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THESIS

COST SAVINGS ASSOCIATED WITH THE LV 100-5 TANK ENGINE

by

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The LV 100-5 turbine engine is the replacement for the AGT 1500 engine in the Abrams Main Battle Tank. The AGT 1500, produced with the Abrams in 1980, has now aged to the point where the engine costs exceed 60% of the total operations and support costs for the tank itself. In looking for a new engine, the Army also looked to improve the notoriously poor fuel economy associated with the Abrams. Besides the tremendous reliability and maintenance improvements, the LV 100-5 is designed to be over 25% more fuel-efficient during movement and 50% more efficient at idle than the AGT 1500. Prototypes of the LV 100-5 are due in May 2002 with full-rate production beginning in 2003.

The objective of the thesis is to accurately determine the savings in gallons and dollars by this significant reduction in fuel usage. Research includes a detailed analysis of the LV 100-5 engine and a comparison to its predecessor, the AGT 1500, followed by the analysis of savings in a combat scenario and its life cycle. The information collected in this thesis provides further information for the Abrams Project Manager in his cost/benefit analysis.

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COST SAVINGS ASSOCIATED WITH THE LV 100-5 TANK ENGINE

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ABSTRACT

The LV 100-5 turbine engine is the replacement for the AGT 1500 engine in the Abrams Main Battle Tank. The AGT 1500, produced with the Abrams in 1980, has now aged to the point where the engine costs exceed 60% of the total operations and support costs for the tank itself. In looking for a new engine, the Army also looked to improve the notoriously poor fuel economy associated with the Abrams. Besides the tremendous reliability and maintenance improvements, the LV 100-5 is designed to be over 25% more fuel-efficient during movement and 50% more efficient at idle than the AGT 1500. Prototypes of the LV 100-5 are due in May 2002 with full-rate production beginning in 2003.

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I. INTRODUCTION

A. BACKGROUND

The Abrams tank is the Main Battle Tank (MBT) for the United States Army. It provides heavy armor superiority on the battlefield by destroying enemy forces on the battlefield using mobility, firepower and shock-effect.

> The 120mm main gun on the M1A1 and M1A2, combined with the powerful AGT 1500 horsepower turbine engine and heavy armor, make the Abrams tank capable of attacking or defending against large concentrations of heavy armor forces. Other features of the M1A1 include a rugged suspension system and a Nuclear, Biological and Chemical protection system. The M1A2 variant includes a Commander's Independent Thermal Viewer, an Improved Weapon Station, position navigation equipment, a distributed data and power architecture, embedded diagnostic system, and an improved fire control system. A radio interface unit allows the rapid transfer of digital situational data and overlays to compatible systems anywhere on the battlefield. (GDLS, 2001)

Production of new Abrams for the U. S. Army is complete. Instead of new production, the Army has a requirement to upgrade over 1,100 older M1 tanks to the M1A2 configuration. A multiyear procurement for 600 M1A2 upgrades, awarded in July 1996, are in their fifth year of deliveries. Further M1A2 improvements, called the Systems Enhancement Package (SEP), are underway.

> These enhance the M1A2 digital command and control capabilities, and add a second generation forward looking infrared system to the gunner and commander thermal sights. An under armor auxiliary power unit, new computer mass memory unit, color maps and displays are included in the enhancement package. (GDLS, 2001)

In addition to upgrades to the M1A2 SEP, the Armor community must also upgrade its Legacy Force to communicate and effectively maneuver with the M1A2 SEP force. In order to do so the Army is upgrading the rest of its M1A1 force to the M1A1D through the Abrams Integrated Management Program for the 21st Century (AIM XXI). AIM XXI is a refurbishment program for M1A1 tanks not being upgraded to the M1A2 configuration. Under AIM XXI, the M1A1 tanks are completely disassembled and overhauled into “like new” condition.

B. PURPOSE

In the next set of upgrades to the M1A2 and M1A1D, the Army is pursuing a program whose objectives are to develop a propulsion system/power-pack (power-pack refers to an engine that is integrated with a transmission) solution, which:

> Significantly reduces the Operations and Support (O&S) cost burden of the Abrams Tank equipped with the existing AGT 1500 engine. The Army specifically established a long-term funding stream for the development, integration, production, and application of an Abrams Tank Propulsion System solution targeted at reducing the O&S burden of the existing system by obtaining a significant net savings. This program could have enormous implications for the Army in the long term because it could help save hundreds of millions of dollars in O&S costs. The tank engine is responsible for about two-thirds of the vehicle O&S costs. (Ogorkiewicz, 2001)

As noted in the quote above, the Army's primary reason for upgrading to a new engine is to combat the rising operations and support costs. The M1's current AGT 1500 gas turbine engine is the top cost driver for the tank program, making up some "64 percent of its overall sustainment costs." (ST 101-6, 2001)

In September 2000, the team of Honeywell and General Electric was selected to fully design and develop the LV 100-5 engine for the Abrams-Crusader Common Engine (ACCE) program under a $195.6 million contract. Once developed, the cost for fielding all required engines is expected to exceed three billion dollars. The Honeywell-GE team will replace Honeywell's AGT 1500 gas turbine engine in the Army's M1 Abrams tanks and Caterpillar's Perkins CV 12 diesel engine in the Crusader self-propelled howitzer.

The Army's Crusader program sought a new engine to help reduce overall weight in the system to make it more deployable and the LV 100-5 offers significant weight savings from the CV 12 diesel engine originally proposed.

At least 2,845 M1 tanks, including all active component tanks, are to be covered by the ACCE program. Production of new engines for the Abrams is currently expected to start in FY 03 and run eight years.

As previously noted, engine-related items account for 64% of the O&S costs in the Abrams fleet. One of these components is fuel usage. One of the criteria for the new engine was that it had to be more fuel-efficient than the AGT 1500. The spokesman for Honeywell's Defense and Space division, Phoenix, said that the LV 100-5 engine is up to 30 percent more fuel efficient during movement and 50 percent more efficient at idle than the current AGT 1500. A primary factor in the increased fuel economy is through the use of an advanced full-authority digital engine control unit. (Heydrich, 2001)

A significant improvement in fuel economy may reduce the costs of supplying a tank battalion. A Force XXI Tank Battalion in offensive operations under current doctrine requires almost 43,000 gallons of JP-8 fuel per day. A current Forward Support Battalion (FSB) quartermaster unit owns eleven 5,000-gallon tankers to support a maneuver Brigade with fuel. These FSB assets provide support to the battalion’s twelve 2,500-gallon organic Support Platoon tankers. Manpower and materiel costs can be reduced by the adoption of the more fuel-efficient LV100-5 engine.

C. RESEARCH QUESTIONS

The primary research question of this thesis is:

What is the effect of a 25-30% fuel savings from the LV 100-5 M1A2 tank engine on the logistical support of the M1A2 tanks in a combat and life cycle scenarios and how might this effect overall force structure at Brigade level?

Secondary research questions include:

1. What are the histories and specifications of the AGT 1500 and LV 100-5 engines?

2. What is the true cost of delivery and handling of fuel and what are the logistical support requirements in various scenarios?

3. What are the cost savings and other benefits obtained by upgrading to the LV 100-5 engine?

D. SCOPE

This thesis includes: (1) an overview of the M1A1/M1A2 program, (2) an estimate of the true cost to handle and deliver fuel, (3) a study of logistics required to support a battalion of M1A1/M1A2 tanks in training and combat environments, (4) an analysis of the possible cost savings achieved by moving to a more fuel-efficient engine, and (5) a study of the effects of a significant fuel savings on the logistics tail of a Tank Battalion. The thesis will conclude with an estimate of total savings in various environments and suggestions for further improvements to the system.

E. METHODOLOGY

The thesis research consisted of the following steps:

1. An extensive literature search of books, magazine articles, Unit SOPs, CD-ROM systems, and other library information resources.

2. A thorough review of the current, AGT 1500, engine.

3. A review of the new, LV 100-5, engine and examine the physical components that comprise the system.

4. A study of the "true cost" of handling and delivering fuel in various scenarios.

5. A study of the logistical support required to support a battalion of M1A1 / M1A2 tanks.

6. An evaluation of the new engine in a three-week combat scenario based on current data. Project the results of these data to their effect on logistical support.

7. An evaluation of the possible cost savings associated with a move to a more fuel-efficient tank engine in various scenarios.

8. A summary of the benefits of implementing the new engine.

F. ORGANIZATION OF THE STUDY

Chapter I, Introduction, outlines the status of the Abrams tank program and why there is a need for a new tank engine. In addition, this chapter outlines the primary and secondary research questions, the study's scope and methodology, and presents an overview of the thesis.

Chapter II, Background, provides an overview of the M1 tank and the two respective engines.

Chapter III, Data, provides the physical combat logistics support requirements and support unit costs needed to sustain a Tank Battalion. Further data analyze these support requirements under combat and life cycle scenarios. It also includes estimates of the cost to deliver and handle fuel in various scenarios.

Chapter IV, Analysis, looks at the amount of POL used from Chapter III to support a combat and life cycle scenarios and estimates the possible cost savings with the new engine. The analysis continues with a look at the gallons of fuel saved to find if a change in MTOE is required to reflect the change in need.

Chapter V, Conclusions and Recommendations, summarizes the findings and states the research limitations. Finally, recommendations for further study are offered.

G. EXPECTED BENEFITS OF THIS THESIS

This study will provide information and supporting documentation requested by the M1A2 Project Manager on the effectiveness of this sort of fuel efficiency on the entire logistics system. This will serve as a means for justifying certain expense or requesting further improvements.

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II. BACKGROUND

A. THE M1A1 / M1A2 TANK

1. Overview

This portion of the thesis is to provide all readers with a brief orientation to the M1 tank, and related variants, to have a point of reference before discussing the tank's engine. The M1A1 is the Main Battle Tank of the US Army and the US Marine Corps. The M1A1 armed with the Rheinmetall-designed 120-mm smoothbore gun "is possibly the best (and most expensive) combination of firepower, mobility, and protection of any tank in Western service." (USAF Cadre Studies, 1996) The M1's performance in Operation Desert Storm demonstrated a "convincing superiority over the export variant of the Soviet-designed T-72 as well as greater reliability and mobility than had been predicted by many analysts." (USAF Cadre Studies, 1996) The following paragraphs will summarize the tanks capabilities in terms of fire control, mobility, and survivability.

Figure 1. M1A2 Tank. (From: GDLS, 2001)

> The M1A2 program updated the M1A1 with improvements in lethality, survivability and fighting ability required to defeat advanced threats. It is the Army's first digitized, direct fire, combat vehicle. It has a digital command and control system that provides situational awareness updates to all the other tanks in a unit. The internal architecture ties all electronic components in the tank together and provides increased survivability and supportability. (AUSA Greenbook, 2001)

The fire-control system is sophisticated, relatively simple to use, and a major contributor to the tank's cost. The commander's independent thermal viewer gives it a hunter-killer capacity where both the tank commander and gunner have the capability to simultaneously scan for targets on different areas of the battlefield. In the M1A2, "electronic complexity and integration many of the systems are linked through a Texas Instruments digital data bus. A total of 21 microprocessors and one-half million lines of code are involved." (USAF Cadre Studies, 1996) The M1A2 also has improved on-board diagnostics that allow the tank to troubleshoot itself without any additional special tools or equipment.

The M1's mobility is achieved through a high power-to-weight ratio, conferred on the tank by its 1,500-hp gas turbine engine. The engine is relatively compact, starts more readily than a diesel, but has lower fuel mileage. In tanks produced after mid-1990, an electronic fuel control system reduced fuel consumption by 18-20%. The Army claims that the AGT 1500 has been much more reliable than a diesel, noting a 5-fold increase in average hours of operation before an overhaul compared to the standard US tank diesel.

The M1 boasts a "Cadillac" suspension system that permits relatively high cross-country speeds. "The M1's high weight (69 tons) limits the number of bridges it may cross and restricts its air transportability to the Lockheed C-5 galaxy or C-17 Globemaster III (which can carry only one tank each)." (USAF Cadre Studies, 1996)

Protection and survivability is afforded by the Abrams' low silhouette and armor developed as part of a classified "black" program. The plating is made of steel-encased depleted uranium mesh, which is said to produce armor capable of defeating most threats at the cost of an increase in weight.

Further survivability protection includes stowage of the main gun's ammunition in a bustle separated from the rest of the turret by fast-closing access doors. "The bustle design is intended to reduce the secondary effects of a hit in the turret by blocking the explosion with the door and venting it through roof blow-out panels." (USAF Cadre Studies, 1996) Another survivability measure is the inclusion of a fire detection and suppression system that covers both the crew and engine compartments.

M1A2 Abrams Technical Characteristics/Features				
Weight	69.54 Tons		Main Armament	120mm M256 Cannon
Length (Gun Forward)	387 Inches		Coaxial Weapon	7.62 M240 MG
Turret Height	93.5 Inches		Loader's Weapon	7.62 M240 MG on Skate Mount
Width	144 Inches		Commander's Weapon	.50 Cal M2 MG
Ground Clearance	19 inches		Gas Turbine Engine	1500 HP
Ground Pressure	15.4 PSI		Hydro Kinetic Transmission	4 Speed Forward 2 Speed Reverse
Power to Weight Ratio	21.6 hp/ton		Cruising Range	265 Miles
Maximum Speed	42 mph		Obstacle Crossing	42 Inches
Cross Country Speed	30 mph		Vertical Trench	9 Feet
Speed on 10% Slope	17 mph		NBC System	200 SCFM - Clean Cooled Air
Speed on 60% Slope	4.1 mph		Crew	4 Men
Acceleration - (0 to 20 mph)	7.2 Seconds			

Figure 2. M1A2 Technical Characteristics. (After: GDLS, 2001)

2. Status

With the previous orientation to the tank and its capabilities, the researcher wanted to provide an understanding of the entire Abrams tank program to put the engine program in perspective.

Production of new Abrams tanks for the US Army is complete. In lieu of new production the Army has a requirement to upgrade over 1,150 early model M1 tanks to the M1A2 configuration. A multi-year procurement for 600 M1A2 upgrades, awarded in July 1996, is in its fifth year deliveries. Initial fielding of the M1A2 to the Army's 1st Cavalry Division, Fort Hood, Texas, was completed in August 1998. Fielding to the 3rd

Armored Cavalry Regiment, Ft. Carson, Colorado was completed in 1999. Further M1A2 improvements, called the Systems Enhancement Package (SEP), are underway. “The M1A2 SEP is the backbone of the Army's first digitized division and the counterattack corps of the Army's Legacy Force.” (AUSA Greenbook, 2001)

> It has an integrated combat command and control (IC3), which incorporates Force XXI battle command brigade and below (FBCB2) to provide command and control and situational awareness. Its sights will use the latest thermal imaging system (second-generation FLIR) for increased lethality and survivability. It also includes improved electronics, taking advantage of the advances in the computer/electronics industry since the introduction of the M1A2. An under-armor auxiliary power unit, a new computerized mass-memory unit, color maps and displays are included in the enhancement package. A thermal management system will increase electronic reliability and decrease crew fatigue. (AUSA Greenbook, 2001)

Production deliveries of the M1A2 SEP began in September 1999. The 4th Infantry Division (Mechanized), Fort Hood, Texas, fielded the M1A2 SEP in May 2000. The First Cavalry Division, Fort Hood, Texas began fielding in July 2001.

Although the M1A2 SEP is considered the centerpiece of the Army's ground force digitization, budgetary limits will permit building only 1,150.

> To achieve this figure, older M1 configurations will be rebuilt directly as M1A2 SEPs and M1A2s will be retrofitted to the SEP configuration. This approach leaves the Army with a large M1A1 fleet that will continue to be the mainstay of the tank inventory into the 21st century. Fleet sustainment has become a critical issue. The Army recently embraced the Abrams Integrated Management XXI program…to permit interoperability with digital forces, the Army also plans to provide the MIA1 an add-on communications package and the designation M1A1D. (Cameron, 1998)

The Abrams Integrated Management Program for the 21st Century (AIM XXI) is a refurbishment program for M1A1 tanks not being upgraded to the M1A2 configuration. Under AIM XXI, the M1A1 tanks are completely disassembled at the Anniston Army Depot, Ala., and overhauled at the Lima Army Tank Plant, in Lima, Ohio (see Figure 3).

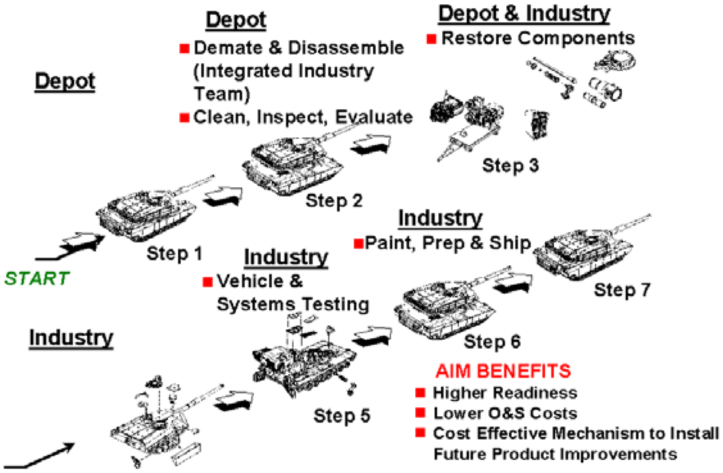

Figure 3. AIM XXI Program Overview. (From: PM Abrams Web page, 1999)

The AIM XXI program is necessary because the Army is required to sustain the readiness of approximately 4,300 aging M1A1 Abrams main battle tanks in its active and reserve units.

> The AIM program is in its third year and has fielded 118 tanks to units at Fort Hood, Texas, and in Germany. Annual production now stands at 135 tanks per year and will continue until 2012. (AUSA Greenbook, 2001)

B. AGT 1500 ENGINE

1. Overview

In the late 1970s the AGT 1500 was selected to power the M1 tank. The AGT was the only successful application of a turbine engine in a military ground vehicle.

> The concept was not new, having been continuously studied since the end of World War II. However, by the 1970s advances in gas turbine technology made possible a reliable engine of great power. Moreover, the experience of military helicopters equipped with turbines indicated that such engines possessed longer service lives and lower maintenance costs. Consequently, the Office of the Secretary of Defense mandated that M1 prototypes include the AGT 1500 gas turbine engine. (Cameron, 1998)

This engine provided 1500 horsepower and a 25:1 power to weight ratio, compared to 13:1 for the M60A3 (the Abrams predecessor). The turbine also offered the Army more flexibility in the logistics arena because it could run on multiple kinds of fuel.

> Turbines can run on just about anything that will burn - car gasoline, diesel fuel, jet fuel, marine fuel. That gives logisticians quite a bit of flexibility and interoperability, especially when the commander also operates helicopters, which run on jet fuel, in addition to operating tanks and trucks. You can supply one type of fuel to the battlefield and operate all the equipment. (Erwin, Nov 2000, p.12)

Over its history, the AGT 1500 engine has served the Abrams tank well. It afforded a significant combat edge due to its reduced weight, power, and stealth. The stealth comes from the turbine's low smoke and noise signatures, which make a vehicle more survivable in combat.

Although a powerful and simple engine with few moving parts, the AGT 1500 is an aging system that requires frequent and costly repair and requires an inordinate amount of fuel. In regards to maintenance cost, the AGT 1500 currently constitutes over half of the Abrams' Operations and Support (O&S) costs and makes the Abrams the Army's most expensive ground system to operate. (DSB Report, 2001)

> Since 1992, we have relied on overhauled engines to support the Armored Force. When an AGT 1500 is overhauled, not all the components are replaced; so with each subsequent overhaul, the engine loses more life. A new engine should deliver about 1,000 hours between depot maintenance events; we are now getting less than 500 hours out of the AGT 1500. The engine then has to be rebuilt, at a cost of approximately $250,000, but never regains its original performance. (Skaff, 2000)

In addressing the second area of concern, fuel consumption, the AGT was found to consume fuel at a rate

> …70% higher than previous diesel engine tanks. The operational consequences of adopting the AGT 1500 became evident when the M1 entered service in the 1980s. To move the combat vehicles of a US Army division equipped with M1s 100 miles required 217,000 gallons of fuel. Some 133,000 gallons were needed for a 1978 division equipped with somewhat lighter M-60 tanks with diesel engines. (Ogorkiewicz, 2001)

It is with this history that the program exists today. In order to confront some of the existing problems, action needed to be taken.

2. Status

Due to the skyrocketing O& S burden, "TSM Abrams upgraded the engine requirements portion of the Abrams Operational Requirements Document (ORD) and established key performance requirements related to improved fuel efficiency and durability." (Skaff, 2000) The Army selected the LV 100-5 over other competitors as the replacement for the AGT 1500. PM Abrams began a comprehensive rebuild program to sustain the armored force until fielding of the LV 100-5 in 2004. This sustainment program is critical because the Army's leadership understands that the Legacy Force is a key component of our National Military Strategy. The Abrams is expected to be in the Army until 2031, which means that it is "conceivable that second lieutenants in today's Armor Basic Course could still command an Abrams battalion." (Cameron, 1998)

This rebuild program is designed to completely rebuild the engine to "like new" condition, offer a twelve-month warranty, and standardize repair while enhancing quality. Through the AIM XXI program, Honeywell provides the parts, engineering support, and technical experience to oversee the rebuild of the AGT 1500 turbine engines.

C. LV 100-5 ENGINE

1. Overview

The Army's primary program objectives are to develop a propulsion system/power pack solution that

> …significantly reduces the Total Ownership Cost (TOC) burden of the Abrams Tank equipped with the existing AGT 1500 engine. The Army specifically established a long-term funding stream for the development, integration, production, and application of an Abrams Tank Propulsion System solution targeted at reducing the O&S burden of the existing system by obtaining a significant net savings. (Ogorkiewicz, 2001)

The Crusader Artillery System was also in need of an engine with similar performance to the tank engine. As a result, senior leaders directed that the Abrams Tank and Crusader Artillery System use a common engine to leverage the programs and reduce maintenance and support burdens on the combined arms team. (Erwin, 2001) In November 2000, the Army awarded a contract to develop and replace our older AGT

1500 tank engines with a new Abrams/Crusader Common Engine (ACCE), the LV 100-5. The Crusader artillery system had initially selected a diesel engine but due to General Shinseki's vision for a lighter and more deployable force, PM Crusader changed to the lighter turbine engine. The US Army expects to save five billion dollars in operations and support (O&S) costs by re-engining its M1 Abrams main battle tank with the LV 100-5 gas turbine and installing the same power plant in the Crusader self-propelled howitzer.

The Army chose the LV 100-5 turbine engine offered by General Electric Aircraft Engines and Honeywell Engines & Systems, who have a 50:50 partnership, for the $3 billion ACCE program. General Dynamics and Germany's MTU also competed with the MT880-series engine, and Caterpillar with its Perkins CV12 engine.

The Army selected the LV 100-5 over the other competitors for the commonality it would provide for the Abrams and Crusader platforms. "A common Abrams-Crusader engine, also would result in efficiencies ranging from lower development costs, economies of scale on the production line, fewer spares to stock and manage, shared costs for tools and diagnostics, and common training skills." (Erwin, 2001) Both programs would share technical data and there would be one depot repair line. Efficiency also would result, he said, from dealing with only one chain of supporting subcontractors. "In Army parlance, the overall logistics footprint would be reduced for both systems." (Erwin, 2001)

Honeywell records show that the LV 100-5 evolved from the -2 version, which was built as a technology demonstrator for the Armored Systems Modernization program. The LV100-2 was to have powered the M1 Block 3 tank, which was foreseen as entering service in FY99 but was canceled following the end of the Cold War.

Honeywell representatives describe the LV 100-5 engine as:

> A state-of-the-art gas turbine, that provides continual and smooth power, rapid acceleration, quick starting even in cold climates, no visible exhaust and quiet running for the Army's ground units. It is also a lightweight engine, at 2,300 pounds, and only 51 inches in length, providing considerable space and weight savings. Like the AGT 1500, it can operate on all grades of jet fuel, diesel and gasoline and can be easily interchanged between the Crusader and Abrams vehicles. The LV 100-5 has 43% fewer

> parts than the AGT 1500, will reduce operations and support cost by a factor of three, and will increase Mean Time Between Failure (MTBF) by a factor of four. (Business Wire, 2000)

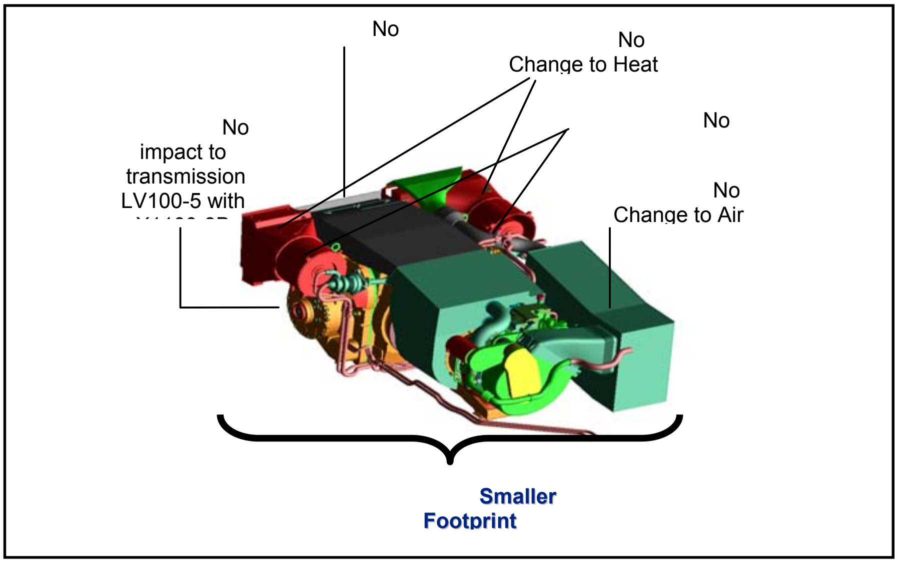

Figure 4. The LV 100-5 Engine. (From: GE-Honeywell, 2001)

The LV 100-5 production version of the new engine shares 41% of its parts with the AGT 1500, and has the same maximum power output of 1,500 horse power, with an ultimate aim to achieve 3,000 hours between overhauls.

The use of commercial technology brings benefits in high reliability and low weight. For example,

> The starter motor is the same as that used with the auxiliary power unit on a Boeing 747 airliner. It weighs only about 18kg, and is mounted high in the engine bay to ease handling by maintainers with low body weights. Other advances include the use of an 'electronic logbook', to be used for trend monitoring and other applications, that stays with the engine throughout its life. (Jane’s IDF, 2000)

Additionally, Honeywell claims it can provide at least a 25% reduction in fuel consumption (up to 50% at idle) without sacrificing current performance. Part of this fuel saving is contributed by the use of an advanced full-authority digital engine control unit. (Defense Daily, 2001)

Other performance improvements and upgrades from the LV 100-2 version, provided by Honeywell representatives include;

- reduced inlet pressure loss
- increased compressor flow and improved airfoil design
- minimized leakage flows
- elimination of second stage Variable Area Turbine Nozzle (VATN)
- added bypass capability in the Engine Recovery Unit (ERU)
- enhanced aero designs and lower inter-turbine duct losses in the High Pressure/Low Pressure Turbine (HPT/LPT)
(Heydrich, 2001)

Figure 5, below, outlines a comparison in weight and performance between the diesel engine and the AGT 1500 and LV 100-5 engines.

	High Performance Diesel	AGT 1500	LV 100-5
Weight (lb)	3600	2500	2300
Fuel consumption (lb / hp hour)	.36	.50	.40
Cooling Volume Required (ft 3)	33	15	5.8
Cooling Weight Required (lb)	1400	200	200

Figure 5. Diesel / Turbine Engine Comparison. (After: PM M1A1, 1999)

2. Status

The initial contract awarded to Honeywell and GE amounts to $195.6 million and covers development of the LV 100-5 engine to meet the ACCE program requirements.

The Abrams-Crusader Common Engine (ACCE) program passed its critical design review in October 2001. The Abrams Product Manager outlines the engine production in two phases. In phase 1, Honeywell is to produce 13 prototypes for testing.

These prototypes are due beginning in May 2002. In phase II, full production begins and the request is for 2,709 engines beginning in 2003 and continuing for eight years.

In reporting completion of the critical design review (CDR), the Honeywell-GE team claims to have made some significant improvements with the integration of the engine to the vehicle, as well as nearly two-dozen small improvements to increase fuel efficiency. The engine is currently 100 pounds under the weight requirement. The two companies expect to achieve additional weight and fuel consumption savings from the ongoing design refinement of the engine.

D. SUMMARY

The M1A1/M1A2 is the Army's Main Battle Tank. The M1A1, or a variant thereof, is expected to be in operation through the year 2031. In order to improve reliability and decrease life cycle cost, the Abrams Product Manager is overseeing the development of a new engine, the LV 100-5 to replace the current AGT 1500. Besides a fourfold increase in reliability, reduced weight, and commonality with the Crusader artillery system, the LV 100-5 is expected to be significantly more fuel-efficient than its predecessor. It is from this understanding of the systems involved that we move into a detailed breakdown of the fuel economies involved and their application to a combat scenario in an armored battalion.

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III. DATA

A. INTRODUCTION

This chapter presents and discusses the data collected to fully understand the cost savings associated with the move from the AGT 1500 to the LV 100-5 tank engine. The primary areas of consideration in this section are fuel cost, fuel handling cost, equipment cost, personnel cost, and overall mileage savings. A brief discussion of each topic is included with the pertinent data.

B. FUEL COST

1. JP-8 as Army Common Fuel

In the 1980's and early 90's the Army used three fuels, gasoline, diesel, and jet aircraft fuel. Today, Army policy dictates JP-8 (Jet Propulsion-8) as the single fuel on the battlefield. JP-8 as a common fuel greatly simplifies fuel logistics, and permits helicopter refueling in the forward battle area. JP-8 was selected over other fuels for several different reasons. First, it has a minimum flash point of 100ºF, while gasoline could ignite at temperatures below freezing. Second, JP-8 has greater availability and better suitability for land-based equipment. Third,

> JP-8 is slightly cheaper than diesel fuel. It is also more refined so it is less likely to plug filters or leave deposits in injection nozzles. It has better stability in long-term storage and burns cleaner. (Siuru, 1989)

The major difference between JP-8 and commercial airline fuel Jet A-1 is that JP-8 has additives to prevent corrosion, fuel system icing, and static electricity. Diesel and gas turbine engines that used to use commercial diesel fuels can burn JP-8. Originally it was "diesel fuel's fire resistance and the fuel economy of diesel engines…that originally led the Army to adopt a diesel-powered ground vehicle fleet." (Siuru, 1989)

2. Cost of JP-8

Information from the Defense Energy Support Center, indicate that the *Standard Price of Fuel* for JP-8 in FY02 is $1.00/USG.

> The Standard Price of Fuel is a tool that was created by DoD's fiscal managers to insulate the Military Services from the normal ups and downs of the fuel marketplace. It provides the Military Services and OSD with budget stability despite the commodity market swings, with gains or losses being absorbed by a revolving fund known as the Defense Working Capital Fund (DWCF). The Standard Price is assembled by projecting of the price of fuel 18 months in the future and combining this with the budgeted cost of transporting, storing, and managing the government fuel system, including war reserve stocks. (DESC Website, 2001)

This cost of 1 dollar per gallon will help in making some of the more straightforward savings analysis that are required.

A recent Defense Science Board (DSB) report on reducing DoD fuel burden written in May 2001, however, claims that the Army neglects to account for the true costs needed to issue fuel. They list the following statistics:

> The Army directly uses $200 million of fuel per year or 300M gallons. The Army has 20,000 active POL soldiers @ $100,000 per annum and 40,000 reserve POL-related soldiers @ $30,000 per annum.
>
> $ 200,000,000 fuel
> $2,000,000,000 active
> $1,200,000,000 reserve
> $3,400,000,000 Total Annual Cost of Army Fuel
>
> Thus it costs the army about 16 times as much to deliver fuel as to purchase it. The ARL calculates that fuel actually costs the army about $13 per gallon, well to tank, in peacetime and at home. (DSB Report, 2001, p. 39)

Of particular note in this calculation by the DSB is the cost of $100,000 per year to pay and support one active duty POL soldier. This number is taken as an average of all enlisted soldiers and includes pay, benefits, food, and housing for one year. However, it is interesting to note that this computation does not take into account the cost borne by the other Army, Air Force, or Navy assets to transport fuel during deployments. It is easy to picture in operations such as those underway in Afghanistan or Kosovo that such transport costs may be indeed substantial. The DSB did amend their initial $13 per gallon estimate by noting if the fuel had to be moved an additional 100 km past the Forward Edge of the Battle Area (FEBA) the cost per gallon would grow to $25. Additionally, the DSB went on to say:

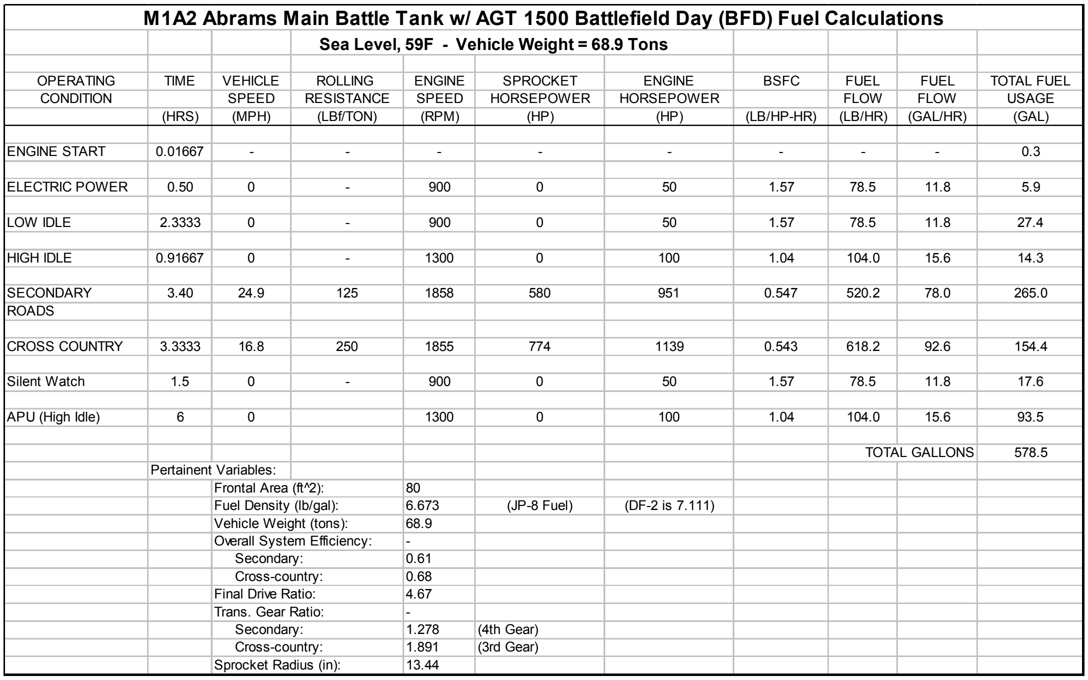
> The true cost of fuel is dominated by handling and distribution. As a result, the cost is very scenario dependant. Taking all of these factors into account, a reasonable estimate of the total cost of fuel when delivered to Army combat platforms is in the $10's/gallon range. Over large distances the total cost would range from at least $40-$50 per gallon for overland transport up to more than $400 per gallon for air delivery using platforms with today's capability. (DSB Report, 2001, p. 20)

Further study of the true cost of fuel will give estimates of $13, $50, and $400 to account for different possible scenarios in which the Army may operate. This DSB perspective on the "true cost" to issue a gallon of fuel will be another means of comparison to the actual savings achieved by using the LV 100-5 over the AGT 1500. It is from this understanding of the cost of the fuel for the M1A2 tank that we move into a further comparison of the two engines.

C. ENGINE COMPARISON

At Honeywell and the Tank Automotive and Armaments Command (TACOM) there are several methods to compare the performance of the AGT 1500 versus the LV 100-5. The method used for this part of the study was to use the comparison of fuel economy of both engines in an equal Battlefield Day (BFD) scenario and measure the results. The BFD scenario was generated by TACOM and members of the armor community. They use historical data to generate an average number of hours for the tank at idle, in movement, at rest etc.., and then calculate the amount of fuel used in gallons for the day. In these calculations the scenario has the M1A2 tank at sea level with a temperature of 59 degrees. The testing is conducted at Honeywell and confirmed by TACOM and PM Abrams representatives.

1. AGT 1500



M1A2 Abrams Main Battle Tank w/ AGT 1500 Battlefield Day (BFD) Fuel Calculations

Sea Level, 59F - Vehicle Weight = 68.9 Tons

OPERATING CONDITION	TIME (HRS)	VEHICLE SPEED (MPH)	ROLLING RESISTANCE (LBf/TON)	ENGINE SPEED (RPM)	SPROCKET HORSEPOWER (HP)	ENGINE HORSEPOWER (HP)	BSFC (LB/HP-HR)	FUEL FLOW (LB/HR)	FUEL FLOW (GAL/HR)	TOTAL FUEL USAGE (GAL)
ENGINE START	0.01667	-	-	-	-	-	-	-	-	0.3
ELECTRIC POWER	0.50	0	-	900	0	50	1.57	78.5	11.8	5.9
LOW IDLE	2.3333	0	-	900	0	50	1.57	78.5	11.8	27.4
HIGH IDLE	0.91667	0	-	1300	0	100	1.04	104.0	15.6	14.3
SECONDARY ROADS	3.40	24.9	125	1858	580	951	0.547	520.2	78.0	265.0
CROSS COUNTRY	3.3333	16.8	250	1855	774	1139	0.543	618.2	92.6	154.4
Silent Watch	1.5	0	-	900	0	50	1.57	78.5	11.8	17.6
APU (High Idle)	6	0		1300	0	100	1.04	104.0	15.6	93.5
								TOTAL GALLONS		578.5
	Pertainent Variables:									
		Frontal Area (ft^2):		80						
		Fuel Density (lb/gal):		6.673	(JP-8 Fuel)	(DF-2 is 7.111)				
		Vehicle Weight (tons):		68.9						
		Overall System Efficiency:		-						
		Secondary:		0.61						
		Cross-country:		0.68						
		Final Drive Ratio:		4.67						
		Trans. Gear Ratio:		-						
		Secondary:		1.278	(4th Gear)					
		Cross-country:		1.891	(3rd Gear)					
		Sprocket Radius (in):		13.44						

Figure 6. Battlefield Day Calculations. (After: PM M1A1, 1999)

As can be seen from the AGT 1500 sheet, the tank uses 578.5 gallons of fuel in this BFD. It is this calculation that is compared to the LV 100-5 performance under the same conditions that serves as the basis for future estimates.

2. LV 100-5

M1A2 Abrams Main Battle Tank w/ LV 100-5 Battlefield Day (BFD) Fuel Calculations

Sea Level, 59F - Vehicle Weight = 68.9 Tons

OPERATING CONDITION	TIME (HRS)	VEHICLE SPEED (MPH)	ROLLING RESISTANCE (LBf/TON)	ENGINE SPEED (RPM)	SPROCKET HORSEPOWER (HP)	ENGINE HORSEPOWER (HP)	BSFC (LB/HP-HR)	FUEL FLOW (LB/HR)	FUEL FLOW (GAL/HR)	TOTAL FUEL USAGE (GAL)
ENGINE START	0.01667	-	-	-	-	-	-	120	16.9	0.3
ELECTRIC POWER	0.50	0	-	875	0	33.2	1.225	40.7	6.1	3.0
LOW IDLE	2.3333	0	-	875	0	41.6	1.094	45.5	6.8	15.9
HIGH IDLE	0.91667	0	-	875	0	42	1.088	45.7	6.8	6.3
SECONDARY ROADS	3.40	24.9	125	1858	580.10	754	0.424	319.7	47.9	162.9
CROSS COUNTRY	3.3333	16.8	250	1855	774	953	0.415	395.5	59.3	197.6
Silent Watch	1.5	0	-	875	0	28.3	1.383	39.1	5.9	8.8
APU (High Idle)	6	0		875	0	42	1.088	45.7	6.8	41.1
								TOTAL GALLONS		435.9
	Pertainent Variables:									
		Frontal Area (ft^2):		80						
		Fuel Density (lb/gal):		6.673	(JP-8 Fuel)	(DF-2 is 7.111)				
		Vehicle Weight (tons):		68.9						
		Overall System Efficiency:		-						
		Secondary:		0.699						
		Cross-country:		0.73						
		Final Drive Ratio:		4.67						
		Trans. Gear Ratio:		-						
		Secondary:		1.278	(4th Gear)					
		Cross-country:		1.891	(3rd Gear)					
		Sprocket Radius (in):		13.44						

Figure 7. Battlefield Day Calculations. (After: PM M1A1, 1999)

In the case of the LV 100-5, the BFD calculation due to various increases in technology shows total gallons used as 435.9 over the same time period. This is an overall 24.65% fuel savings in comparison to the AGT 1500. The magnitude of this savings is further reflected in the 56% reduction in high-idle time fuel economy from 14.3 gallons used with the AGT 1500 to 6.3 gallons with the LV 100-5.

These numbers have been validated through Honeywell and PM Abrams representatives in their most recent testing and Critical Design Review (CDR).

D. UNIT STRUCTURE

1. Tank Battalion

An M1A2 Tank Battalion is the primary point of analysis for this research. A tank battalion consists of three “line companies” and one Headquarters Company. As noted below, each line company has three platoons of four tanks each plus two headquarters tanks. This means there are fourteen tanks per line company.

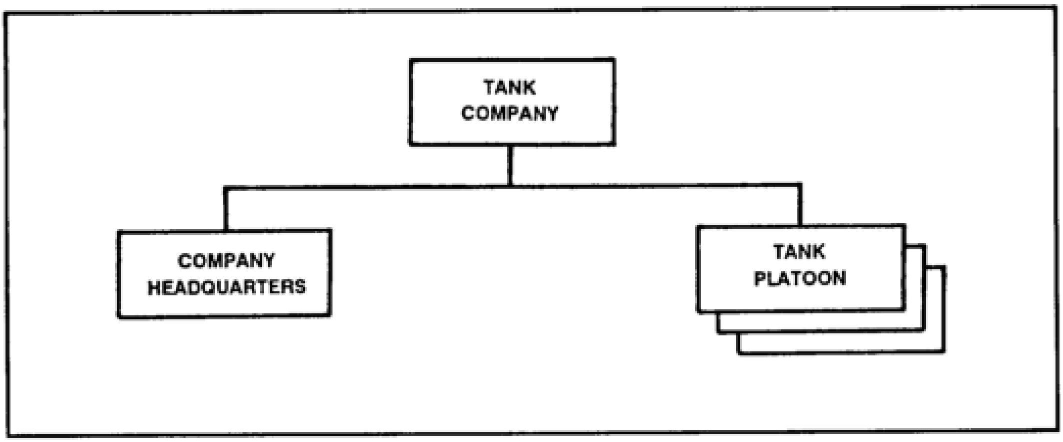


Figure 8. The Tank Company Organization (From: FM 17-15, 1999)

When adding each of the company's tanks plus the two battalion headquarters tanks (one for the Commander and one for the Operations Officer) together there are a total of forty-four tanks in an M1A2 battalion. Although the battalion rarely operates "pure" in a combat environment, the researcher has chosen to consider the effects of the move to a more fuel-efficient engine from this aspect to simplify analysis. Any change in fuel economies or savings will be reflected as how it impacts a Tank Battalion of 44 tanks.

To support itself, the Tank Battalion maintains a Headquarters Company (HHC). The HHC provides all of the support assets necessary to support combat operations. Of particular interest is the Battalion Support Platoon, which will be described in the following section.

2. Battalion Support Platoon

a. Support Platoon Equipment and Cost

As mentioned above, within each Tank Battalion is a Headquarters Company (HHC). Within each HHC, there is a Battalion Support Platoon that provides all of the fuel, packaged products, ammunition, and barrier material for the battalion. Of specific interest for this research is the fact that the M1A1 battalion is authorized twelve M978 High Mobility Tactical Trucks (HEMTT) to supply JP-8 fuel to the battalion. The M1A2 battalion under CSS redesign has only nine fuelers per battalion.

> The Heavy Expanded-Mobility Tactical Truck (HEMTT) is the workhorse of Army combat divisions, providing combat vehicles and weapons systems. C-130 transportable, it is the key combat service support enabler for the BCT. The 10-ton, eight-wheel drive family of vehicles is designed to operate in any climatic condition. There are six basic configurations of the HEMTT-series trucks. (AUSA Greenbook, 2001)

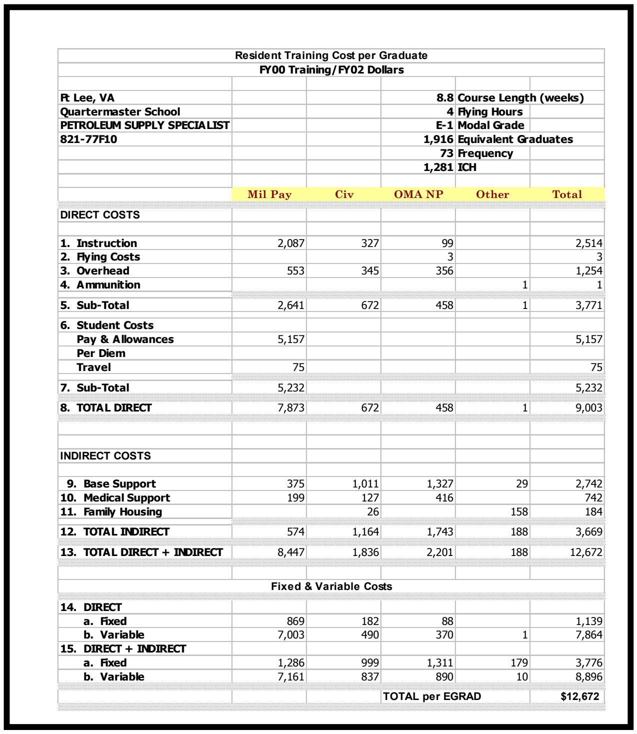
Although the capacity of each of these fuelers is 2,500 gallons, common practice in units is to carry 2,200 gallons each for safety reasons. (Gilliam, 2001) This means that the battalion support platoon can, at any one time, carry a total of 26,400 gallons of JP-8 to support the M1A1 battalion or 19,800 gallons for the M1A2 battalion in CSS redesign. The current cost of one M978 HEMTT and its associated Basic Issue Items (BII) is $237,210. (Gilliam, 2001)

The Life Cycle Cost (LCC) associated with the M978 is estimate at $3 million. This cost is spread over the 20-year life cycle of the truck. Included in this cost are a yearly O&S cost estimated at $5 thousand. (Nordhougen, 2002)

b. Support Platoon Personnel Costs

The fuel operators for the M978 are designated with the Military Occupational Specialty (MOS) of 77F. Each support platoon is authorized two 77F personnel for each of their M978 trucks. This means that there are a total of 24 77F personnel directly employed in the business of fuel handling for an M1A1 tank battalion during combat operations. In the M1A2 battalion this means there are 18 77F personnel available for fuel missions. The Defense Science Board Report noted earlier in this chapter used an estimate of $100,000 per year as the cost to support one fuel operator for one year. (DSB Report, 2001)

The cost to train these 77F operators at their Advanced Individual Training is outlined in Figure 9 below. The total cost of the eight-week course for one 77F soldier is $12,672.



Resident Training Cost per Graduate

FY00 Training/FY02 Dollars

Ft Lee, VA			8.8	Course Length (weeks)	
Quartermaster School			4	Flying Hours	
PETROLEUM SUPPLY SPECIALIST			E-1	Modal Grade	
821-77F10			1,916	Equivalent Graduates	
			73	Frequency	
			1,281	ICH	
	Mil Pay	Civ	OMA NP	Other	Total
DIRECT COSTS					
1. Instruction	2,087	327	99		2,514
2. Flying Costs			3		3
3. Overhead	553	345	356		1,254
4. Ammunition				1	1
5. Sub-Total	2,641	672	458	1	3,771
6. Student Costs					
Pay & Allowances	5,157				5,157
Per Diem					
Travel	75				75
7. Sub-Total	5,232				5,232
8. TOTAL DIRECT	7,873	672	458	1	9,003
INDIRECT COSTS					
9. Base Support	375	1,011	1,327	29	2,742
10. Medical Support	199	127	416		742
11. Family Housing		26		158	184
12. TOTAL INDIRECT	574	1,164	1,743	188	3,669
13. TOTAL DIRECT + INDIRECT	8,447	1,836	2,201	188	12,672
Fixed & Variable Costs					
14. DIRECT					
a. Fixed	869	182	88		1,139
b. Variable	7,003	490	370	1	7,864
15. DIRECT + INDIRECT					
a. Fixed	1,286	999	1,311	179	3,776
b. Variable	7,161	837	890	10	8,896
			TOTAL per EGRAD		$12,672

Figure 9. 77F Training Cost. (From: Atkinson, 2001)

This training course is conducted at Fort Lee, Virginia and is briefly described as:

> The Basic Petroleum Logistics Division (BPLD) provides initial technical and tactical petroleum training to Petroleum Supply Specialist (77F10), Advanced Individual Training (AIT) soldiers to meet the worldwide petroleum needs of the United States Army. The course consists of eight weeks with four days of extensive hands-on training on U.S. Army petroleum-related equipment. Within this curriculum, they train over 3,000 soldiers. (Hudgins, 2001)

Some of the training subjects covered in the classroom and hands-on environment include: petroleum supply operations, environmental standards and spill contingency, safety, health hazards, fire fighting and first aid, supply point equipment and operations, and operation of various petroleum fueling vehicles. (Hudgins, 2001)

Over the 20-year life cycle of a HEMTT truck it is important to note that such training costs are recurring. It is anticipated that new operators per HEMTT are trained every four years. Therefore the recurring training cost over a twenty- year period for two operators per truck is $126,720.

c. Support Platoon Doctrine

The Battalion Support Platoon fuels the force using doctrine that urges them to "fuel forward" in order to support the high consumption M1 tanks. Normally fuel is delivered to the tank battalion through a standard logistics package (LOGPAC). The battalion standard operating procedure establishes this standard LOGPAC. Normally, a company team LOGPAC will consist of a unit supply truck (with food, water, mail, other supplies, and replacement personnel), M978 fuelers with bulk fuel and other packaged fuel products (oils and lubricants), and M977 ammunition trucks (a mix of ammunition for the weapon systems of each company). Other vehicles may be added to carry additional supplies/personnel.

LOGPACs are organized in the field trains by the company supply sergeant under supervision of the HHC commander and the Support Platoon Leader. LOGPACs are organized for each company team in the TF and moved forward on at least a routine resupply, usually twice a day. Special LOGPACs are organized and dispatched as required by the tactical situation and logistical demands.

When possible, all LOGPACs move forward as a march-unit under the control of the Support Platoon Leader. The LOGPACs move along the main supply route (MSR) to a logistical release point (LRP), where the unit 1SG or a unit guide takes control of the company LOGPAC and brings it to the company area.

This results in tailgate or service station resupply methods as described in Figure 10.

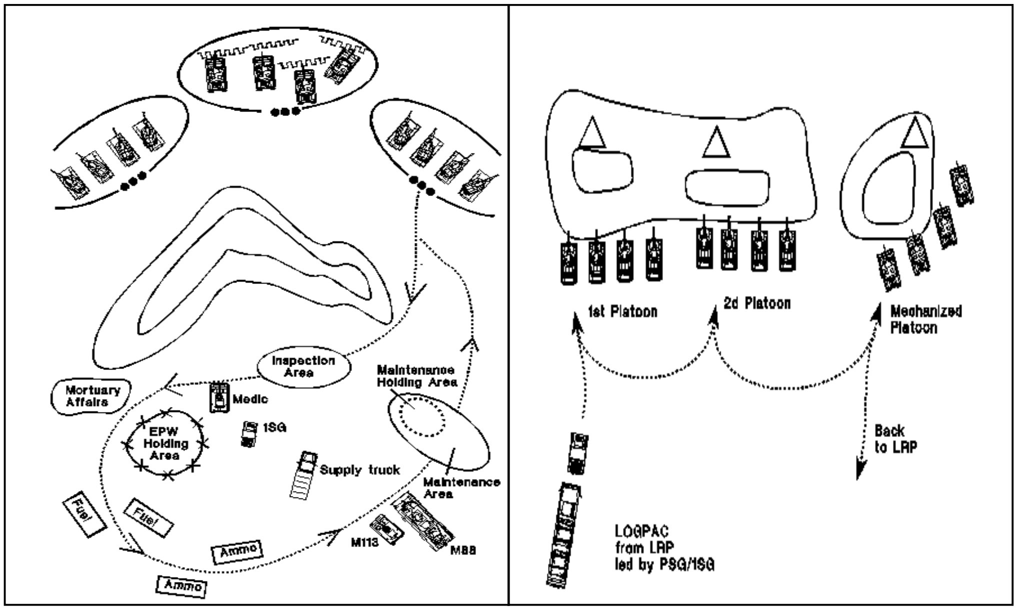


Figure 10. Service Station and Tailgate Resupply Operations. (From: FM 17-15, 1999)

After completing resupply at the company, the LOGPAC follows unit SOP and returns to the LRP or to the field trains.

This resupply of each company in the battalion encompasses the travel time forward to the tank positions then the total time needed to actually dispense fuel. This LOGPAC is usually conducted in conjunction with other logistics like food and takes a total time of about 3 hours per mission. The distance traveled in this time frame is a round trip of anywhere from 16 – 24 kilometers based on the mission and terrain.

This doctrine forces the Support Platoon Leader to supply the tanks at forward locations then consolidating (via crossload) remaining fuel and moving to a rear area with empty HEMTTs for refuel from the Forward Support Battalion (discussed below). The total time required to travel to the resupply point and back varies greatly but can be fairly estimated at 3 hours per mission.

When looking at possible savings due to increased fuel efficiency for a tank the analysis must also include a look at the amount of time that can be saved by logistical and combat units with less fuel missions. In short, a Battalion Support Platoon can save a total of six hours if it could reduce it’s number of fuel missions to a tank company by one.

3. Forward Support Battalion

The Forward Support Battalion is the primary supplier of all classes of supply for a maneuver Brigade.

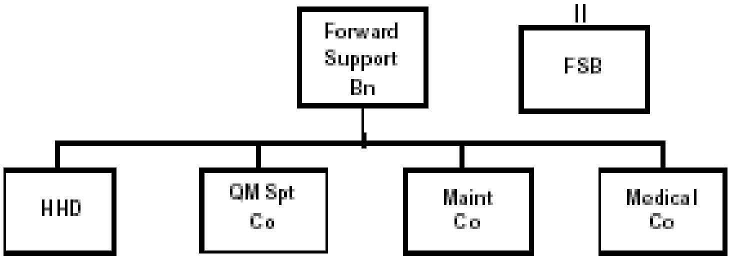


Figure 11. FSB Organization. (From: FM 63-20, 2001)

As can be noted from the above diagram, the FSB provides maintenance, medical, and other supplies. Of particular interest to our study is the ability of the FSB to support the Tank Battalion Support Platoon with fuel. The company within the Forward Support Battalion responsible for this mission is the Quartermaster Support Company. The Company structure is listed below:

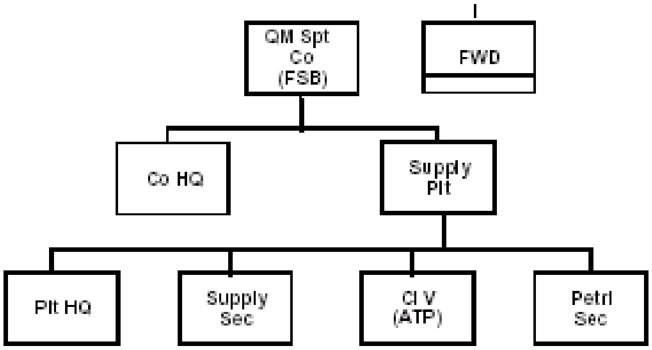


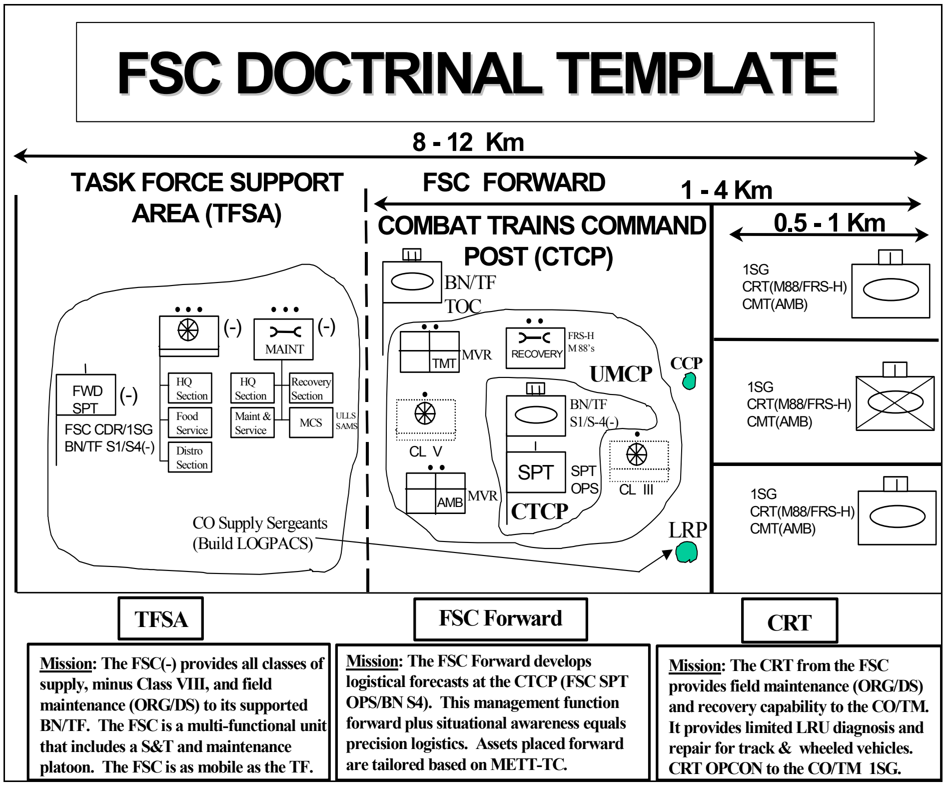
Figure 12. QM Support Co Organization. (From: FM 63-20, 2001)

In order to provide fuel to the Brigade an FSB has a petroleum section (see figure) that has eleven M969 fuel tankers. The M931 Five-Ton tractor moves these tankers.

These M969 tankers have a 5,000-gallon capacity but generally carry 3,500 for safety purposes. This means there are a total of 38,500 gallons available at any one time in the FSB to support the Brigade. The M969 trucks plus all associated BII have a current cost of $90,610 for the trailer and a cost of $86,205 for each M931A2 Five-Ton prime mover. The Life Cycle Costs (LCC) for each of these vehicles is estimated to be 2 million each over a 20-year life cycle. This includes yearly O&S costs estimated at $10 thousand each. (Nordhougen, 2002)

Like the Battalion Support Platoon, each of the M969 trucks is to be manned by two 77F personnel during maneuver operations. This brings the total number of fuel operators in the FSB to 22 in order to keep all of the units in the Brigade properly supplied with fuel. The recurring training costs are identical to those required for the M978 crews. Thus, the recurring training cost over a twenty-year period for two operators per truck is $126,720.

4. Doctrinal Positioning of Support Assets



Mission: The FSC(-) provides all classes of supply, minus Class VIII, and field maintenance (ORG/DS) to its supported BN/TF. The FSC is a multi-functional unit that includes a S&T and maintenance platoon. The FSC is as mobile as the TF.

Mission: The FSC Forward develops logistical forecasts at the CTCP (FSC SPT OPS/BN S4). This management function forward plus situational awareness equals precision logistics. Assets placed forward are tailored based on METT-TC.

Mission: The CRT from the FSC provides field maintenance (ORG/DS) and recovery capability to the CO/TM. It provides limited LRU diagnosis and repair for track & wheeled vehicles. CRT OPCON to the CO/TM 1SG.

Figure 13. FSC Doctrinal Template. (From: FM 63-20-1, 2001)

The figure above provides a picture of all of the positioning of the aforementioned items. The Tank Battalion support assets are normally echeloned into Company Trains, Battalion Combat Trains, and Battalion Field Trains.

The Combat Trains are organized to provide immediate critical support for the combat operation. They can be positioned anywhere from 1-4 kilometers from the line units. Of interest to this study are the M978 fuelers, usually 1 to 2, that are kept at the Combat Trains for emergency resupply purposes. The Combat Trains also include the Combat Trains CP (CTCP), the Unit Maintenance Command Post (UMCP), the Battalion Aid Station (BAS), the decontamination vehicle, some supply ammunition vehicles, and some supporting elements from the FSB.

The Battalion Field Trains are normally in the Brigade Support Area (BSA) and under the control of the HHC commander, who coordinates with the Brigade S4 and FSB commander for security and positioning. Based on this doctrine, the FSB and the Battalion Field Trains, which include the bulk of the Battalion Support Platoon fuel assets, are co-located in the BSA.

The FSB positions its fuelers between the Brigade Support Area and the Corps Support assets that resupply the FSB fuelers. So after completing resupply at the battalion level, the Battalion Support Platoon moves its empty assets back another 5 kilometers to the FSB resupply tankers for refuel (not shown in the doctrinal template above). This refuel of Support Platoon assets takes FSB petroleum unit about 2-3 hours per mission.

This doctrinal template is provided by the researcher to ensure understanding of the distances and time required for resupply during combat operations. The distance traveled forward by the fueler followed with a refuel at a Tank Company position with the tailgate or service station method and the subsequent return trip and resupply are time and manpower intensive operations. Any reduction in the frequency of such operations allows logistics assets to be focused on other missions and combat units to concentrate on their combat missions.

E. COMBAT SCENARIO

1. National Training Center

The National Training Center (NTC) is located in the Mojave Desert at Fort Irwin, California. The NTC is the U.S. Army's premier training facility worldwide. The NTC mission is to provide realistic joint and combined arms training focused on developing soldiers, leaders, and units of America's Army for success on the 21st century battlefield. (CTC Handbook, 2001) Fort Irwin's size makes it ideal for conducting realistic, large-scale, combined arms training operations. The base encompasses approximately 643,000 acres of land - roughly the size of the state of Rhode Island. About 321,000 acres of this land are suitable for maneuver areas and ranges. (CTC Handbook, 2001)

> The NTC is uniquely equipped and organized to provide tough, realistic combined arms training according to joint operations doctrine for brigades/ regiments in a mid- to high-intensity environment, while retaining the training feedback and analysis/focus at brigade level. Annually, 10 brigade combat teams consisting of from four to seven battalion and squadron task forces (averaging approximately 5000 soldiers each rotation, to include brigade slice) rotate through the NTC for intensive combat training against an OPFOR highly trained in threat doctrine. During their 28-day stay at Fort Irwin, typical units experience 7 days of reception, staging, onward movement and integration (RSOI) operations, 14 days of tactical operations that include both force-on-force and live-fire training and 7 days of combat force regeneration. Units, equipped with Weapons Engagement Simulation Systems, conduct training in areas containing sophisticated data collection and recording systems that provide a record of engagement for review, analysis, and use in planning and conducting training upon return to home station. (CTC Handbook, 2001, p. 3-D-2)

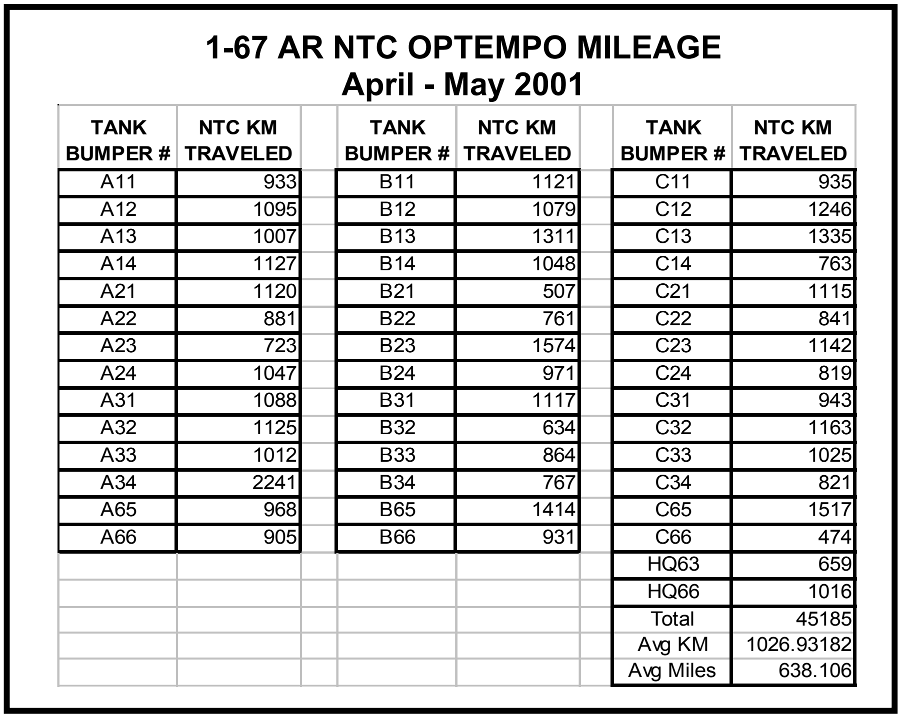
The main emphasis of the training at NTC is the combined arms battalion task forces deployed in a brigade maneuver box. Characteristics of the NTC force-on-force battlefield include:

- Complicated battlefield scenarios
- Open desert type terrain.
- Extended Lines of Communication.
- Mid- to high-intensity missions. (CTC Handbook, 2001 p. 3-D-2)

2. NTC Scenario

The researcher gathered two sets of information on rotational units at the National Training Center. The first information was supplied by a contractor working at the NTC who tracked the average miles and hours used in a typical day rotation. Larry Miller of Cobro Corporation reported that the "average tank accumulates 325 miles and 100 hours during a typical rotation." (Miller, 2001) This averages out to 3.25 miles per hour of operation. The data provided by Cobro Corporation was recommended by personnel at the United States Army Material Systems Analysis Activity (AMSAA) who used to track mileage and hour data when the NTC maintained a fleet of tanks for use by rotational units. The NTC no longer maintains its own fleet and units bring their own tanks from their respective posts via railroad.

The researcher collected the second set of data from 1-67 Armor Battalion at Fort Hood, Texas who had an NTC rotation earlier this year (May 2001). The 1-67 AR Battalion maneuvered for twenty-one days in mock combat operations at the NTC with their M1A2 tanks. The length of their maneuver rotation exceeded those of other units by seven days due to the fact that this unit is part of the digitized brigade at Fort Hood and they needed extra time to work out doctrinal methods and validate their equipment. These twenty-one days included several offensive and defensive scenarios that may be encountered by units in "real-world" desert warfare scenarios. The data collected by the Battalion Executive Officer for this timeframe are noted in Figure 14 below.



1-67 AR NTC OPTEMPO MILEAGE
April - May 2001

TANK BUMPER #	NTC KM TRAVELED	TANK BUMPER #	NTC KM TRAVELED	TANK BUMPER #	NTC KM TRAVELED
A11	933	B11	1121	C11	935
A12	1095	B12	1079	C12	1246
A13	1007	B13	1311	C13	1335
A14	1127	B14	1048	C14	763
A21	1120	B21	507	C21	1115
A22	881	B22	761	C22	841
A23	723	B23	1574	C23	1142
A24	1047	B24	971	C24	819
A31	1088	B31	1117	C31	943
A32	1125	B32	634	C32	1163
A33	1012	B33	864	C33	1025
A34	2241	B34	767	C34	821
A65	968	B65	1414	C65	1517
A66	905	B66	931	C66	474
				HQ63	659
				HQ66	1016
				Total	45185
				Avg KM	1026.93182
				Avg Miles	638.106

Figure 14. 1-67 AR NTC Mileage. (After: Smith, 2001)

This mileage data show that the average tank traveled 638 miles during the twenty-one day exercise. Although the actual number of hours used by each tank was not available, it can be inferred from the Cobro Corporation representative that the hours run were 196.31 hours (638 / 3.25).

These are the closest data we can accurately gather on a tank maneuvering in a wartime environment. It is with these data that the researcher wants to compare with similar tanks hypothetically using the LV 100-5 engine and measure the possible savings.

3. Life Cycle Data

The researcher wanted to compare the fuel usage in a ten-year period for an average Tank Battalion using the AGT 1500 with one hypothetically using the LV 100-5. The researcher contacted the Executive Officer of 1-68 Armor at Fort Carson, Colorado. 1-68 Armor is an M1A1 Tank Battalion. The XO indicated that 1-68 tanks traveled an average of “640 miles per year” (Wawro, 2002) plus an additional “325 miles” (Miller,

2001) during their National Training Center Rotation. This indicates that each tank travels approximately 965 miles during a typical year. When multiplied by the 44 tanks in the battalion this total 42,460 miles traveled per year. Over a ten-year period, assuming a constant OPTEMPO, this totals to 424,600 miles for the battalion. If the LV 100-5 is fielded in a battalion in 2006 and the tank stays in service until 2031, the battalion will accumulate 1,061,500 miles over those 25 years. Using the ten and 25-year mileage estimates, the researcher will analyze the cost savings possible using the LV 100-5 over the AGT 1500.

F. UNDER ARMOR AUXILLARY POWER UNIT

One item not considered in collection of these data is the addition of the Under Armor Auxiliary Power Unit (UAAPU).

> The UAAPU is located in the left rear of the vehicle chassis and displaces 55 gallons of fuel. This under armor protection offers the same protection to the APU as it does the main engine. The APU is a turbine unit, providing both electrical and hydraulic power to the entire tank, and is operated from within the driver's compartment. In addition, the APU receives its fuel from the tank's main fuel system, eliminating the need to carry special fuel. The UAAPU provides electrical and hydraulic power during mounted surveillance and aids reducing main engine operating hours and vehicle fuel consumption while providing electrical power to charge the main batteries. (Skaff, 2000)

The reason for having a UAAPU is that as electrical demands increase, especially in a Mounted Surveillance mode (where all systems powered up but the main engine cannot be operated) the power drain from these systems requires the main engine to operate every hour for 15 minutes to recharge the batteries. "Therefore, an auxiliary power source is required to reduce noise and fuel consumption. Presently the Army has an externally mounted auxiliary power unit for the M1A1 series tank that provides electrical power only. However, the M1A2 SEP has increased electrical and hydraulic requirements that must be maintained during mounted surveillance." (Skaff, 2000)

The primary benefits of the UAAPU are that it provides 6 kW of electrical power, provides electric power to charge the main batteries, reduces main engine operating hours, and reduces fuel consumption by 8.5 gallons per hour.

As noted by MAJ Gregory M. Parrish the former Executive Officer of 1-67 Armor, "the tanks were fielded minus the UAAPU. We lost eighty gallons of fuel capacity to make room for the APU and we discovered that with the engine shut down and all of the digital systems running, we had an average battery life of 18-20 minutes before being forced to restart the engine."

This lack of an UAAPU for 1-67 AR tanks and when considering performance of the LV 100-5 and AGT 1500 will reflect consumption significantly higher than if the UAAPU were included.

G. SUMMARY

This chapter lists all pertinent data to calculate possible fuel savings with a more fuel-efficient engine. The chapter started with a listing of the current cost of tank fuel. Of particular note was a Defense Science Board Report estimate that calculated the cost of one POL soldier for one year was $100,000. This calculation was figured in with Reserve unit personnel costs and fuel costs to get a cost of $13 per gallon to fuel Army equipment. Further study of the true cost of fuel gave estimates ranging from $50 to $400 to account for different possible scenarios in which the Army may operate. These numbers stand in contrast to the simple calculation of $1 per gallon in fuel cost at the pump for DoD.

Next there was a comparison between the AGT 1500 and the LV 100-5 engines in a typical battlefield day (BFD) scenario. This BFD scenario outlines the proven capability and performance of both the LV 100-5 and the AGT 1500 and confirms a 24.65% fuel savings with the LV 100-5.

The researcher included the numbers and cost of fueling equipment at the Brigade and below level to use as reference for future analysis. If warranted, the number of personnel and equipment could be adjusted based on the amount of fuel saved over time.

The chapter included data from a recent National Training Center rotation for a maneuver battalion to provide a "wartime" scenario for analysis. These data are used as a point of reference to calculate actual savings in a combat environment and can be compared to the laboratory BFD calculations.

Included in these data are a summary of mileage traveled over a one-year period for a Tank Battalion. This mileage was then projected out over a ten and a 25-year period for purposes of cost analysis in the following chapter.

One limitation on data was the lack of the UAAPU for maneuver units, which causes units to use more fuel than they would otherwise. The inclusion of the UAAPU for future studies will be recommended as a point for future studies.

It is with these data in hand that the researcher moves into his analysis of the data.

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IV. ANALYSIS

A. INTRODUCTION

This chapter analyzes the data presented in Chapter III. First, the researcher plans to analyze the data from the Battlefield Day (BFD) calculations, then from the actual data collected from the rotational unit at the National Training Center, and finally from an average Tank Battalion over a one-year time period.

B. FUEL COST SAVINGS

1. Battlefield Day Scenario

According to the data in Figures 6 and 7, the AGT 1500 uses 578.5 gallons of fuel in this Battlefield Day (BFD). In the case of the LV 100-5, the BFD calculation due to various increases in technology shows total gallons used as 435.9 over the same time period. This is an overall 24.65% fuel savings in comparison to the AGT 1500. The magnitude of this savings is further reflected in the 56% reduction in high-idle time fuel economy from 14.3 gallons used with the AGT 1500 to 6.3 gallons with the LV 100-5.

Savings Calculated Using
$1/Gallon Fuel Estimate

	Gallons	**Cost JP/gal**	**Cost / BFD**
AGT 1500	578.5	$ 1.00	$ 578.50
LV 100-5	435.9	$ 1.00	$ 435.90
		Cost Savings w/LV 100-5 per BFD	**$ 142.60**

Figure 15. Fuel Cost Savings. (After: DESC, 2001)

Figure 15 notes that there is a straight $142.60 savings per tank during one BFD scenario when considering the cost of fuel at $1 per US gallon. When considered across an entire battalion of forty-four tanks the savings is $6,274.40 per BFD.

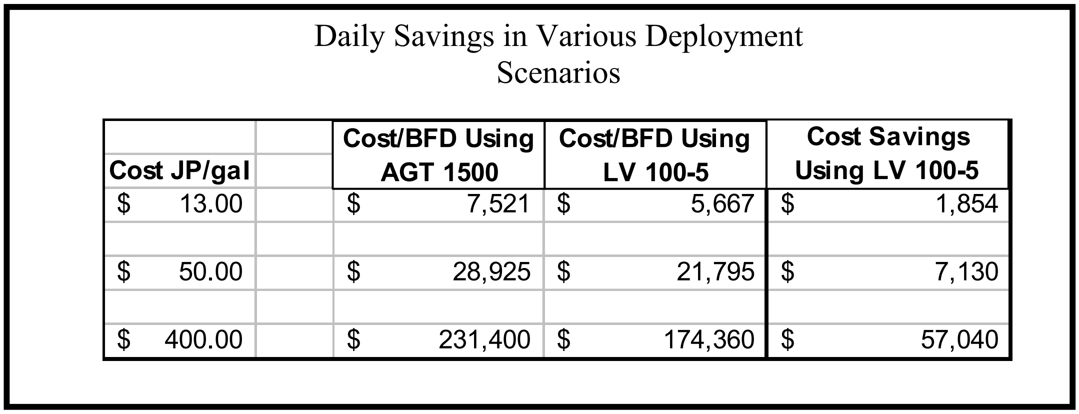
The amount listed in Figure 16, below, reflects the conservative Defense Science Board cost estimate of $13 per gallon from “well to tank.”

Savings Using Defense Science Board
Estimate of $13 Gallon

	Gallons	Cost JP/gal	Cost / BFD
AGT 1500	578.5	$ 13.00	$ 7,521
LV 100-5	435.9	$ 13.00	$ 5,667
		DSB Cost Savings Estimate per BFD	$ 1,854

Figure 16. DSB Fuel Cost Savings. (After: DSB Report, 2001)

This cost reflects a savings of $1,854 per tank in a BFD scenario. When this cost is adjusted to reflect the savings across a battalion of forty-four tanks, the savings is $81,567 per day. If the battalion sustained offensive operations for a three-day period, the savings jumps to $244,702 for the Army. It is important to remember that this estimate of $13 per gallon does not include other deployment scenarios in which a tank battalion may operate. In Figure 17, the DSB estimate is modified to fit other deployment scenarios where costs per gallon increase from $50 to $400 per gallon. The $50 per gallon estimate anticipates using 5,000-gallon tankers to resupply a unit 400km beyond the FEBA, whereas the $400 per gallon estimate anticipates resupply by CH-47 to a force 400km beyond the FEBA. (DSB Report, 2001, p. 19)



Daily Savings in Various Deployment Scenarios

Cost JP/gal		Cost/BFD Using AGT 1500	Cost/BFD Using LV 100-5	Cost Savings Using LV 100-5
$ 13.00		$ 7,521	$ 5,667	$ 1,854
$ 50.00		$ 28,925	$ 21,795	$ 7,130
$ 400.00		$ 231,400	$ 174,360	$ 57,040

Figure 17. Daily Savings in Various Deployment Scenarios. (After: DSB Report, 2001)

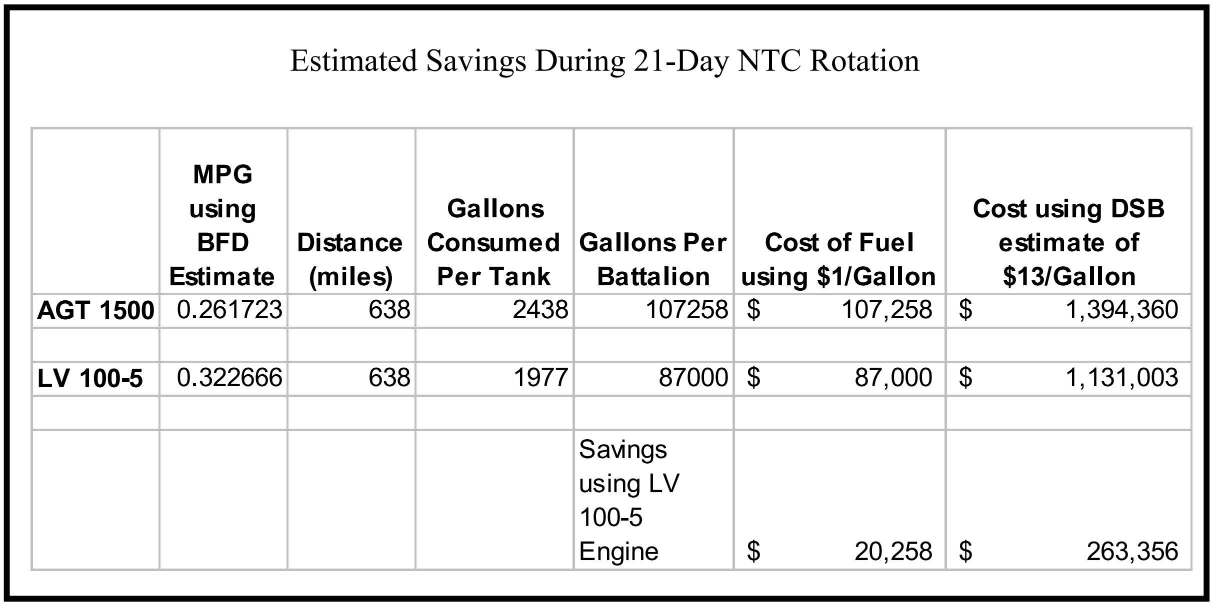
Under these varying scenarios, the 24.65% increase in fuel efficiency with the LV 100-5 under the BFD OPTEMPO, cause savings to leap upwards of $57,000 per day. Granted, the $400 per gallon handling cost is extreme, but not impossible. The $50 cost per gallon for handling is altogether reasonable given the considerations in the DSB report. If armor battalions had to operate in landlocked Afghanistan, for example, the possible costs of trucking in fuel from port, through Pakistan, to units in need make this figure plausible

The problem with the BFD estimates is that they seem to overstate mileage and hours used per day when compared to the NTC data. Whereas the BFD scenario calculates that a tank travels 140.65 miles per day, data from the NTC calculates about 30 miles per day (638 miles / 21 days) or 23 miles per day (325 miles / 21 days) for other units. In terms of hours, the BFD scenario accumulates 12 hours while moving the 140.65 miles. The average tank at the NTC however ran an average of 9.35 hours (196.31 hrs / 21 days) per day for 1-67 AR and 7.14 hours (100 hrs / 14 days) for previous units.

These discrepancies will be highlighted further in the next section as the researcher looks at cost savings associated with NTC operations.

2. National Training Center Scenario

According to the data in Figure 14, 1-67 AR tanks traveled an average of 638 miles per tank in their twenty-one day rotation. The researcher needed to translate this mileage traveled into number of galloons consumed during the rotation for estimation purposes. In order to do this the researcher used the Battlefield Day numbers as a point of reference. In the BFD scenarios each tank traveled 140.65 miles during the day ((3.4 hours * 24.9 mph) + (3.333 hours * 16.8 mph)). When comparing the miles traveled to the total gallons consumed for the day, the researcher comes up with .261723 miles per gallon for the AGT 1500 and .3226657 miles per gallon for the LV 100-5. It is with these rough estimates that the researcher developed the following cost estimates for the twenty-one day NTC scenario:

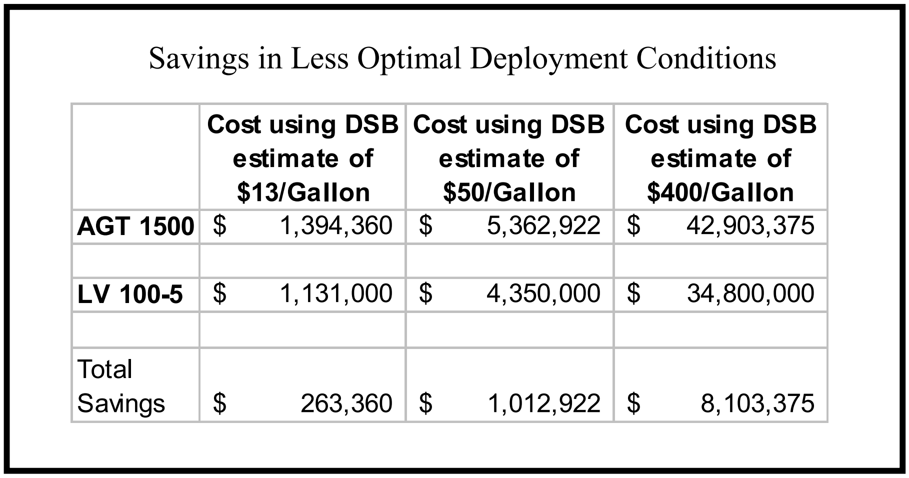


Estimated Savings During 21-Day NTC Rotation

	MPG using BFD Estimate	Distance (miles)	Gallons Consumed Per Tank	Gallons Per Battalion	Cost of Fuel using $1/Gallon	Cost using DSB estimate of $13/Gallon
AGT 1500	0.261723	638	2438	107258	$ 107,258	$ 1,394,360
LV 100-5	0.322666	638	1977	87000	$ 87,000	$ 1,131,003
				Savings using LV 100-5 Engine	$ 20,258	$ 263,356

Figure 18. NTC Fuel Cost Savings. (After: DSB Report, 2001)

These data show that a tank battalion could directly save $20,258 in fuel costs alone at $1 per gallon during a twenty-one day wartime scenario. The Defense Science Board Report estimates that this fuel-efficient engine would save the Army almost $264,000 over the same time frame. Although this is a good estimate in light of the training environment and relatively easy deployment arena offered at the NTC, different estimates of the true cost to deliver fuel in other environments may be more realistic. Figure 19 outlines the possible cost savings where delivery and handling are much more difficult at costs from $50 to $400 per gallon.



Savings in Less Optimal Deployment Conditions

	Cost using DSB estimate of $13/Gallon	Cost using DSB estimate of $50/Gallon	Cost using DSB estimate of $400/Gallon
AGT 1500	$ 1,394,360	$ 5,362,922	$ 42,903,375
LV 100-5	$ 1,131,000	$ 4,350,000	$ 34,800,000
Total Savings	$ 263,360	$ 1,012,922	$ 8,103,375

Figure 19. Savings in Less Optimal Deployment Conditions. (After: DSB Report, 2001)

The savings associated with such scenarios, as can be envisioned in the rapidly changing environment we see today, are indeed substantial. An $8.1 million dollar savings can be achieved with increased fuel efficiency in the most costly delivery scenario over the same 21-day combat scenario.

3. Life Cycle Implications for the Tank Battalion

Much of the earlier analysis focused on the one-time costs saved during a day or an NTC rotation. The researcher wanted to look into the longer-term savings associated with the move to the LV 100-5. As noted in Chapter 3, the researcher contacted an M1A1 tank battalion and asked their staff point of contact to give their yearly mileage. 1-68 Armor averaged a total of 965 miles for one year of training that included an NTC rotation. When projected over 10 years this mileage totaled 424,600 miles for the entire battalion. When using the NTC MPG estimates discussed in Figure 18, the following estimates of savings achieved by using the LV 100-5 over the AGT 1500 were discovered:

Fuel Cost Saved Per Battalion Over Ten-Year Life Cycle

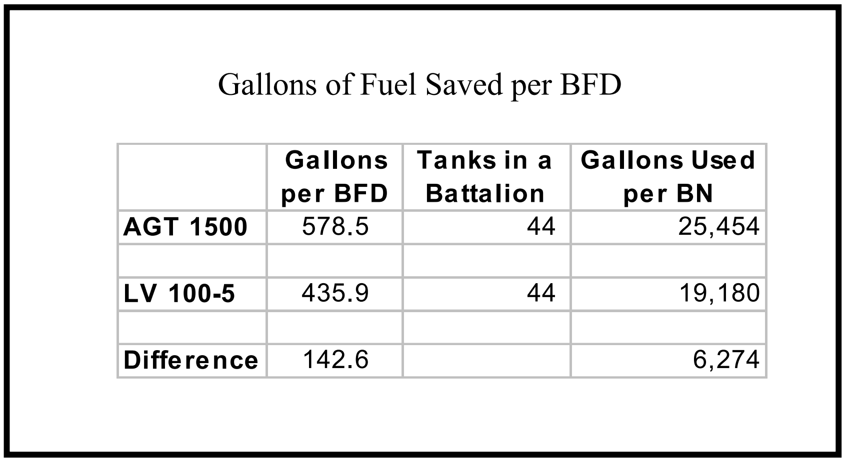
	MPG	**Distance (miles)**	**Gallons Consumed Per Tank**	**Gallons Per Battalion**	**Cost Per Battalion at $13/Gallon**
AGT 1500	0.261723	424,600	1,622,326	71,382,339	$ 927,970,411
LV 100-5	0.322666	424,600	1,315,913	57,900,173	$ 752,702,255
Difference			306,413	13,482,166	$ 175,268,156

Figure 20. Life Cycle Cost Savings Per Battalion. (After: DSB Report, 2001)

Over a ten-year period, the average tank battalion may save a total of $175.2 million in fuel costs by switching to the LV 100-5 engine. This estimate uses the $13 per gallon cost estimate to handle and deliver fuel as espoused in the DSB report. The net present value (NPV) of $175.3 million over 10 years at a 7% discount rate is $123 million. When considered over a 25-year period, the total savings jumps to $438 million ($175m * 2.5). The NPV of $438 million over 25 years at a 7% discount rate is $204 million.

C. EFFECT ON OTHER UNITS USING BFD CALCULATIONS

When looking at the numbers expressed above, the researcher wanted to further explore the Defense Science Board claim of a cost of $13-$400 per gallon from well to tank and see if this cost could relate to changes in force structure due to the potential savings. In order to do this, the researcher looked at the gallons of fuel saved and how that might impact these units.



Gallons of Fuel Saved per BFD

	Gallons per BFD	Tanks in a Battalion	Gallons Used per BN
AGT 1500	578.5	44	25,454
LV 100-5	435.9	44	19,180
Difference	142.6		6,274

Figure 21. BFD Gallons of Fuel Saved. (After: DSB Report, 2001)

1. Battalion Support Platoon

Figure 21 indicates that a battalion can save 6,274 gallons of JP-8 and the cost to deliver it in one BFD scenario. When considering that an M978 Support Platoon fueler holds 2,200 gallons of fuel, this saves the Support Platoon approximately three fuelers worth of use per BFD scenario.

As noted in the section concerning doctrine, the Support Platoon fuelers fuel a Tank Battalion two times during the day and have one or two fuelers dedicated as standby and the Combat Trains Command Post. This requires the activity of six fuelers twice a day (two per line company). The decrease in supply needed by 6,274 gallons indicates the possibility that a Support Platoon could reduce the number of fuelers required on one of the two missions per day saving almost six hours of manpower and equipment use. This decrease in asset use increases the flexibility of logistics leaders in employing their assets to best support the battalion at critical times and locations.

There is a possibility for one to interpret this data and suggest the elimination of one M978 from the Support Platoon MTOE. The cost savings could be enormous:

two soldiers at a cost of $100,000 each per year = $200,000
two slots at 77F Training school at a cost of $12,672 each = $25,344
one M978 at $237,210

This savings seems a possibility for the "older" M1A1 battalions with an MTOE of 12 M978s per Support Platoon. The reduction in fuelers from 12 to 11 per battalion still leaves enough fuelers, even at a 90% Operational Readiness (OR) rate to accomplish the mission. The previous analysis, however, only covers certain "one-time" cost savings and doesn't cover the possible recurring savings possible by reduction of one HEMTT. For example, over a twenty-year life cycle of the tank, the reduction in one HEMTT can save:

two soldiers at 100,000 per year for 20 years = $4,000,000
two slots at 77F Training school over 20 year Life Cycle = $126,720
one M978, 20-year Life Cycle Cost = $1,000,000

This indicates a 20-year savings of upwards of $5.1 million with the reduction of one M978.

The researcher does not believe that the fuel savings warrant any further reductions to M1A2 battalions operating under CSS redesign with 9 M978s per support platoon. This particular unit seems to have just enough fuelers available to accomplish the mission and further reductions would reduce effectiveness of the unit. The major problem is that further reduction would not take into account the various maintenance problems that inevitably hamper any military operation. At an operational readiness rate of 90%, a Support Platoon may only be operating with 8 fuelers at the start of an operation and this puts and inordinate strain on the logistics system.

2. Forward Support Battalion

When related to the Forward Support Battalion, a decrease in consumption of over 6,200 gallons of fuel per day saves the time and effort used to refuel two of the M969 fuel trucks in support of Brigade operations. When considering our data estimate of 3 hours to travel doctrinal distance and resupply a Battalion Support Platoon, the fuel savings offered by the LV 100-5 saves 12 man hours and gives the FSB commander greater flexibility in responding to other Brigade support requirements.

There is room under the BFD scenario to suggest the elimination of one M969 and its associated costs. Again, the savings are enormous:

2 soldiers at a cost of $100,000 each per year = $200,000
2 77F training slots = $25,344
1 M969 = $90,610
1 M932A1 Prime Mover = $86,205

As noted in the discussion with the HEMTT savings, this analysis only covers certain “one-time” cost savings and doesn’t cover the possible recurring savings possible by reduction of one M969. For example, over a twenty-year life cycle of the tank, the reduction in one HEMTT can save:

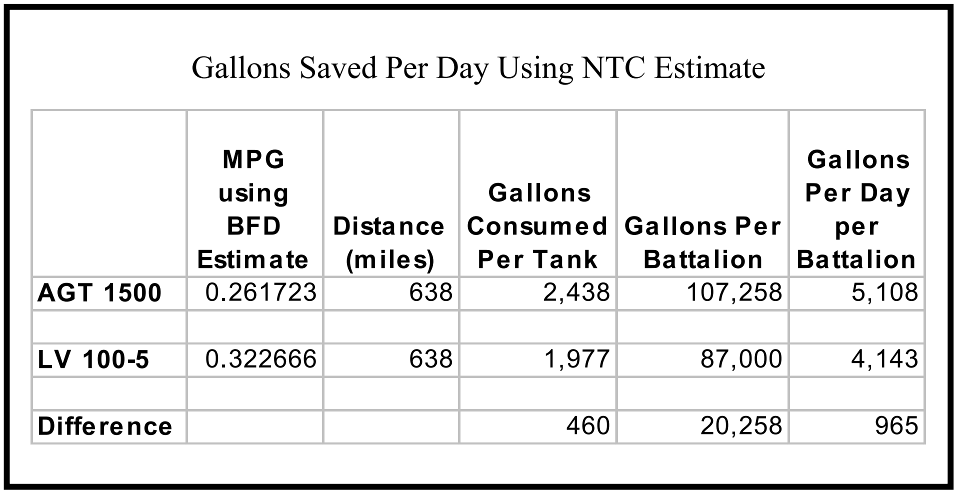
2 soldiers at 100,000 per year for 20 years = $4,000,000
2 slots at 77F Training school over 20 year Life Cycle = $126,720
1 M969 and M931 Prime Mover, 20 year Life Cycle Cost = $1,000,000

This indicates a 20-year savings of upwards of $5.1 million with the reduction of one M969 tanker.

These savings depend on the unit operating in a BFD scenario, but show the possible effect of movement to a LV 100-5 engine on the logistics system.

D. EFFECT ON OTHER UNITS USING NTC CALCULATIONS

As noted earlier, the BFD calculations differ significantly with the data collected at the NTC from operational units. The major difference is that the actual unit at the NTC maneuvers over less distance and operates for fewer hours than the scenario generated in the BFD calculation. The NTC estimate is noted below in Figure 22.



Gallons Saved Per Day Using NTC Estimate

	MPG using BFD Estimate	**Distance (miles)**	**Gallons Consumed Per Tank**	**Gallons Per Battalion**	**Gallons Per Day per Battalion**
AGT 1500	0.261723	638	2,438	107,258	5,108
LV 100-5	0.322666	638	1,977	87,000	4,143
Difference			460	20,258	965

Figure 22. NTC Gallons of Fuel Saved. (After: DSB Report, 2001)

The NTC data modified by the researcher show significantly less savings than the BFD calculations. The gallons saved per battalion drop to 965 gallons per day. The savings over the entire 21-day rotation is still an impressive 20,258 gallons, compared with that used to supply tanks with the current AGT 1500 engine.

1. Battalion Support Platoon

This 964 gallons of fuel saved per day in the NTC environment basically reflects the cost and time required for ½ of an M978 fueler. Although still significant, this amount of savings is not enough to justify any MTOE adjustment. It may save the man-hours associated with one less LOGPAC, however, and significantly increase the flexibility of the HHC commander and support platoon leader in their support of the battalion. The use of two fuelers per LOGPAC is not solely a function of quantity of fuel demanded by the unit but is also a function of the time required to fill a company with only one as compared to two fuelers.

The movement of the Force XXI M1A2 units to CSS redesign with nine M978 fuelers per Support Platoon indicates that doctrine is already anticipating increased fuel efficiency and situational awareness with the LV 100-5 and other improvements. This leaves room for the Support Platoon to operate at 90% readiness and still supply two fuelers per Company plus two on standby at the Combat Trains. This leaves little margin for error and certainly no more room for M978 reduction at the Battalion Support Platoon.

2. Forward Support Battalion

As noted in discussing the NTC data and its effect on the Battalion Support Platoon, the data does not support the consideration of adjusting the MTOE due to savings associated with the LV 100-5. The 965 fewer gallons required per day to resupply the Support Platoon, while significant, does not indicate the need to adjust the MTOE.

In addition, the FSB supports the entire maneuver Brigade. Although an Armor Battalion is a significant portion of the Brigade, there are Mechanized Infantry, Engineer, Aviation, and Support Battalions that also demand significant fuel support. The largest fuel users are typically the attached aviation assets. The FSB is required by doctrine to support these helicopters as well as the organic maneuver units. Any reduction in one of the eleven tankers may significantly impact support of such units.

As mentioned in the analysis of the HEMTT, further reductions of fuel assets may not adequately consider the likelihood that the FSB is operating at less than 100% operational readiness. If the FSB loses one or two assets to enemy fire or maintenance, their ability to provide fuel support is severely hindered. These types of doctrinal considerations make it difficult to recommend decreasing these types of assets unless the fuel savings makes more dramatic increases.

E. UNDER ARMOR AUXILLARY POWER UNIT

The data collected indicated that the tanks measured were not equipped with the Under Armor Auxiliary Power Unit (UAAPU). The researcher notes that once added to the tank, the fuel economy will again increase dramatically. The UUAPU reduces the amount of time a tank now has to run to keep its batteries fully charged. Currently the tank must run at idle every 20 minutes to keep the batteries charged and prevent the need to "jump start" the tank. This is significant because the tank must currently run at idle, where it consumes the most fuel, in order to charge its batteries.

The inclusion of the UAAPU when pursuing further studies is critical to get a better estimate of fuel use and potential savings. The result of the lack of an UAAPU is that estimates about future savings may be somewhat inflated over actual savings achieved once the UAAPU is included.

F. SUMMARY

This chapter initially analyzed the fuel cost savings given the BFD scenario. The amount of such savings is amplified as consideration is giving to the different types of deployment situations that a unit may enter. This analysis continued with the look into a twenty-one day "wartime" scenario at the NTC. Although the savings are shown to be significant, when considering different scenarios, where the cost of handling fuel increases, the implications of a more fuel-efficient engine are amplified.

The researcher then analyzed the cost savings possible when considering more than a “onetime” deployment or scenario. When projecting fuel savings over a ten and 25-year period for an “average” Tank Battalion, the savings are extraordinary.

The analysis then focused on possible MTOE adjustments due to fuel savings in both the BFD and NTC scenarios. Although the BFD scenario indicates the possibility of reducing Support Platoon fuelers, the actual NTC training data indicates that this is not definitive. In neither case did the data indicate a reduction in M969 tankers at the FSB was warranted. The primary reasons are that the amount of fuel saved is not enough and doctrinal considerations do not permit such an adjustment under the current MTOE. The chapter concludes with the note that the lack of UAAPU prevented a better estimate of the true savings that can be achieved with the LV 100-5.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

For this section the researcher will restate his primary and secondary thesis questions and summarize their answers.

1. Secondary Question I

What are the histories and specifications of the AGT 1500 and LV 100-5 engines?

The AGT 1500 turbine tank engine entered service as part of the M1 tank in 1980 and despite being 1960's era technology, has served the M1 tank family well throughout its history. The Army selected a turbine engine because US data indicated that when compared to diesel engines, the turbine had a longer life cycle, was less costly to maintain, ran on multiple types of fuel, had lower noise and smoke signatures, while still delivering the necessary horsepower to propel the tank. Fuel efficiency was neither a priority nor a major consideration. Overhauls of the engines began in the mid 1980's and continue to this day to keep performance up to standard. Overhauled AGT 1500's even provide the power in the Army's "new" M1A2 SEP and AIM tanks. Unfortunately continued overhauls without significant upgrades have degraded engine life to low levels. Currently, the AGT 1500 "constitutes over half of the Abrams' Operations and Support (O&S) costs and makes the Abrams tank the Army's most expensive ground system to operate." (Skaff, 2000) Included in this O&S cost were the increased fuel requirements demanded by a turbine engine in comparison to its diesel predecessors. Several studies showed that in extreme cases, the AGT 1500 consumed fuel at a rate 70% higher than previous diesel engine tanks.

The LV 100-5 is a 1990's technology turbine engine that builds on lessons learned from previously attempted engine upgrades and offers a lighter, less logistically burdensome, and more fuel-efficient turbine engine. Despite the need for an engine that increased reliability and performance, the Army wanted an engine that reduced O&S costs, including fuel use. The LV 100-5, developed in partnership between GE and Honeywell, was selected over other competitors in November 2000. The LV 100-5 offered commonality with the Crusader artillery system, lighter weight and smaller size than competitors, and aimed to reduce fuel use by up to 30%. The capabilities of the LV 100-5 have been proven in tests by GE/Honeywell and were verified in the October 2001 Critical Design Review (CDR). In fact GE/Honeywell representatives indicate that possibilities exist for additional fuel consumption savings as the engine design continues to be refined. The Abrams Product Manager outlines the engine production in two phases. In phase I, GE/Honeywell is to produce 13 prototypes for testing. These prototypes are due beginning in May 2002. In phase II, full production begins and the request is for 2,709 engines beginning in 2003 and continuing for eight years.

2. Secondary Question II

What is the" true" cost of fuel and what are the logistical support requirements for both engines in combat and training environments?

The Defense Energy Support Center indicates that the Standard Price of Fuel is $1.00 per gallon. This is the cost that is used as input in calculating the yearly O&S cost demanded by the Abrams tank (and other combat systems). However, the researcher used a recent Defense Science Board report that found that the "true cost" of delivering and handling fuel is indeed much higher. The DSB report indicated that this true cost is also extremely scenario-dependant and may fluctuate depending on the mission and type of deployment. To this end, the researcher used estimates ranging from $13 to $400 per gallon to estimate the true cost of fuel. This staggering adjustment is necessary to account for the personnel and equipment costs burdened on all services to get the fuel into theater and to the unit in need. It became evident that claims of the AGT 1500 making up "some 64% of all O&S costs for the Abrams" are actually much higher if the DSB estimates of the true cost of fuel are used.

The researcher went into detail outlining the equipment required to support a battalion of 44 tanks in a combat environment. The tank battalion currently has either a force of 12 M978 support platoon fuelers in direct support of the battalion or a total of 9 support platoon M978 fuelers for the M1A2 battalions operating in CSS redesign. Each M978 fueler normally carries only 2,200 gallons of its 2,500-gallon capacity due to safety restrictions. In addition to the organic fuel assets, a battalion has the support of a Forward Support Company (FSC) that provides fuel to the entire maneuver brigade. Each FSC within the support battalion has eleven M969 5,000-gallon tankers to support the brigade. Although the M969 has a capacity of 5,000 gallons, it normally only carries 3,500 gallons for safety purposes. The FSC receives its resupply from the Corps refueling assets.

Each company receives its fuel twice a day during LOGPAC resupply operations. During a LOGPAC, the Company First Sergeant (1SG) guides the Support Platoon fuelers to the company area and conducts resupply via the tailgate or service station method. Support Platoon fuelers are then taken back to a consolidation point where fuel is cross-leveled and empty fuelers are moved to FSC refuel sites where M969 tankers refuel the M978 support platoon trucks. Each fuel truck in the FSC and Support Platoon is designed to be manned by two MOS 77F petroleum operator specialists who dispense the fuel and maintain the equipment. During these resupply operations it is estimated that the company LOGPAC takes three hours for the round-trip and the resupply from the FSC takes an additional three hours, round-trip.

3. Secondary Question III

What are the cost savings and other benefits obtained by upgrading to the LV 100-5 engine?

In terms of overall fuel economy, the research showed the LV 100-5, at the current stage of its development, to be 26.75% more fuel efficient overall than the AGT 1500. This fact was confirmed during the LV 100-5's Critical Design Review (CDR) in October 2001. Figures 6 and 7 in Chapter III depict that in one 12-hour Battlefield Day (BFD) scenario the AGT 1500 uses 578 gallons and the LV 100-5 uses 435 gallons. Of particular interest within this fuel reduction was the performance of the engine at idle where the LV 100-5 displayed a 56% reduction in fuel use compared to the AGT 1500.

When further analyzing fuel cost in the BFD scenarios, it was found that use of the LV 100-5 saves $1,854 per day using the $13 per gallon estimate. When adjusting for other possible deployment scenarios, the daily savings increased to $7,130 ($50 per gallon estimate) and to $57,040 ($400 per gallon estimate).

This thesis does not address the total savings achieved through the reduced Operations and Support (O&S) cost associated with the LV 100-5 due to reduced maintenance requirements and reduced time between overhauls, although this number is likely significant.

4. Primary Question

What is the effect of a 25-30% fuel savings with the LV 100-5 engine on the logistical support of an M1 Tank Battalion in a combat scenario and during its life-cycle and how might this affect overall force structure at Brigade level?

When comparing the engines in the BFD scenario, the use of the LV 100-5 directly saves the Army $6,274 dollars worth of fuel for one tank battalion. When factoring in the Defense Science Board "true cost" of fuel for delivery from well to tank of $13 per gallon, the savings achieved by using the LV 100-5 jumps to $81,567 per day when supplying the tank battalion.

When taking data from the NTC where the Army conducts its most realistic wartime training, the savings are also shown to be significant. During the 21-day rotation of 1-67 AR, the Army could have saved $263,356 if they had use of the LV 100-5 engine in their battalion of tanks. This figure applies the $13 per gallon cost estimate espoused by the Defense Science Board. Since the NTC is a training environment where the transport and handling of fuel is relatively easy, the researcher then adjusted the cost of fuel to $50 and $400 in simulation of a more rigorous deployment environment. In these cases the savings for a battalion over 21 days varied from over $1 million to $8 million.

Based on the data and analysis the researcher believes that there are significant economies achieved with movement to the LV 100-5 engine over the AGT 1500. Distinction must be made, however, between the extent of the savings garnered between the Battlefield Day (BFD) estimates and the National Training Center (NTC) estimates for proper perspective.

When considered over a ten-year life cycle the data showed the possibility of saving over $175 million in fuel handling costs for a Tank Battalion. To reach this number the researcher calculated the total mileage driven in one year by an average tank battalion and projected a similar OPTEMPO over ten years. The $13 per gallon estimate of fuel handling cost was used in this case. Considering the Abrams is expected to remain in service until 2031, the researcher estimated a battalion fit with the LV 100-5 in 2006, with 25-years of service remaining, may save upwards of $438 million in comparison with a tank with the AGT 1500.

The research showed that a unit could save over $462,000 in one time costs by reducing one M978 from a Battalion Support Platoon and upwards of $5.1 million when considering an M978's 20-year life cycle. The adjustment of MTOE in Force XXI units to reflect CSS redesign of nine M978's per Support Platoon indicate that this savings may already have been considered. The eventual reduction in M978's in the older M1A1 battalions from 12 to 9, once the battalions are upgraded with an LV 100-5 and a UAAPU, saves an additional $15.3 million over 20 years. Further reductions are not at all justified in the M1A2 SEP battalions operating under CSS redesign with only nine M978's in their Support Platoon. The data does indicate, however, that the use of the LV 100-5 significantly increases the flexibility of logistics leaders to better support the Battalion and the Brigade.

Although the research showed the possibility of saving $402,159 in one time costs or $5.1 million with the reduction of one M969 from the FSB, this is not recommended. Doctrine permits eleven M969's per FSB to support the entire Brigade and all of its subordinate elements of which the Armor Battalion is only one part. The reduced burden offered by the tanks with the LV 100-5 allows commanders to focus their fuel priorities on the units that need it most. It also saves precious man-hours and equipment wear and tear for up to six hours per day. The hourly cost savings of such reductions is difficult to quantify but still important, especially in combat environments where the situation is fluid.

B. RECOMMENDATIONS FOR DOD

As noted in the Defense Science Board report, the Army needs to continue to focus efforts to reduce the burden placed on our logistics system with its fuel requirements. Although the Army consumes only about "5.7 percent of the DoD's total fuel," (DSB, 2001) the cost savings achieved by reducing the burden on the Army, Air Force, and Navy logistics assets to transport this fuel to theater with increasingly fuel-efficient vehicles is significant. The Army Resource Lab (ARL) estimated that increased fuel efficiency across the Army could enable some of the $3.4 billion in annual POL logistics to be diverted to other purposes. (DSB, 2001) Thus it is in the DoD's best interest, especially in this era of declining budgets, to continue to pursue such fuel efficiencies as achieved by the LV 100-5 engine. The DSB mentions a desire of the Army to achieve a 75% efficiency improvement for future combat platforms and systems. The implications of such savings would be huge in direct fuel and infrastructure costs.

Each system, as it computes LCC needs to address methods to reduce the logistics burden on the system. One method is to calculate the "true cost" of fuel per the DSB report and use that cost to guide future estimates. The DSB report noted that the Army's estimate of Total Ownership Cost (TOC) for selected systems are based on the "standard price of fuel rather than the cost of delivering fuel to the battlefield. No analysis was presented that estimated the POL logistics assets that could be eliminated or troops that could be redirected to combat functions if fuel efficiency benefits were achieved." (DSB, 2001) Using the true cost of fuel as proposed in the DSB report as calculated in this thesis will give planners a better picture of the true TOC associated with selected systems.

Second, the Army needs to continue to pursue R&D efforts to find methods to reduce fuel burden for all systems. Investment in technologies that help equipment reap savings like those achieved with the LV 100-5 should continue to be a focus for DoD as a method to reduce TOC across the Army. The incorporation of the LV 100-5 into the Crusader artillery system is a start in the right direction. Technologies need to be investigated that reduce fuel use and increase efficiency among all of the Army's top fuel users. The DSB report notes that only two of the top ten fuel users are actual "combat platforms," (the Abrams and the Apache) while the others are trucks and utility helicopters (UH-60).

In particular for the Abrams tank, the UUAPU is a critical addition to the current system to further reduce undue fuel burden. The sooner this system is incorporated with the LV 100-5, the greater the fuel and cost savings for the Army.

C. SUGGESTED FURTHER STUDIES

This study only scratches the surface of possible areas of study concerning O&S costs associated with the Army's mechanized fleet. There are many areas that would benefit Program Shops in justifying costs to implement less logistically burdensome systems for the Army.

What is the combined effect of the Under Armor Auxiliary Power Unit (UUAPU) and the LV 100-5 on the Army logistics system over a set time period?

What is the total cost savings associated with the LV 100-5 when considering all O&S costs compared to the AGT 1500?

Is the Defense Science Board's (DSB) estimate of the "true cost of fuel" for the Army the best measure of this logistical cost?

What other methods are possible in selected systems to reduce the total LCC associated with fuel use?

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