an optimization model to determine whether manning levels were adequate to perform the forecasted demand for engine repair. By applying linear regression, double exponential smoothing, and optimization modeling, Hersey et al. (2008) concluded that the number of engines FRCW will repair would rise. In the study, Hersey et al. (2008) also mathematically demonstrated that FRCW is working at or near 100% capacity.

Hersey et al. (2008) concluded that the mean time between failures (MTBF) equals the mean time since repair, and MTBF is decreasing on five of the six engine modules. Another important recommendation of the Hersey et al. (2008) study is to move the depot from FRC Southwest to FRCW, which would reduce shipping costs and in-transit inventory. Hersey et al. (2008) also found that inconsistent demand was creating a potential bottleneck in the afterburner repair shop because repairs were being postponed while awaiting parts (AWP), which was forcing management to choose between a stoppage of work or a cannibalization action. To overcome the AWP situation, Hersey et al. (2008) recommended an annual review of the safety stock within the supermarket along with a forecast of the demand and MTBF for each module. In this study, we replicate the Hersey et al. (2008) study, but we use new data and focus on Whidbey Island, resulting in some new insights on the topic.

Schoch (2003) studied the so-called I3 to D concept, used for F414-GE-400 module and engine repair, in which the I-level maintainers do not repair modules. Instead, they send all modules requiring repair to the depot for D-level repairs. At the time of the study, this was a new concept. In the study, Schoch (2003) developed a simulation model that incorporated F/A-18E/F flight schedules and engine failures to populate the repair cycle. The simulation provided A_o, probability of engine failures, and number of spare engines required given an infrastructure and sparing profile. Schoch (2003) used three previous years of module failures and depot repair times to calibrate the model. Simulation results for the baseline studied showed the distinct influence of certain input parameters, which are listed as follows:

- Aircraft service entry time had a short-term effect on A_o.
- Cannibalization of the engines among F/A-18s improved A_o.
- Scheduled maintenance impacted A_o.
- All the components of depot repair turnaround time (RTAT), "In Work" and "Other" influenced A_o.

The simulation was also used to examine the impact of varying build windows and depot RTAT. It allows easy changes of input parameters to be made so that a multitude of effects on A_o and probability of failure can be readily studied.

Hagan and Slack (2006) studied how to decrease the F414 engine throughput time at the AIMD at NAS Lemoore by employing organizational modeling and evaluating how changes to the organizational structure could affect engine throughput time. To achieve the purpose, Hagan and Slack (2006) developed a baseline model of the organization's existing structure and performance and compared this with the duration of required maintenance. Various modification/interventions were made, including paralleling the tasks associated with accomplishing administrative paperwork when receiving the engine and tasks associated with on-engine maintenance, combining personnel positions, decreasing centralization from high to low, adding personnel, and modifying the duration and frequency of meetings. The findings of Hagan and Slack's (2006) study indicated that the paralleling effort significantly decreased the maintenance duration, which likewise decreased centralization from high to low, decreased meeting frequency, and slightly increased duration, which in turn facilitated a decreased duration. The study calculated that the benefit due to the interventions to reduce the F414 throughput duration was significant, and Hagan and Slack (2006) estimated that there is a reduction of over 35% in engine throughput time from the baseline case.

Hagan, Slack, Zolin, and Dillard (2007) studied the impacts of using the NAVAIR Enterprise AIRSpeed program of Lean, Six Sigma, and the Theory of Constraints by AIMD at NAS Lemoore. Particular attention was given to achieving time and cost reductions and calculating the improvements of implementing changes in the organizational structure or management practices. Their study considered that portion of the AIMD Power Plants Division that accomplishes F414 maintenance. It considered only tasks associated with maintenance efforts, starting from receipt of the engine to the point at which the engine is determined ready-for-issue (RFI). To achieve their objective, Hagan et al. (2007) employed organizational simulation software to test interventions that could reduce throughput time for the F414 engine. They developed a baseline model and modeled and simulated interventions. The simulated results indicated that paralleling some tasks could significantly decrease maintenance duration while maintaining quality. Twenty-six days of repair time per engine were saved by the implementation of the interventions. The study by Hagan et al. (2007) also proved that organizational modeling and simulation could identify time and cost savings over and above techniques, such as Lean and Six Sigma.

Jafar, Mejos, and Yang (2006) conducted a study on the J52-P408 engine repair process and the implementation of the AIRSpeed program at AIMD at NAS Whidbey Island. Although this study was conducted on the J52-P408 engine used by EA-6B Prowler aircraft, it provided an overview of the engine repair process at NAS Whidbey Island. Jafar et al. (2006) analyzed the incorporation of the TOC and the following methodologies in the engine repair process: just in time, and Lean Six Sigma. They also examined the effects of these methodologies in relation to repair cycle-time and overall readiness level. In their study, they also described and compared the earlier and the current AIRSpeed engine removal and repair processes, starting from the flight line to the RFI pool at AIMD. Using simulation modeling tools and private industry production and inventory management philosophies, Jafar et al. examined how the application of AIRSpeed processes contributes to the mission readiness of the Navy's and Marine Corps' fleets of EA-6B Prowler aircraft, while reducing operation and maintenance cost.

Based on the analysis of the simulation model and embellishment results, Jafar et al. (2006) concluded that the AIRSpeed process at AIMD J52 Engine Repair Shop is effective. The methodologies employed by FRCNW's AIRSpeed team proved to be beneficial in expediting the engine repair process once the engine was inducted. Consequently, crew utilization rates decreased from 64% down to 33%, increasing efficiency and providing more time for quality work, professional training, and family time.

Hall, Leary, Lapierre, Hess, and Bladen (2001) studied the F/A-18E/F F414 In-flight Engine Condition Monitoring System (IECMS). IECMS combines diagnostic algorithms, engine control system computer sensors, and airframe computers to process and report real-time engine health. Experts from Boeing, GE Engines, and the Navy conducted this interesting study in order to test the cell performance of the F414-GE-400 engine. Hall et al. (2001) described system elements with an emphasis on the manner in which they are integrated into IECMS and the benefits of IECMS to the pilot, maintenance crew, and weapon system readiness. In the study, Hall et al. (2001) presented comparisons between the baseline and advanced IECMS capabilities. Differences between the baseline and advanced IECMS include anomalies detected by IECMS during engine ground runs and in-flight, along with the resulting maintenance actions or design changes that improved system safety, reliability, and maintainability.

Hall et al. (2001) concluded that the advanced IECMS system is fully integrated between the engine and airframe and effectively uses available avionics computers and interfaces, which contributes to low system weight. This advanced system includes many improvements, including the following:

- better aircrew displays and additional cautions and advisories,
- added mission computer resources,
- reliable, new Full Authority Digital Engine Control with outstanding fault detection and isolation capabilities,
- improved monitoring hardware installation and signal processing,
- expanded memory unit data recording,
- added engine-mounted master electrical chip detector, and
- added maintenance codes for improved fault detection and isolation.

All of these improvements contributed to reduced pilot workload and aircraft/engine maintenance. Hall et al. (2001) concluded that due to IECMS, aircraft readiness improved with fewer engine runs, less required downtime for troubleshooting, and rapid turnaround through onboard diagnostics. Hall et al. (2001) also found that during the Navy Engineering and Manufacturing Development Technical Evaluation phase when aircraft reliability, maintainability, and built-in-test performances were measured, the advanced IECMS achieved a 100% engine failure detection rate and a 0% false alarm rate. They also concluded that as the F/A-18E/F weapon system continues to grow and mature, IECMS is designed with the flexibility to accommodate future engine/airframe enhancements well into the 21st century.

Tallant, Hedrick, and Martin (2008) studied the supply side of engine database errors and how the errors pertain to the F404 engine. In this study, Tallant et al. (2008) assessed cost as an independent variable of the maintenance manpower of both the OEM Contractor Logistics Support (CLS) and an estimated organic Navy complement of maintainers for the P-8 Poseidon program. Tallant et al. (2008) made comparisons to similar aircraft procurements and analyzed them for possible benefits and limitations regarding a single-source provider of CLS. Furthermore, they reviewed logistic acquisition culture and operational impacts to determine the feasibility of CLS. Some of the methodology that was used in the Tallant et al. (2008) study is relevant to our research.

The Government Accountability Office (GAO) reports are an important source of impartial recommendations and information for Department of Defense (DoD) programs. The reports pertaining to the Growler aircraft highlight the importance of our current project. The high costs associated with procuring, operating, and maintaining DoD aircraft are always scrutinized by Congress. Any organizational or structural changes to minimize these types of costs are always welcomed by lawmakers.

In 2002, the DoD completed an analysis of alternatives for the EA-6B that concluded the inventory of EA-6Bs would be insufficient to meet the DoD's needs beyond 2009. Based on this conclusion, the Navy began development of the EA-18G aircraft as a replacement for the EA-6B. The GAO (2006) report *Option of Upgrading Additional EA-6Bs Could Reduce Risk in Development of EA-18G* provides background knowledge on the Growler and its predecessor the Prowler. The report looked at the missions and services the Prowler has accomplished and how best to develop the Growler without rushing it out to the fleet. The 2006 GAO report examined the validity of the DoD's 2002 conclusion that the Prowler inventory would be insufficient beyond 2009. The report concluded that the acquisition approach used to develop the Growler is knowledge based and might mitigate future risks.

The GAO (2010) report *Tactical Aircraft—DoD's Ability to Meet Future Requirements Is Uncertain, With Key Analyses Needed to Inform Upcoming Investment Decisions* assessed the DoD's tactical aircraft requirements, the extent to which plans for upgrading and retiring legacy aircraft and acquiring new aircraft are likely to meet the requirements, and how changes in strategic plans and threat assessments have affected requirements. This GAO (2010) study was relevant to our project because it provided background knowledge and an understanding of the Growler aircraft itself. The report suggested that Congress consider requiring that the costs associated with modernizing and sustaining the legacy fleet be included in future investment plans, and recommended that the DoD define the number of tactical aircraft required in the future and the size and severity of projected shortfalls. Moreover, the DoD should clearly articulate how systems like unmanned aircraft are accounted for and complete a comprehensive cost-benefit analysis of options for addressing expected shortfalls.

The GAO (2012) report *Airborne Electronic Attack Achieving Mission Objectives Depends on Overcoming Acquisition Challenges* studied the DoD's strategy for acquiring airborne electronic attack capabilities, the DoD's progress in developing and fielding systems to meet airborne electronic attack mission requirements, and the DoD's additional actions to address gaps in airborne electronic attack capability. In order to achieve these objectives, the GAO (2012) analyzed documents related to mission requirements, acquisition and budget needs, development plans, and performance. The GAO (2012) report recommended that the DoD conduct program reviews for certain new, key systems to assess cost, schedule, and performance; determine the extent to which the most pressing capability gaps can be met and then take steps to fill them; align service investments in science and technology with the department-wide electronic warfare priority; and review capabilities provided by certain planned and existing systems to ensure investments do not overlap.

In a report published by the Congressional Research Service and authored by Bolkcom (2006) titled *Navy F/A-18E/F Super Hornet and EA-18G Growler Aircraft: Background and Issues for Congress*, Bolkcom studied the background of the F/A-18 from the legacy aircraft (versions A-D) to the Super Hornets (versions E and F). Bolkcom (2006) also gave the backdrop for the Prowler being replaced by the Growler. The study provided important aspects of the legacy and Super Hornet versions of the F/A-18 as well as the Prowler prior to the Growler entering service. Bolkcom (2006) compared the aircraft with their respective predecessors and provided views and arguments from both sides to enable Congress to decide on the financial aspects linked with the procurement and research, development, test, and evaluation of the aircraft. The Growler uses an F414-GE-400 engine, which is also used by the FA-18E/F Super Hornet. Bolkcom's (2006) report explained the idea of the Navy using a common engine and airframe to replace the Prowler, which resulted in the use of the same assembly line and reduced training, operating, and maintenance costs from operating single common platform. By assigning I-level maintenance of the F414 engine to FRCW, located at NAS Lemoore, CA, maintenance costs were further reduced.

The DoD’s (2011) *Selected Acquisition Report: EA-18G* described the background and current status of the Growler from the Navy’s point of view. This report provided information about the updated status of the Growler program and any potential problems the program manager foresaw, as well as past delays that occurred. It provided information about how many Growler aircraft the Navy was expected to procure. Based on this number, we could analyze and recommend whether FRCNW should or should not modify its engine test cell to test the F414 engine. The DoD’s (2011) *Selected Acquisition Report: EA-18G* also provided the timeline for full-rate production (FRP) and the FRP acquisition program baseline (APB) for the Growler. Total procurement of the Growler was planned for 114 aircraft. As of December 31, 2011, the DoD’s (2011) *Selected Acquisition Report: EA-18G* stated that the EA-18G program had delivered 56 aircraft to the fleet, and the Growler aircraft had flown 33,533 hours. The report also concluded that there are no software-related issues with this program.

The Boeing (2012) article *Backgrounder: EA-18 G Growler* provided an interesting overview about the Growler aircraft from Boeing’s perspective. The basic information about the Growler is available through various means, but Boeing’s information is considered to be the official version. The article presented important information relating to the aircraft, with special emphasis on its background, purpose, capabilities, general characteristics, milestones achieved, and current status (in terms of number of aircraft delivered to Navy) as of September 2012. This article helped us forecast the demand of F414 engine repair because the contract through 2015 includes delivery of an additional 58 Growlers.

The NAVAIR (2012) article “EA-18G Growler” provided us a description of the Growler from the user’s point of view. This Navy website briefly explains the description, capabilities, and specifications of the Growler. In the article, NAVAIR (2012) stated that the Growler is similar to the Super Hornet, which enables cost effective maintenance supportability for both aircraft, setting the stage for continuous capability enhancement and a long life.

The GE Aviation (2012) article “Model F414-GE-400” provided us with basic information about the F414 engine, which is used by the Super Hornet and Growler aircraft. The information provided by GE Aviation is considered to be the most reliable and relevant in terms of the engine's technical and physical traits. The article provided us background knowledge about the evaluation of the engine and its various phases of development. This information was very helpful in understanding the dynamics and operational capabilities of the F414 engine.

An article from GlobalSecurity.org (2011) titled "F414" fully described the F414 engine and explained its evolution from the F412 (designed for the A-12) to the F414 and its use of the F404 engine (designed for the F/A-18). The article dissected the engine down to its different modules, which helped us in understanding the workings and repair process of the engine. The article also compared the F414 and F404 engines in terms of capabilities and performance, and this information helped us in assessing the possibility of an F414 engine test cell at FRCNW.

IV. METHODOLOGY AND REFERENCE DATA

This chapter encompasses the primary data sources and a brief introduction of various techniques, methods, and assumptions used to systematically analyze the data regarding F414-GE-400 engine and answer the research questions. We also explain the reasons we selected the techniques we used during our research.

A. ANALYSIS TECHNIQUES

The FRCs have consolidated their major repair processes; hence, they are considered the centers of excellence for their respective areas. In both Logistics Engineering and Supply Chain Management courses taken at NPS, the concept of consolidated centers is discussed and shown why they are more economical. Other courses, such as Operations Management, Business Modeling and Analysis, and Simulation Modeling for Management Decision-Making, also completed at NPS, provided us key techniques for analyzing the data. Using these techniques, we analyzed the data with the help of both academic theories and on-the-job practices to visualize the organizational flow and on-ground, real-world scenarios that exist within the repair cycle.

1. Cost–and–Benefit Analysis

The concept of cost-and-benefit analysis is a method to assess the relative worth of a plan by using an evaluation of options. Mishan and Quoh (2007) explained that cost-and-benefit analysis is a way of selecting the best solution, as well as a way of evaluating previous choices. We use this concept broadly in our project to calculate the costs associated in terms of material, labor hours, readiness for the Growler's engine, and proposed afterburner (AB) module repair facility at FRCNW. Although the military typically prefers readiness to cost effectiveness (as in the case of aircraft carriers having an engine test cell to achieve maximum A_o, we also analyze and compare our findings with existing costs incurred at FRCNW. From these findings, we derived recommendations in terms of cost savings and effect on A_o.

2. Life–Cycle Cost

The life-cycle cost (LCC) is an important concept that Jones (2006, p. 11.11) as "an inexact process that attempts to gather and use estimate assumptions and historical information to predict what may happen in the future and translate the results into cost." The primary reason for developing an LCC model is to estimate the total costs needed to support the system over the period of time. The two major aspects of our LCC model are the acquisition costs and the operations and maintenance cost. For the sake of parsimony the acquisition costs considered in our study will only include the acquiring of various components for FRCNW's engine test and the initial training. The operations and maintenance will include labor, training and transportation cost savings. Jones states, "although [LCC is] imperfect, it is the only tool available to the supportability engineering to assess the impact of design, operation, and support decisions on the total program" (2006, p. 11.11). He further explains that "LCC modeling allows the supportability engineering to create a reasonable projection of cost based on an assembled data set, and then look at the impact of changes to the base line data" (2006, p. 11.11) making the application to our scenario reasonable.

We calculate the LCC of modifying the engine test cell at FRCNW to run the F414 engine, which we analyze in the final chapter to assist the decision-makers in gauging the monetary impacts of any modifications.

3. Areas of Focus With Regard to Current Operations

a. Reliability

Reliability can be used to portray a sense of confidence in a system or the probability of satisfactory performance during a given period under specific operating conditions. Reliability of a specific system can be calculated by statistics from one of these three sources:

- use of in-service data from similar equipment,
- test or trials data (conducted in similar conditions), and
- generic parts data.

b. *Mean Time between Failures*

MTBF of any component or system provides the maintenance manager and decision-makers the average time between two consecutive failures. It can be calculated by dividing the total measured usage of any equipment in a specified time by the total occurrences of failures.

$$MTBF = \frac{Total\ Measured\ Usage}{Number\ of\ Failures} \quad (1)$$

The OEM generally provides the MTBF of any item, but we can also calculate it by Equation 1. It can also be calculated by using Equations 2–4

$$\mu = k \times \lambda \times t \quad (2)$$

or

$$\lambda = \frac{\mu}{k \times t} \quad (3)$$

then

$$\text{MTBF} = \frac{1}{\lambda} \quad (4)$$

where μ is the total number of failures during the duration *t*,

k is the total number of components,

λ is the failure rate (reciprocal of the MTBF), and

t is the total mission duration or the total usage

We will be using Equation 2 for calculating the actual MTBF of the F414 engine at NAS Whidbey Island and compare it with the fleet average and the MTBF provided by the F414 Deputy Assistant Program Manager for Logistics.

c. *Operational Availability*

Jones (2006) described availability as “the probability that an item is in operable and committable state when called for at an unknown (random) time” (2006, pp.

10.1–10.6). In the military, the term A_o is used, which Jones defined as "the actual gauge of the availability of a system is the percentage of the time when under actual operating conditions it is available to perform its mission" (2006, pp. 10.1–10.6). A_o is calculated as shown in the Equations 5–7:

$$A_o = \frac{Mean\ Time\ Between\ Failures}{Mean\ Time\ Between\ Maintenance + Mean\ Downtime} \quad (5)$$

or

$$A_o = \frac{Uptime}{Uptime + Downtime} \quad (6)$$

or

$$A_o = \frac{Total\ Time - Corrective\ Maintenance\ Downtime - Preventive\ Maintenance\ Downtime}{Total\ Time} \quad (7)$$

A_o provides the percentage of systems in mission capable status as shown in Equation 8 and, therefore, it can be rewritten as

$$A_o = \frac{Number\ of\ Mission\ Capable\ Systems}{Total\ Number\ of\ Systems} \quad (8)$$

The efficiency of any system is measured in A_o. The Navy determines a desired level of reliability at which its aircraft should be maintained throughout the fleet; therefore, we will also calculate A_o before and after incorporating any changes in the existing repair cycle.

d. Calculating the Probability of Failure

In every decision made there is some form of risk analysis performed. MS Excel spreadsheets have the capability to calculate and display various distribution models. We used MS Excel in our analysis in estimating the distribution of the frequency of engine failure only due to afterburner failures in the following four scenarios:

- Status quo (46 aircraft): All Growler engines are sent to FRCW for repair, taking eight days for transportation to receive a replacement RFI engine.
- 46 aircraft and F414 engine test cell capability at FRCNW taking two days to repair an AB failure for spray bars, having the engine available for issue.
- 114 aircraft all Growler engines are sent to FRCW for repair taking eight days for transportation to receive a replacement RFI engine.
- 114 aircraft and F414 engine test cell capability at NAS Whidbey Island, taking two days to repair an AB failure for spray bars and have their the engine available for issue.

e. Spare Parts Quantity Determination

Maintaining any level of A_o requires a repair facility to possess spare parts in order to support corrective and preventative maintenance. The unavailability of a spare when needed results in defective/nonoperational equipment, resulting in loss of A_o. Spare parts are often costly in terms of capital; therefore, it is imperative that the number of spares required to achieve the desired level of A_o be calculated based on anticipated failures. Jones (2006) concluded,

> There is no magic formula that can be used to identify requirement of spares because there is no method of spare parts forecasting that can accurately predict the future. The only methods available use either past experience or statistical projections of future maintenance activity to estimate the anticipated number of spares that will be required for a given period of time in future. (2006, p. 18.1)

For the purpose of this project, we analyze FRCW's NALCOMIS data and apply various probabilistic statistical models while considering various factors, such as equipment usage, maintenance capabilities, age of the system, and so forth, affecting the outcome. To achieve the numbers as accurately as possible, appropriate safety-level quantities were also added to cater some margin of error.

f. Logistics Cycle Time Reduction

Logistics cycle time is a key element in determining the level of inventories to be maintained. Little's Law shows the relationship between time and inventory: As time elapses, more inventory is required. In modern concepts of logistics, time is considered money and can affect the A_o of an engine. The equation $I = R \times T$ is relevant because as the repair or cycle-time is reduced, less inventory is required, which leads to substantial dollar savings (where I = inventory, R = rate at which an item is delivered, and T = the time it takes to process the item).

In the current process, the defective engine is shipped from NAS Whidbey Island and transported to NAS Lemoore, while at the same time, an RFI engine is sent from NAS Lemoore to NAS Whidbey Island. The transportation time between the two naval air stations takes eight days on average. Modifying the engine test cell to run F414 engines and having limited AB module repair capability at FRCNW (keeping the repair time and testing time same at both stations) may enable Growler squadrons at NAS Whidbey Island to save 14 days of transportation time. We calculate the effect of this reduction on inventory, overall cost, and A_o of the engine.

g. Inventory Carrying Cost

The concept of inventory carrying costs explains the often-obscure costs associated with carrying inventory. Inventory costs can amount to substantial amounts of money and negatively impact the organization's financial position. For example, inventory that sits idle ties up capital investment, and generates extra labor and storage costs, which could have been utilized toward a more rewarding project or investment. In the LCC model we use an annual inventory carrying rates of 10% and 15% to show how this can change an organizations net present value.

h. Data Sources

The primary sources referenced in the following list were the informational base we used as we constructed this document. The persons referenced by title are the subject-matter experts in their particular fields or persons directly involved with the subject.

- PMA-265 Deputy Assistant Program Manager for Logistics supplied the reliability of the engine through the mean engine flight hours between removal/repair for the F414 engine and associated modules.
- Electronic Attack Wing's Analyst provided 2012's operating hours for the Growler in terms of RFT/RBA and the flight hours that were flown.
- FRCNW Database Administrator extracted our primary data from the Aviation Financial Analysis Tool and Deckplate databases.
- FRCW 400 Division Officer provided the division's monthly production report.
- FRCW 400 Division Production Control's Supervisor provided Deckplate data, the periodic maintenance information card section for the F/A-18E/F and EA-18G engines.

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V. ANALYSIS

This is the analysis of the present scenario of the repair and maintenance process of Growler engines at FRCNW. While analyzing the processes at FRCNW, we calculated the A_o of the Growler engine and certain costs that are associated with the repair of the F414 engine. We then present four different scenarios and calculated the frequency of potential stock outs related to an AB failure. We also calculated the impact of transportation time and protection level upon the spare engine pool at NAS Whidbey Island. The operation of the Growler and its engine is a very complex procedure; therefore we will be using certain assumptions to make the study conclusive and easier to understand.

A. ASSUMPTIONS

For the sake of simplicity and understandability, we made certain assumptions throughout the study:

- We are only concerned with the Growler's engines.
- There are two spare engines kept at NAS Whidbey Island for the Growler squadrons. It takes eight days to ship an RFI engine from NAS Lemoore to NAS Whidbey Island.
- FRCW is able to support the quantity of engines ordered by Growler squadrons, and there are no delays in terms of transportation.
- The infrastructure required for FRCNW's engine test cell is currently in place (the test cell for the J-52 engine).
- The only costs incurred are those particular to the F414 engine and additional manpower required.
- The various costs incurred upon operating an engine test cell will remain the same throughout the enterprise; whether it is run at FRCW or FRCNW.
- The Growler is fitted with two F414-GE-400 engines; in case of an engine failure, the aircraft is not mission capable.
- We are using the actual data of calendar year 2012, and the average number of flying hours per Growler will remain constant for years to come.

- There are 46 Growlers in the present scenario and this will increase to 114, which is the total number of aircraft at the completion of the acquisition process in year 2018 (increasing by 12 per year until 2018 where eight will complete the acquisition)
- The cost of the F414-GE-400 engine is about 3.7 million dollars.

B. CALCULATING THE ENGINE A_o IN PRESENT SCENARIO

A_o is considered to be the best possible measure for performance. Measuring the performance of the current repair/maintenance system, we calculated the actual A_o of the Growler's engine for the calendar year 2012 using actual engine failures and instances of stock outs. We plotted the engines that were ordered by the Growler squadrons and compared it with the NAS Whidbey Island's spare engine pool of two. With the assumption that Whidbey Island receives an RFI engine within eight days of an engine being ordered, we found that there were seven instances when three engine failures occurred within this eight day period, resulting in a stock out of an engine for one day. In order to find the Growler engine's actual A_o, we used Equation 9 based on the fore mentioned parameters.

$$A_o = \frac{(Number\ of\ Mission\ Capable\ Aircraft \times days\ of\ the\ year) - \#\ of\ engine\ instances\ of\ stock\ out}{Total\ Number\ of\ Aircraft \times days\ of\ the\ year} \tag{9}$$

$$A_o = \frac{(46 \times 365) - 7}{(46 \times 365)}$$

$$A_o = \frac{16,783}{16,790}$$

$$A_o = 99.95\%$$

This extremely high A_o is due to the fact that Growler is a new aircraft, and during the calendar year 2012 there were 30 engine failures. Of those 30 engine failures, 93.3% of the time, the squadrons were able to replace the defective engine with an RFI engine from the spare pool at NAS Whidbey Island. The seven instances comprises of the remaining 6.7% of the time squadrons were not able to replace the defective engine due to a stock out in the spare pool which resulted in an aircraft being non-operational.

C. CALCULATING THE PRESENT MEAN TIME BETWEEN FAILURES AT WHIDBEY ISLAND

From the actual set of data there were 30 occurrences of F414 engine failures at NAS Whidbey Island during the calendar year of 2012. We calculated that each Growler flew an average of 374.413 hours (17,223 budgeted hours during year 2012 divided by 46 aircraft) during the same period. Because there were 46 Growlers at NAS Whidbey Island, we can calculate the actual MTBF obtained for Growler's engine by using Equation 3.

$$\lambda = \frac{30}{(46 \times 2) \times \left(\frac{17,223}{46} \right)}$$

$$\lambda = \frac{30}{(92) \times (374.413)}$$

$$\lambda = 0.000871$$

$$as\ MTBF = \frac{1}{\lambda} = 1,148.2 \qquad (10)$$

The MTBF of the F414 engine for the entire fleet (including F/A-18 Super Hornet squadrons) is 582 hours, whereas the calculated MTBF for the Growler's engine is 1,148.2 hours as shown in Equation 10. The difference between the MTBFs can be attributed to the Growler's F414 engines being newer compared to the Super Hornets'. As the Growler continues to operate, their newer engines will become intermixed with the rest of the fleet's spare pool through the repair cycle, thus their engine MTBF will be lower and normalize to the fleet's MTBF.

D. CALCULATING THE AVERAGE NUMBER OF ENGINE FAILURES BY USING FLEET MEAN TIME BETWEEN FAILURES

If we calculated the average number of failures for the year using Equation 2, the fleet's MTBF of 582 hours (for 46 aircraft or k = 92 engines), and assuming annual flight hours per aircraft of 374.413 (17,223 budgeted hours divided by 46 aircraft), in Table 1 we calculated there would have been 60 failures, compared to the 30 actual occurrences during the year.

Table 1. Average Number of Engine Failures Using Fleet Mean Time Between Failures for 46 Aircraft

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
92	0.00171821	374.4130435	59.18556701

Similarly, in Table 2, with 114 aircraft (k = 228 engines), with the same number of average flight hours per aircraft, we calculated that there would have been approximately 147 engine failures during the year.

Table 2. Average Number of Engine Failures Using Fleet Mean Time Between Failures for 114 Aircraft

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
228	0.001718213	374.4130435	146.6772748

Our observations show that Growlers at NAS Whidbey Island have experienced an engine failure rate 50% below the fleet average. Again, this can be attributed to the Growler's newer engines.

E. CALCULATING THE ENGINE TRANSPORTATION COSTS IN THE PRESENT SCENARIO

Due to the non-availability of repair capability for Growler engines at FRCNW there is an incurred cost to send a defective engine to FRCW for repair. From the data obtained from NAS Whidbey Island's Aviation Supply Detachment it costs an average of $1,713.50 to transport an engine from NAS Whidbey Island to NAS Lemoore, equating to $3,427 round trip. On average, it takes eight days of travel time for the one-way trip. We assume that no matter where the defective engine is repaired, FRCNW or FRCW, all repair costs (other than transportation) will remain the same. Therefore, we can calculate that from the 30 actual defective engines that were experienced at NAS Whidbey Island during 2012, the shipping costs should have been \$102,810 and 480 days of transit time will occur. By using the present MTBF calculated in Equation 10 for NAS Whidbey Island, i.e., 1,148.2 hours, the forecasted engine failure using Equation 2, 114 aircraft will be 75 engines. This will increase the transportation costs to \$257,025 (75 engines × 3,427) and will encompass 1,200 days of transit time.

F. CALCULATING THE ENGINE TRANSPORTATION COSTS USING FLEET MEAN TIME BETWEEN FAILURE

Using the fleet's MTBF, we previously calculated in Table 1 the number of expected engine failures of 46 Growlers to have been 60. With 114 Growlers, the expected number of engine failures using the fleet's MTBF is approximately 147 shown in Table 2. As the Growlers' newer engines age, their MTBF will normalize to the fleet's average. This will also affect the transportation cost of engine repair as follows:

With current strength of 46 aircraft: 60 engines × \$3,427 (cost of transportation) = \$205,620 per year

With current strength of 114 aircraft: 1470 engines × \$3,427 (cost of transportation) = \$503,769 per year

G. IMPACTS OF TRANSPORTATION TIME UPON THE SPARE ENGINE POOL

1. Calculating the Number of Spare Engines for 46 Aircraft with a Four Days Transportation Time

By reducing the shipping time to seven days, when supporting 46 Growlers, A_o will improve but would not have an effect on the required number of spare engines. To reduce the number of spares engines from two to one would require turnaround (TAT) to be reduced to four days, which will lower our inventory. As shown in Equation 11, the mission duration time during the four days of shipping would equate to 4.1 flight hours (see Table 3).

$$\left(Mission\ duration = t = \left[\left(\frac{17,223}{46} \right) \div 365 \right] \times 4 = 4.103157 \right). \tag{11}$$

Table 3. Number of Spare Engines for 46 Aircraft with a Four Days Transportation Time

# of components	failure rate	flight hours per year	exp # of failures during the mission	
k	λ	t	μ=kλt	
92	0.001718213	4.103156641	0.648608954	
Protection Level	0.85		Required Spares	1

2. Calculating the Number of Spare Engines for 114 Aircraft with a Six Days Transportation Time

Similarly, having 114 aircraft and reducing TAT by two days would lessen the number of spare engines required from five to four. This reduction in spares will not have an effect on the A_o of the aircraft and but would reduce the total inventory required from five to four spare engines (see Table 4).

Table 4. Number of Spare Engines for 114 Aircraft with a Six Days Transportation Time

# of components	failure rate	flight hours per year	exp # of failures during the mission	
k	λ	t	μ=kλt	
228	0.001718213	6.154734961	2.411133284	
Protection Level	0.85		Required Spares	4

H. IMPACT OF PROTECTION LEVEL UPON THE SPARE ENGINE POOL

1. Calculating the Number of Spare Engines for 46 Aircraft with an 85% Protection Level

Being able to maintain a certain ready basic aircraft (RBA)/ready for tasking (RFT) requires a certain number of spare engines to be available at FRCNW. There are currently two spare engines on hand to support the Growler squadrons at NAS Whidbey Island. Utilizing the fleet's MTBF of 582 hours and 17,223 flight hours flown by the Growler during calendar year 2012, we can calculate the number of spare engines required at NAS Whidbey Island. Based on 17,223 flight hours in 2012, each of the 46 Growlers flew an average of 31.2 flight hours per month. The engine repair TAT is eight days, which is the transportation time between the two naval air stations. The mission duration as shown in Equation 12, during the TAT or t applied is 8.2 flight hours. The results of applying these values in a Poisson spare parts calculation formula, while assuming a protection level of 85%, are displayed below and in Table 5:

Total budgeted hours during 2012 = 17,223 hours

Number of aircraft = 46

Transportation Time = 8 days

$$\left(Mission\ duration = t = \left[\left(\frac{17,223}{46} \right) \div 365 \right] \times 8 = 8.206313 \right) \quad (12)$$

Table 5. Number of Spare Engines for 46 Aircraft with an 85% Protection Level

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
92	0.001718213	8.206313282	1.297217907
Protection Level	0.85		Required Spares 2

Table 5 validates the quantity of spare engines presently at NAS Whidbey Island as per the model. Due to newer engines of the Growlers, the actual achieved protection level for the spare engine pool at NAS Whidbey Island was 93.3%, higher than the target value.

2. Calculating the Number of Spare Engines for 46 Aircraft with a 90% Protection Level

Currently, there are 46 Growlers at NAS Whidbey Island. As shown in Table 6, if the Growler Wing decided to increase its protection level to 90%, an additional engine would be required at a cost of $3.7 million.

Table 6. Number of Spare Engines for 46 Aircraft with a 90% Protection Level

# of components	failure rate	flight hours per year	exp # of failures during the mission	
k	λ	t	μ=kλt	
92	0.001718213	8.206313282	1.297217907	
Protection Level	0.90		Required Spares	3

3. Calculating the Number of Spare Engines for 114 Aircraft with an 85% Protection Level

When the full complement of 114 Growlers are received and operational at NAS Whidbey Island, the number of spare engines (following the similar MTBF, flying hours and TAT) required to support an 85% protection level will increase to five (see Table 7).

Table 7. Number of Spare Engines for 114 Aircraft with an 85% Protection Level

# of components	failure rate	flight hours per year	exp # of failures during the mission	
k	λ	t	μ=kλt	
228	0.001718213	8.206313282	3.214844378	
Protection Level	0.85		Required Spares	5

4. Calculating the Number of Spare Engines with 114 Aircraft with a 90% Protection Level

Increasing the protection level from 85 to 90% with 114 Growlers, keeping the failure rate and mission duration as per the base case, would require an additional engine at a cost of $3.7 million (see Table 8).

Table 8. Number of Spare Engines for 114 Aircraft with a 90% Protection Level

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
228	0.001718213	8.206313282	3.214844378
Protection Level	0.90		Required Spares 6

I. EFFECTS OF LIMITED REPAIR CAPABILITY AND UPGRADING ENGINE TEST CELL UPON ENGINE SPARE POOL

1. Calculating the $\lambda_{effective}$ of AB Module

Using fleet MTBF when determining the failure rate of the F414 engine is correct; however, it is misleading to use the fleet's MTBF when calculating the failure rate of the Growler's AB module. Fleet MTBF is composed of not only engine discrepancies but also of scheduled maintenance. FRCW has the capability to perform MEIs on engines, replace modules, and perform AB repair. When a non-RFI engine is inducted at FRCW for repair, it is often the case that one or more modules other than the defective module the engine was turned in for will need replacement. This is attributed to other modules approaching their scheduled maintenance time. Because FRCNW would not have the capability to replace engine modules, $\lambda_{effective(AB)}$ should be used in lieu of fleet MTBF to calculate the failure rate of the Growler's AB. $\lambda_{effective(AB)}$ removes the scheduled maintenance portion of the Growler's AB's λ when calculating the failure rate. To calculate $\lambda_{effective(AB)}$, it is necessary to subtract the frequency of scheduled maintenance from the $\lambda_{(AB)}$, the AB module failure rate including scheduled maintenance. As discussed in the Planned Maintenance System Section, scheduled maintenance based on hours can be performed within a window of ± 10 % of the time at which the maintenance is due (Table 9). The AB Modules have an MTBF of 673 hours and a scheduled removal of 2,000 hours that are used to calculate $\lambda_{effective(AB)}$.

Table 9. Scheduled Maintenance Interval and Window for F414 Engine Modules

Module	**Scheduled Maintenance Interval (hours)**	**Lower Limit -10%**	**Upper Limit +10%**
Fan	2,000	1,800	2,200
HPC	1,700	1,530	1,870
Combustor	4,000	3,600	4,400
HPT	2,220	1,998	2,442
LPT	4,000	3,600	4,400
AB	2,000		

The formula and calculation of $\lambda_{effective(AB)}$ is displayed in Equation 13:

$$\lambda_{effective(AB)} = \lambda_{(AB)} - \lambda_{(AB\ scheduled\ \text{maintenance})} \tag{13}$$

or

$$\lambda_{effective(AB)} = \frac{1}{673} - \frac{1}{2000} = 0.00986$$

2. Calculating the Probability that Only AB Module Will Need to Be Replaced

Since FRCNW would only have limited repair capability for the AB Module, calculating the probability that no other modules would need replacement due to scheduled maintenance is required. Regardless if FRCNW has limited repair capability, the engine would still need to be sent to FRCW when any module is within their tolerances of schedule maintenance. The probability that the age of a particular module at any arbitrary point is less than the its lower limit as shown in Table 9 can be expressed as the lower limit divided by the upper limit. In this case, the particular module does not need replacement. Thus the probability that only an AB module fails and no other module is above the lower limit of its scheduled maintenance interval is the product of dividing the lower limit of the inspection interval by the upper limit for each module. The formula for calculating this probability (Pr) is shown in Equation 14.

Pr (Only AB module fails and no other module is above the lower limit of its schedule maintenance interval)

$$= \left(\frac{Fan\ lower\ limit}{Fan\ upper\ limit} \times \frac{HPC\ lower\ limit}{HPC\ upper\ limit} \times \frac{Combustor\ lower\ limit}{Combustor\ upper\ limit} \times \frac{HPT\ lower\ limit}{HPT\ upper\ limit} \times \frac{LPT\ lower\ limit}{LPT\ upper\ limit}\right) \quad (14)$$

$$= \left(\frac{1{,}800}{2{,}200} \times \frac{1{,}530}{1{,}870} \times \frac{3{,}600}{4{,}400} \times \frac{1{,}998}{2{,}442} \times \frac{3{,}600}{4{,}400}\right) = 0.366$$

This shows that there is a 36.6% probability that in case of an AB failure, no other module will need replacement due to having reached the lower limit of its scheduled maintenance interval. The remaining 63.4% of the time when an AB module fails, there will be at least one other module that needs replacement due to reaching the lower limit of its scheduled maintenance interval, in which case the engine will not be repaired at FRCNW.

3. Calculating the Frequency of AB Failures with 46 and 114 Aircraft

a. Excel Poisson Distribution Function

Utilizing Microsoft Excel, we used the Poisson distribution to calculate the frequency of AB module failures, which provided the number of engine failures attributed to the AB module. In the current scenario there are eight days of transportation time from when an engine is ordered by a Growler squadron till it is received from FRCW When FRCNW has an upgraded engine test cell there will be a two-day turnaround time, from the time an engine is faulty for a spray bar issue till it is RFI. A probability frequency chart was constructed to find the number of occurrences an AB will fail during each scenario. From these changes in frequency, we can argue whether an engine test cell would be worthwhile at FRCNW for the limited repair of the AB Module.

b. Building the Probability Chart

The probability chart was based on the $\lambda_{effective(AB)} = \lambda_{(AB)} - \lambda_{(AB\ scheduled\ \mathrm{maintenance})}$ (t is in terms of per day and multiplied by eight, to take into account the eight days of transportation from FRCW to replenish a non-RFI engine). By calculating the probabilities of the failures for each of the two scenarios (one for eight days and the other for two days), we applied the Poisson distribution to each of those failure rates. The distribution showed the number of engine failures due to the AB module during the turnaround time.

Tables 10 and 11 depict the probabilities of failures due to the AB module with 46 and 114 aircraft, respectively. In the current scenario (with 46 aircraft and eight days of transportation time) there is a probability of 76.1% that there are no failures, 20.8% there is one failure, 2.8% there are two failures, and less than 0.3% that there are three or more failures relating to the AB module. When the full complement of Growler aircraft are based at NAS Whidbey Island, the probability is 50.8% that there are no failures, 6.4% there is one failure, and less than 0.022% there are two or more failures relating to the AB module. In each table the two day scenarios reflect how the engine test cell would reduce the turnaround rate, thus increasing the operational availability of the engine. These probabilities assume that the other modules within the Growler engine do not fail or have schedule maintenance. We can only estimate that there will be an incremental improvement of the engine operational availability with an engine test cell.

Table 10. Frequency of AB Failures for 46 Aircraft

Failures	8 Days	2 Days
0	0.761192	0.934058
1	0.207706	0.063719
2	0.028338	0.002173
3	0.002578	0
4	0.000176	
5	0	

Table 11. Frequency of AB Failures for 114 Aircraft

Failures	8 Days	2 Days
0	0.508525	0.844458
1	0.343885	0.142764
2	0.116275	0.012068
3	0.02621	0.00068
4	0.004431	0
5	0.000599	
6	0.000001	
7	0	

4. Calculating Average Number of Engine Failures Due to Spray Bars in the AB Module

Using the Equation 2 , where λ is λeffective(AB), we calculated in Table 12 that there are 13 AB failures for 46 aircraft during one year. The calculations of k, , and t are shown in Equations 15- to 17.

$$k = 46 \times 2 = 92 \tag{15}$$

$$\lambda_{effective(AB)} = \left(\frac{1}{673} - \frac{1}{2000}\right) \times 0.366 = 0.0003608 \tag{16}$$

$$t = 17{,}223 \div 46 = 374.4130435 \tag{17}$$

Table 12. Average Number of Engine Failures Due to AB Module for 46 Aircraft

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
92	0.000360834	374.4130435	12.42927353

From the NALCOMIS data, we derived that 66.61% of AB module defects were attributed to main spray bars we multiplied the fleet's spray bar failure rate of 66.61% to the λ calculated in Table 12. Using Equation 18, we derived $\lambda_{effective(AB)\text{ with spray bar failure}}$. The new calculations are shown in Table 13.

$$\lambda_{effective(AB)\text{ with spray bar failure}} = \lambda_{effective(AB)} \times \text{AB}\ (\textit{SprayBarFailure}\text{ Probability}) \tag{18}$$

$$\lambda_{effective(AB)\text{ with spray bar failure}} = \left\{\left[\frac{1}{673} - \frac{1}{2000} \times 0.366\right] \times 0.6661\right\} = 0.000240351$$

Table 13. Average Number of Engine Failures Due to Spray Bars for 46 Aircraft

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
92	0.000240351	374.4130435	8.279139099

Table 13 shows that about nine engines (8.3 was rounded up) per year would be affected by spray bar related issues in the AB module. If FRCNW were to receive limited repair capability and an upgraded engine test cell, these nine engines could be repaired.

We recalculated for 114 aircraft $(k = 114 \times 2 = 228)$ in Table 14, while keeping λ and t the same as in Table 13 and found that on average 21 engine failures per year would be attributed to defective spray bars in the AB module. These 21 engines could be repaired by FRCNW.

Table 14. Average Number of Engine Failures Due to Spray Bars for 114 Aircraft

# of components	failure rate	flight hours per year	exp # of failures during the mission
k	λ	t	μ=kλt
228	0.000240351	374.4130435	20.51786646

5. Calculating the Cost of Transportation for Engines Having AB Module (Main Spray Bar) Defects

To calculate the number of Growler ABs affected by spray bar related issues, under the present scenario of 46 aircraft, we calculated in Table 13 that there would have been approximately nine AB failures attributed to defective spray bars in AB modules. The cost of transportation would be $30,843 per year $(\text{nine engines} \times \$3{,}427 \text{ transportation cost of an engine})$. With the full complement of 114 aircraft, there would be 21 engine failures attributed to defective spray bars in AB modules. The cost of shipping 21 engines (round-trip) between the two naval air stations would be $71,967 per year $(21 \text{ engines } \times \$3{,}427 \text{ transportation cost of an engine})$.

6. Calculating the Cost of Upgrading FRCNW's Engine Test Cell

On April 30, 2012, a site survey was conducted to analyze the requirements needed to run F414 engines at FRCNW. Taking into account common equipment already in place, the equipment cost of upgrading the engine test cell would be approximately $500,000. Currently, there are no personnel qualified to run this engine at FRCNW, and it is assumed that the test cell will need additional manpower. The costs are broken down in Tables 15 and 16:

Table 15. F414 Test Cell Operator Annual Allowances and Costs

Billets for the Navy Enlisted Classification Code 6422 (Test Cell Operator) Cost			
Pay Grade	Allowance	Annual DOD Composite Rate	Total Cost
AD3 (E-4)	3	$ 66,402.00	$ 199,206.00
AD2 (E-5)	2	$ 81,880.00	$ 163,760.00
ADC (E-7)	1	$ 109,814.00	$ 109,814.00
			$ 472,780.00

We used the DoD Military Personnel Composite Standard Pay and Reimbursement Rates for FY 2013 (SECDEF 2012) from the Office of the Under Secretary of Defense to calculate each operators cost.

Table 16. F414 Test Cell Equipment Costs

Fleet Readiness Center Northwest Test Cell Equipment Costs	
Nominclature	Cost
Peculiar Support Equipment	$ 298,000.00
Software Upgrade	$ 100,000.00
Vibration Card	$ 30,000.00
Modification of Fuel Lines	$ 12,000.00
Engine Correlation	$ 60,000.00
Total	$ 500,000.00

From the figures we gathered from FRCNW, we itemized the cost of upgrading the engine test cell. As shown in Table 16, the one-time test cell equipment upgrade cost would be $500,000. We also assumed that $50,000 per year would be required to operate and maintain the test cell equipment. An initial training cost of $2,300 per operator will be incurred upon upgrading the engine test cell. Additional operators will be able to qualify through on-the-job training at FRCNW.

J. LIFE-CYCLE COST AND EFFECTS ON OPERATIONAL AVAILABILITY OF THE GROWLER AFTER MODIFYING FRCNW'S ENGINE TEST CELL

The LCC analyzes the financial aspects of upgrading FRCNW's engine test cell to be configured to run F414-GE-400 engines. Prior to the test cell being upgraded, the Ao of the Growler engine was 99.95%. Assuming that FRCNW acquired test-cell capability for the F414, we constructed an Excel spreadsheet covering a 30-year timespan to compute basic net present value. We assumed that there would be an incremental increase to the Growler inventory by 12 aircraft per year until fiscal year (FY) 2018, when the final eight aircraft would be delivered and complete the 114 aircraft acquisition (see Tables 19–20). We also assumed the failure rates in terms of the AB module to remain with the fleet's averages (see Table 18).

For this type of internal government investment, we used the real capital discount rate of 1.1% per year promulgated by the Office of Management and Budget through Circular A-94 (OMB 2012). This 1.1% represents the real Treasury borrowing rate, the difference between the nominal interest rates of 3.0% on treasury notes and bonds and an inflation rate of 1.9% for the FY 2013.

The engine carrying cost is another factor that we considered in terms of cost avoidance for FRCNW having an engine test cell. To calculate the number of engines in the spare pool without the engine test cell, we used Excel with Visual Basic Application of the Poisson distribution to find the average number of expected failures during the transportation time of eight days using λ_{engine} (as we did in Table 1) with a protection level of 85%. We then calculated the number of engines the spare pool should have once able to perform limited repairs to the AB and having the engine test cell upgraded. The parameters of the calculations were the same except for the λ (which is shown in Equation 19). The difference of engines in the spare pool shows a potential savings in terms of being able to decrease the engine pool size. We used 10% and 15% of the engine's value to compute the annual engine carrying cost, which was only applied when we were able to save an engine from the inventory at FRCNW as shown in Table 17.

$$\lambda = \lambda_{engine} - \lambda_{effective(AB)\text{ with spray bar failure}} \quad (19)$$

$$\lambda = \left[\frac{1}{582} - \left(\left\{\left[\frac{1}{673} - \frac{1}{2000}\right] \times 0.366\right\} \times 0.6661\right)\right] = 0.00148$$

Table 17. Engine Carrying Avoidance

Engine Carrying Cost				
	Number of Engines in the Spare Pool		Engine Carrying Cost	
No of A/C	Without Test Cell	With Test Cell	10%	15%
58	3	3	$ -	$ -
70	3	3	$ -	$ -
82	4	3	$ 370,623	$ 555,935
94	4	4	$ -	$ -
106	5	4	$ 370,623	$ 555,935
114	5	4	$ 370,623	$ 555,935

To calculate the amount of expected Growler engine failures in future years, we used Equation 2, assuming the AB's MTBF remained at 673 hours and the mission duration of a Growler was 374.41 flight hours annually. The following example shows this calculation for 2013 (see Table 18):

$$k = 58 \text{ aircraft} \times 2 \text{ engines} = 116 \text{ engines at NAS Whidbey Island} \quad (20)$$

$$\lambda_{effective(AB)} = \left(\frac{1}{673} - \frac{1}{2000}\right) \times 0.366 = 0.0003608 \quad (21)$$

$$t = \frac{17,223}{46} = 374.41 \text{ annual flight hours per aircraft} \quad (22)$$

$$\mu = 116 \times 0.0003608 \times 374.41 \approx 15.671 \text{ engines failed due to the AB only} \quad (23)$$

$$\text{Spray Bar issues} = 15.671 \times 66.61\% \approx 11 \text{ engines failed due to the spray bar issue only} \quad (24)$$

Table 18. Annual F414 AB Spray Bar Failures

	A/C	Engine	AB Failure	LMainSpray
2013	58	116	15.6717	11
2014	70	140	18.9141	13
2015	82	164	22.1565	15
2016	94	188	25.399	17
2017	106	212	28.6413	20
2018	114	228	30.803	21
2019 - 2041 are same numbers				
2042	114	228	30.803	21

The Life Cycle Cost Models depicted in Tables 19–20 display a 30 year time-span. We assumed the Prowlers would have been phased out at the completion of the Growler's transition in FY 2018. We also estimated an additional operations and maintenance cost of $50,000 once the Prowlers were phased out to keep the engine test cell functional. We used Table 18's spray bar failures as the number of engines that would be repaired at FRCNW. These engines would also have an effect on transportation cost avoidance of $3,427 per an engine's round trip. Table 15's figures were used for the additional personnel cost to operate the upgraded engine test cell. It is estimated that it would cost $2,300 per operator for the initial training. With six personnel as show in Table 15, this cost would be $13,800. Table 16's total cost was used for the initial capital investment. Table 17 shows how the engine cost avoidance was calculated. With all these calculations, we are able to determine if the project of upgrading the engine test cell at FRCNW is a worthwhile venture.

Table 19. Life-Cycle Costs at an Engine Carrying Rate of 10%

Engine Carrying Cost of 10%								
Life Cycle Cost Worksheet	Discount Rate %:	1.1%	Engines Repaired at FRCNW					
Net Present Value: -$3,459,663		11	13	15	17	20	21	21
Number of Aircraft		58	70	82	94	106	114	114
YR	0	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18 ...	FY 42
Initial Training	$13,800							
Capital Investment	$500,000							
Upkeep Cost							$50,000	$50,000
R&D, O&M, and other costs								
Personnel		$472,780	$472,780	$472,780	$472,780	$472,780	$472,780	$472,780
Revenue/Savings								
Transportation Cost (savings)		$37,704	$44,559	$51,414	$58,269	$68,552	$71,979	$71,979
Engine Cost Avoidance		$0	$0	$370,623	$0	$370,623	$370,623	$370,623
Acquistion & Capital Investment	$513,800	$0	$0	$0	$0	$0	$50,000	$50,000
R&D, O&M, and other costs		$472,780	$472,780	$472,780	$472,780	$472,780	$472,780	$472,780
Revenue/Savings		$37,704	$44,559	$422,037	$58,269	$439,175	$442,602	$442,602
Net Cash Flow	-$513,800	-$435,076	-$428,221	-$50,743	-$414,511	-$93,729	-$80,178	-$80,178
Year-->	0	1	2	3	4	5	6 ...	30

Table 19 shows the yearly net cash flow is a negative number, resulting in the net present value (NPV) being approximately a negative three-and a half million dollars. Table 19 uses an engine carrying cost of 10% while keeping the transportation and personnel costs constant over the 30-year period. Using the NPV Decision Rule, we determined this project is not worth investing in due to a negative NPV.

Engine Carrying Cost of 15%								
Life Cycle Cost Worksheet	Discount Rate %: 1.1%		Engines Repaired at FRCNW					
Net Present Value: **$666,298**		**11**	**13**	**15**	**17**	**20**	**21**	**21**
Number of Aircraft		58	70	82	94	106	114	114
YR	**0**	**FY 13**	**FY 14**	**FY 15**	**FY 16**	**FY 17**	**FY 18 ...**	**FY 42**
Initial Training Cost	$13,800							
Capital Investment	$500,000							
Upkeep Cost							$50,000	$50,000
R&D, O&M, and other costs								
Personnel		$472,780	$472,780	$472,780	$472,780	$472,780	$472,780	$472,780
Revenue/Savings								
Transportation Cost (savings)		**$37,704**	**$44,559**	**$51,414**	**$58,269**	**$68,552**	**$71,979**	**$71,979**
Engine Cost Avoidance		**$0**	**$0**	**$555,935**	**$0**	**$555,935**	**$555,935**	**$555,935**
Acquistion & Capital Investment	$513,800	$0	$0	$0	$0	$0	$50,000	$50,000
R&D, O&M, and other costs		$472,780	$472,780	$472,780	$472,780	$472,780	$472,780	$472,780
Revenue/Savings		$37,704	$44,559	$607,349	$58,269	$624,487	$627,914	$627,914
Net Cash Flow	-$513,800	-$435,076	-$428,221	$134,569	-$414,511	$151,707	$105,134	$105,134
Year-->	**0**	**1**	**2**	**3**	**4**	**5**	**6 ...**	**30**

Table 20. Life-Cycle Costs at an Engine Carrying Rate of 15%

In Table 20, we recalculated the Life Cycle Cost Model using a 15% engine carrying cost in terms of a sensitivity analysis. While the yearly net cash flow was mostly positive, the net NPV result was a minuscule positive number. We used the NPV Decision Rule again to determine if the project would be viable. Although the NPV was positive, we determined this project to be not worthy of investment because the engine failure rates are overestimated since the Growler engines are still relatively new. Thus the actual costs expected should be lower than we have used in this analysis.

VI. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

In this chapter, we present the results of the analysis, recommendations, and areas for further research. The research question of the project was, Should FRCNW gain limited repair capability for the F414-GE-400 engine, including updating its existing engine test cell? We analyzed the present scenario at FRCNW, without the limited repair capability and engine test cell, and then simulated a scenario where FRCNW was provided with limited repair capability and an updated engine test cell. Both of the scenarios were then compared in terms of availability of engines in the spare engine pool.

A. RESULTS

1. Calculating the Number of Engine Failures Due to Spray Bar Issue in the AB Module

As the research question is regarding providing limited repair capability and updating the existing engine test cell, enabling FRCNW to repair the spray bars in AB module, we calculated the number of engines that will be affected by said issue. Our calculations show that in the present scenario (with 46 Growlers), an average of nine engine failures per year will be attributed to spray bar issues in the AB module. Once the number of Growlers reaches 114, our calculations show an average of 21 engine failures per year will be attributed to spray bar issues in the AB module.

2. Calculating the Number of Spare Engines

We calculated the number of spare engines required in the present scenario (using fleet MTBF) and validated the two spare engines currently held at NAS Whidbey Island, considering a protection level of 85%. The same process was repeated for the scenario of 114 Growlers operating at NAS Whidbey Island. The result of this calculation using fleet MTBF suggested that five spare engines would be required, once operating at the full planned complement. This calculation was important to determine, if we can reduce the number of engines in spare pool and reduce the inventory carrying cost.

With 46 aircraft, by adding an additional engine to the spare engine pool, a maximum protection level of 95% could be achieved at a cost of $3.7 million. For 114 aircraft, five spare engines would provide a protection level up to a maximum of 89%. By adding an engine to the spare pool, a maximum protection level of 95% could be achieved at a cost of $3.7 million. Similarly, we calculated the effect of reduction in transportation time on the spare engine pool. By reducing the transportation time from eight to four days for 46 aircraft, we were able to reduce the spare engine pool by one engine. For 114 aircraft, to reduce the spare engine pool by one engine would require a reduction in transportation time by two days.

3. Calculating the Transportation Costs

We calculated the transportation costs for both the scenarios (FRCNW with and without limited repair capability for the F414 engine, including updating the existing engine test cell). It costs $3,427 to transport an F414 engine round trip between NAS Whidbey Island and NAS Lemoore. The transportation costs for nine engines per year (equating to $30,843 per year) could be saved after providing FRCNW of limited repair capability for the Growler's F414 engine, including updating the existing engine test cell. For the full complement of 114 Growlers, the savings will be for 21 engines per year (equating to $71,967 per year). Based on the data and our assumptions, it costs $500,000 (in acquisition costs) and $13,800 for initial training to upgrade FRCNW's existing engine test cell. The proposal limited F414 engine test cell also requires the additional manpower cost of $472,780 per year.

4. Calculating the Life-Cycle Costs of Upgrading FRCNW's Engine Test Cell and Providing Limited F414 Engine Repair Capability

We computed LCC calculation over a 30-year life-cycle, beginning with 58 Growlers in FY 2013, and increasing at a rate of 12 aircraft per year until FY 2018 using the real capital discount rate of 1.1%. We assumed that transportation and personnel costs would remain constant and estimating $50,000 as an upkeep cost for the engine test cell, beginning in FY 2018 through FY 2042. When examining the LCC Models and evaluating their NPVs, the choice of having an engine test cell at FRCNW is not a sound decision because the Growler's engine are relatively new, resulting in a higher operational availability. As the additional Growlers join the fleet, their MTBF will continue to be above the fleet's average for a considerable amount of time. While our calculation for the LCC were based on the fleet's F414 engine MTBF and thus overstates the costs that would be incurred.

5. Probability of Afterburner Failures and Effects on FRCNW's Spare Engine Pool

The spare engine pool is stocked based upon the MTBF of the entire engine. Since the AB is one of six modules that comprise the Growler engine, when looking at Tables 10 and 11, reducing the repair time of the AB module will have a minimal effect on the spare engine pool. Thus it is hard to estimate how much utility an engine test cell would add to the repair process.

B. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of our analysis, we do not recommend providing FRCNW with limited repair capability (i.e., enabling FRCNW to repair the spray bars in AB module) for the Growler's F414 engine, or updating the existing engine test cell. The reasons/arguments for this recommendation are listed below.

1. Additional Operating Costs versus Engine Carrying Avoidance

In Chapter V, we calculated an annual operating cost of $472,780 (which will increase to $522,780 beginning FY 2018) for FRCNW's upgraded engine test cell. When we calculated our LCC using a 10% annual engine carrying cost, it resulted in a negative NPV hence it was not considered. When we utilized an engine carrying cost of 15%, the result was a positive NPV of $666,298 during a 30 year period. However, the engine carrying avoidance was not fully experienced (meaning a positive net cash flow) until FY 2017 and continued till FY 2042. This means that the operations and maintenance costs were not off-set by the engine carrying avoidance until FY 2017. While the NPV is positive it is not recommended for FRCNW to invest additional resources to gain a minimal return on investment.

2. Effect on the Number of Spare Engines Required

During our analysis, we calculated the number of spare engines required and whether we could reduce the number of engines by incorporating the proposed limited repair capability. We concluded that one engine could be reduced from the spare pool without a loss of valuable protection level when upgrading the engine test cell. The reduction of an engine from the spare pool will result in monetary savings because the enterprise will have to purchase fewer replacement modules/engines in the future. However, the fleet-wide effect of reducing one spare engine from NAS Whidbey Island's spare pool will be relatively small to the overall enterprise. Therefore, upgrading the FRCNW engine test cell is not recommended.

3. Concept of Fleet Readiness Center/Center of Excellence and Centralized versus Decentralized Facilities

Providing limited F414 engine repair capability at FRCNW does not match the NAVAIR concept of FRCs/Centers of Excellence. This concept, implemented in 2006, integrated the ashore IMA and the depot as one repair facility. The current process enables FRC personnel to examine an engine irrespective of defective module. This inspection allows for the replacement of any approaching high time components and repair of any discrepancies identified during the major engine inspection (MEI). Providing FRCNW with limited repair capability of the AB module would allow them to interdict spray bar–related issues; however, they would not have the capability to perform MEIs and thus miss discrepancies that otherwise would have been corrected. Adding limited AB module repair capability at FRCNW would result in maintenance being duplicated at FRCW.

The FRC concept is also in line with established business theory regarding centralized versus decentralized facilities. Utilizing centralized facilities, such as FRCW, results in lower safety stocks and overhead while greater economies of scale can be taken advantage of. The disadvantages of centralized facilities are longer lead-times and increased transportation costs. In our study, these disadvantages do not outweigh the advantages.

C. AREAS OF FURTHER RESEARCH

The objective of this project was to make a recommendation for or against providing limited engine repair capability pertaining to the AB module at FRCNW. We proposed a scenario that analyzed limited repair capability at FRCNW to include upgrading the engine test cell to run the F414 engine. We sought to determine whether providing limited repair capability would positively or negatively affect the readiness of the Growler's engines at NAS Whidbey Island. The results from our scenario showed that it was neither cost effective nor beneficial to the spare engine pool to provide FRCNW with such capability. The number of aircraft at which it could make sense was not considered because only 114 aircraft are to be stationed at NAS Whidbey Island. While performing the project, we came across certain areas, which required further research. Due to the limited scope of our project, we did not analyze these areas, but they are recommended for further research. Some of the key areas are outlined in the following subsections.

1. Bottleneck at FRC Southeast Located at NAS Jacksonville, FL

A bottleneck is an important concept, which might have a major impact on possible improvements in the repair process of the F414 engine. To maximize the output of any system, the bottleneck must be identified as early as possible so that maximum resources can be directed to clear it. Jacobs, Chase and Aquilano (2009) illustrated this concept as the production resource capacity that limits the capacity of the overall process. A bottleneck controls the capacity of the entire system (Jacobs et al., 2009, pp. 164–165).

The Growler's engine repair process consists of the squadrons operating at NAS Whidbey Island, the I-level repair facility located at NAS Lemoore, CA, and the D-level repair facility (for the modules) located at NAS Jacksonville, FL. While answering the research question, we found the depot located at NAS Jacksonville as the bottleneck in the repair process of F414 engine. The depot takes on average 60 days (plus the transportation time) to repair the defective modules sent from NAS Lemoore.

In order to reduce the TAT of an F414 engine, the module repair process at NAS Jacksonville needs improvement. A thesis/project is recommended to study the current module repair process and suggest improvements, which will result in reducing the TAT and improvement in Ao of both the Super Hornets and Growlers engines.

2. Re-examination of This Study Following Delivery of the 114th Growler

When the final Growler is delivered, presently scheduled for FY 2018, we recommend that the research question be re-evaluated using future NAE practices. The evolution of naval aviation has produced the FRC/Center of Excellence concepts. It can be expected that these practices can further evolve into a set of practices designed to meet future naval aviation goals. Results of this study could be refuted or validated with these future parameters.

D. SUMMARY

This project introduced an issue of providing FRCNW limited repair capability for the Growler's engine, including updating the existing engine test cell. We provided vital background information, coupled with a literature review, to better understand the issue. We presented the concepts/techniques used to analyze the issue in Chapter IV, followed by a detailed analysis of the research question. We further summarized and discussed the results/findings of the analysis in this chapter, along with recommendations based upon the calculations and observations.

We concluded that FRC West is providing F414-GE-400 engine repair to the fleet as per the concept of FRC/Center of Excellence and is meeting the objective. The Growler aircraft and its engines are relatively new, therefore, experiencing higher MTBF as compared to the fleet. As elapsed flight hours increase, the MTBF of the Growler's engines will merge with the MTBF of the fleet's F414 engines. Providing FRCNW with limited repair capability for the F414-GE-400 engine, including updating the existing engine test cell, will cost not only the acquisition cost but also an annual operating cost. The monetary effect of upgrading FRCNW's engine test cell in terms the engine carrying cost was established to fully explore the NPV of the project. It was determined there will be a relatively small positive effect upon Ao of the Growler's engine. The Growler's engine will be able to maintain a higher A_o for a longer duration in the present repair process due to their higher MTBF and continuous induction of new aircraft and engines until FY 2018. Considering all of the above factors and the concept of FRCs, we do not recommend providing limited repair capability or updating the existing engine test cell at

FRCNW. In the end, we have suggested some key areas for further research which will affect the Ao of both the Growlers and the aging Super Hornets.

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