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A BUSINESS CASE ANALYSIS OF THE HARD TARGET VOID SENSING FUZE (HTVSF) JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

by

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December 2008

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13. ABSTRACT (maximum 200 words)

The Hard Target Void Sensing Fuze (HTVSF) is a Joint Capability Technology Demonstration (JCTD) initiative that is being managed by the United States Strategic Command (STRATCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature and maturing technologies and rapidly transit new capability to address military problems. HTVSF is a programmable smart fuze that shall comprise several modes, capable of counting the number of 'voids' or levels it passed through as well as functioning based on time delay. It aims to enhance weapon effects by detonating the PGMs, namely Guided Bomb Unit missiles (GBU-24 and GBU-28), with penetrator warheads such as BLU 109 and BLU 113 (Bomb Live Unit) at the desired location by functioning reliably after penetrating >10000 psi concrete.

The purpose of this study is to analyze the cost savings and the benefits of implementing the HTVSF capability. This thesis will conduct a business case analysis, including a baseline analysis and an extensive sensitivity analysis focusing on the ROI of HTVSF and its capability to support transition decisions of HTVSF JCTD.

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A BUSINESS CASE ANALYSIS OF THE HARD TARGET VOID SENSING FUZE (HTVSF) JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

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ABSTRACT

The Hard Target Void Sensing Fuze (HTVSF) is a Joint Capability Technology Demonstration (JCTD) initiative that is being managed by the United States Strategic Command (STRATCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature and maturing technologies and rapidly transit new capability to address military problems. HTVSF is a programmable smart fuze that shall comprise several modes, capable of counting the number of 'voids' or levels it passed through as well as functioning based on time delay. It aims to enhance weapon effects by detonating the PGMs, namely Guided Bomb Unit missiles (GBU-24 and GBU-28), with penetrator warheads such as BLU 109 and BLU 113 (Bomb Live Unit) at the desired location by functioning reliably after penetrating ≥ 10000 psi concrete.

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EXECUTIVE SUMMARY

The Hard Target Void Sensing Fuze (HTVSF) is a Joint Capability Technology Demonstration (JCTD) initiative managed by the United States Strategic Command (STRATCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature and maturing technologies and rapidly transit new capabilities to address military problems.

The HTVSF is a smart fuze that will comprise several modes of operation, especially the capability to count the number of 'voids' or levels it penetrates and detonate on a time delay. It aims to enhance weapon effects by detonating the Precision Guided Munitions (PGMs) (namely 2,000 lbs. and 5,000 lbs. systems) at the desired penetration location by functioning reliably after penetrating high strength concrete ($\geq$10,000 psi).[1] The JCTD seeks to develop HTVSF to be employed against a new and emerging class of hard and deeply buried targets, provide risk reduction for future weapon and fuze integration efforts, and facilitate mass production of HTVSF. The purpose of this study is to analyze cost savings, as well as other benefits associated with the execution of the HTVSF program. This thesis will conduct a business case analysis and an extensive sensitivity analysis focusing on the ROI of HTVSF and its capability to support transition decisions of HTVSF JCTD.

To establish a Business Case Analysis base case for HTVSF, a notional (hypothetical) scenario was crafted where 10 sorties of Strike Eagle Fighters (F-15Es) are tasked to perform continuous strike operations against Hard and Deeply Buried Targets (HDBTs) in Country A, 720 nm away from Alpha Air Base for a period of 24 hrs. The results of the analyses are shown in Table 1.

---

[1] The American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6000 psi. The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample pressure [1].

Table 1.   Cost Savings comparison between missiles equipped with HTVSF and
missiles equipped with FMU-143 (Base Case) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	45.18	237.41	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Line = 1 Pm_{HTVSF} = 0.9 $Pm_{FMU-143}$ = 0.4783
Operations & Support	0.01	0.02	Number of Defense Line = 2 Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	221.29	249.15	
Potential Cost Savings =	27.86		
ROI (%) =	16.92		

- Cost Savings

  - The estimated cost savings between employment of missiles equipped with HTVSF and missiles equipped with FMU-143 are summarized in Table 1 above.

  - The estimated cost to employ GBU-24 equipped with HTVSF is $221.29M (FY18$), compared to the cost of GBU-24 equipped with FMU-143 at $249.15 (FY18$). This translates to a savings of 11.2%.

  - The base case Return on Investment (ROI) is 16.92%, based on a Cost Savings of $27.86M (FY18$) and Investment of $164.57M (FY18$).

Figure 1 shows the interactions between Cost Savings, Probability of Survival of F15Es (Ps), Number of Lines of Defense and Number of missions. The following key observations are made:

- For the base case (first mission) with three lines of defense, the maximum potential cost savings is about 123M (FY18$)

- For Mission 2 and subsequent missions, the Cost Savings remains positive for all numbers of defense lines and Ps. This is intuitive as the RDT&E cost of HTVSF is considered as non –recurring from Mission 2 onwards.

- For both missions, Cost Savings for Ps=0.9 starts to decrease at around three lines of defense lines. Cost Savings for Ps=0.95 starts to decrease at about seven lines of defense. This shows that the returns of employing HTVSF diminish rapidly if Ps is low where aircraft attrition is high, regardless of the fuze employed.
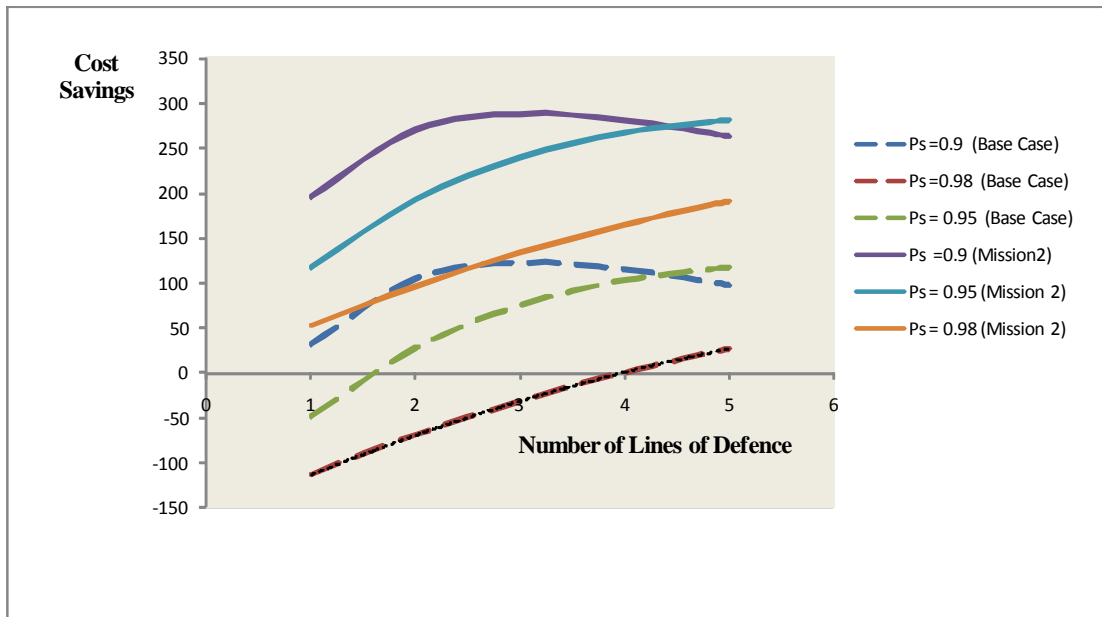
Figure 1. Interaction Plot between Cost Savings, Ps and Number of Lines of Defense

Table 2.   Cost Savings comparison of various factors used in Base Case and Sensitivity Analysis. (All costs in FY18$M)

Description	Base Case	Base Case Cost Savings	Sensitivity Analysis	Sensitivity Analysis Cost Savings
RDT&E	165		192	0.43
Subsequent Mission (RDT&E)	165		0	192.43
Subsequent Mission (Probability of Survival, Ps of F15E and Defense Layers)	• Ps = 0.95 • Number of Defense Layers =2 • RDT&E = 165		• Ps = 0.98 • Number of Defense Layers =1 • RDT&E = 0	52.06
Number of Defense Layers	2	27.86	3	75.45
Number of Defense Layers and Ps of F15E	• Number of Defense Layers =2 • Ps = 0.95		• Number of Defense Layers =3 Ps = 0.98	-31.41
First Unit Cost, T1	154		635	0
Learning Slope, b	90%		100%	5.98
Values of λ	4		3	-26.20
			5	72.43

- Sensitivity Analysis (with respect to Base Case)

Table 2 shows the summary of the cost comparison of various factors used in Base Case and Sensitivity Analysis.

- RDT&E Sensitivity. With all other factors held constant, the base case ROI never falls below 0% when the RDT&E for HTVSF increases (about 16%) from $164.57M to $192M (FY18$).

- Subsequent Mission Sensitivity. With all other factors held constant, the base case ROI increases 700% in the immediate mission after the base case in 2018. In the immediate mission where the probability of survival of F15E increased from 0.95 to 0.98 and there is only a single line of defense, there is still an increase in cost savings of 58%.

- Number of Defense Layers and Probability of survival of F15E Sensitivity. If the number of defense layers increases from 2 to 3 and the probability of survival of F15E increases from 0.95 to 0.98, there is a minor deficit in the ROI of 19%.

- Theoretical First Unit Cost Sensitivity. With all other factors held constant, the base case ROI does not fall below 0% even when the theoretical First Unit Cost increases from $154k to $635k (FY18$) (312% increase).

- Learning Slope of Production Curve Sensitivity. With all other factors held constant, the base case ROI remains positive at 3.63%, even when the learning slope increases from 90% to 100% (i.e., no learning in production line).

- Bottom Line

  - Aircraft attrition is proportional to the number of waves of F15Es sent to achieve the intended target kill. As such, the employment of missiles equipped with HTVSF saves both costs and enhances operation effectiveness compared to using the legacy fuze.

  - A low Probability of Survival of F15E will result in high aircraft attrition rates for missiles equipped with both types of fuzes. Return On Investment (ROI) for HTVSF diminishes rapidly with decreasing probability of F15E sorties crossing enemy's lines of defense.

  - As the above mentioned factors are by no means a comprehensive list, the benefits of the HTVSF should not be limited to these factors presented in this paper. The operational advantages that cannot be quantified by employing HTVSF are 1) The element of surprise created for the enemy and denial of reaction time on the first GBU-24 missile (equipped with HTVSF) strike on each target as compared to repeated strikes (missiles equipped with FMU-143) on the same target to achieve the same kill and 2) The boost in morale for the F15E pilots as their risk is greatly reduced since HTVSF equipped GBU-24 missiles ensure a high precision kill.

  - The HTVSF with programmable void sensing capability appears to be a critical investment that can provide the DoD with a new capability in Hard and Deeply Buried Target Defeat globally.

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I.   INTRODUCTION

A.   PURPOSE OF THE STUDY

The Hard Target Void Sensing Fuze (HTVSF) is a Joint Capability Technology Demonstration (JCTD) initiative managed by the United States Strategic Command (STRATCOM). As such, it is part of the JCTD Program, which seeks to accelerate the development and operational evaluation of mature and maturing technologies and rapidly transit new capabilities to address military problems. The HTVSF is a smart fuze that will feature several modes of operation, including the capability of counting the number of 'voids' or levels it passed through, as well as detonating on time delay. It aims to enhance weapon effects by detonating the PGMs (namely 2,000-lb. and 5,000-lb. systems) at the desired penetration location by functioning reliably after penetrating $\geq$10,000 psi high strength concrete. The JCTD seeks to develop HTVSF employment against the new and emerging class of hard and deeply buried targets, provide risk reduction for future weapon and fuze integration efforts, and facilitate mass production of HTVSF. The purpose of this study is to analyze the cost savings, as well as other benefits associated with the execution of the HTVSF Program. This thesis will conduct a business case analysis, including a baseline analysis and an extensive sensitivity analysis focusing on the ROI of HTVSF and its capability to support transition decisions of HTVSF JCTD.

B.   PENETRATOR WARHEAD AND FUZE

1.   Penetrator Warheads

The objective of the HTVSF JCTD is to design, develop, and demonstrate a hard target ($\geq$10,000 psi concrete) fuze with void sensing to survive and function in 2,000- and 5,000-lb. weapons, BLU 109 and BLU 113 penetrator warheads, respectively. The specifications of the two warheads are shown in Figure 2.

a.   *BLU-109 [2]*

The BLU series bomb bodies use PBNX-109 as explosive filler. The BLU-109A/B used with the GBU-24 and GBU-31 is a special purpose bomb that consists of steel alloy used for hardened targets. It is an improved 2,000-pound-class bomb designed as a penetrator without a forward fuze well. It has a slimmer

configuration and its skin is much harder than that of the standard MK-84 bomb. The skin is a single-piece, forged warhead casing of one-inch, high-grade steel. Its usual tail fuze is a mechanical-electrical FMU- 143. This 1,925-pound bomb has a 550-pound tritonal high-explosive blast warhead. The BLU-109/B was always mated with a laser guidance kit to form a laser-guided bomb in Desert Storm (for example).

b.   BLU-113 [3]

The Guided Bomb Unit-28 (GBU-28) is a special weapon originally intended for penetrating hardened Iraqi command centers located deep underground. It is a 5,000-pound laser-guided conventional munitions that uses a 4,400-pound penetrating warhead (BLU 113). The GBU 28 "Bunker Buster" was put together in record time to support targeting of the Iraqi hardened command bunkers by adapting existing material. Work on the bomb was conducted in research laboratories, including the Air Force Research Laboratory Munitions Directorate located at Eglin AFB, Florida and the Watervliet Armory in New York.

It was proven that the bomb could penetrate over 20 feet of concrete, while an earlier flight test had demonstrated the bomb's ability to penetrate more than 100 feet of earth. The Air Force produced a limited quantity of the GBU-28s during Operation Desert Storm to attack multi-layered, hardened underground targets. Only two of these weapons were dropped in Desert Storm, both by F-111Fs. One weapon hit its precise aim point, and the onboard aircraft video recorder displayed an outpouring of smoke from an entrance way approximately 6 seconds after impact. After Operation Desert Storm, the Air Force incorporated some modifications, and further tested the munitions. The FY1997 budget request contained $18.4 million to procure 161 GBU-28 hard target penetrator bombs.

S/N0	Specifications	GBU-24 BLU 109	GBU-28 (BLU 113)
1	Mission	Offensive counter air, close air support, interdiction	Offensive counter air, close air support, interdiction
2	Target	Fixed hard	Fixed hard
3	Class	2,000 lb. Penetrator, Blast/Fragmentation	4,000 lb. Penetrator, Blast/Fragmentation
4	Weight (lbs.)	1950	4,414
5	Length (in.)	98.54	153
6	Diameter (in.)	14.5	14.5
7	Explosive	535 lbs. Tritonal	647lbs. Tritonal
8	Fuze	FMU-143 Series	FMU-143 Series
11	Unit Cost	$2,126	$1,165.00
12	Platforms	F-117 F-15E F-16A-D F-111D-F	F-15E, F-111F

Figure 2.   Specifications of BLU 109 and BLU 113

2.   Warhead Fuze

- What is a fuze?

A fuze is a weapon subsystem/device that keeps the warhead safe for storage, transportation, handling and deployment.

- Basic Functions of a Fuze

  - Safing - Keeping the weapon safe.

  - Arming - Getting the fuze ready to fire the warhead.

  - Sensing - Recognizing or detecting the presence of possible target or a collision.

  - Firing - Igniting the warhead at the most optimal time or preset delay time.

- 2 Main States of Fuze

The fuze is essentially a binary state mechanism. The two states that the fuze can be in are Safe state and Armed state.

  - Safe State. In the safe state, the fuze is prevented from igniting the warhead and will be safe for all logistics and operational deployment activities.

- **Armed State**. When a fuze is in the armed state, it means that all safeguards have been removed and the fuze is ready to ignite the warhead. It requires only a stimulus to ignite the warhead.

3. Basic Fuze System

Figure 3 shows the setup of a basic fuze system in a typical munition.
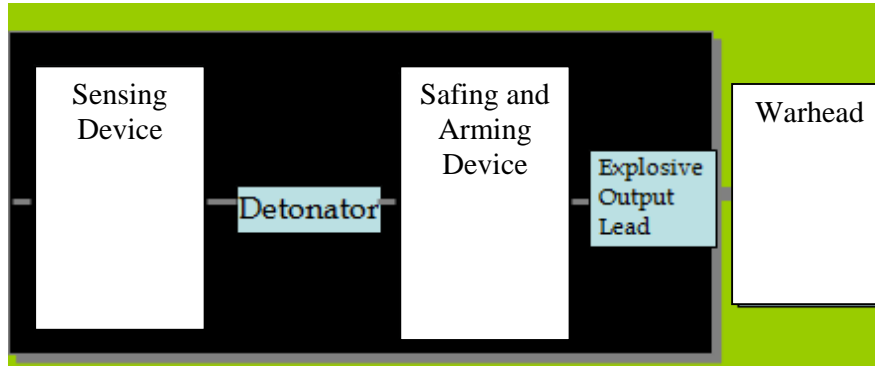
Figure 3.   Basic Fuze System Setup (After: [4])

C. HARD AND DEEPLY BURIED TARGET DEFEAT

1. Concept of Operations

Hard and Deeply Buried Target Defeat (HDBTD) is the capability to deny sanctuary to adversaries by developing end-to-end capabilities for detection, characterization, target planning, defeat, and combat assessment directed at HDBTs, and other hard-to-defeat, high-value facilities. HDBTD employs a full range of measures to destroy, disrupt, or deny HDBTs as well as mission-critical elements within the networks that support, or are supported, by such facilities. This Joint War-fighting Capability Objective (JWCO) was validated by the Joint Chiefs of Staff (JCS) on December 22, 1999 [5]. Figure 4 shows the pictorial form of the concept of operations employed for HDBTD.
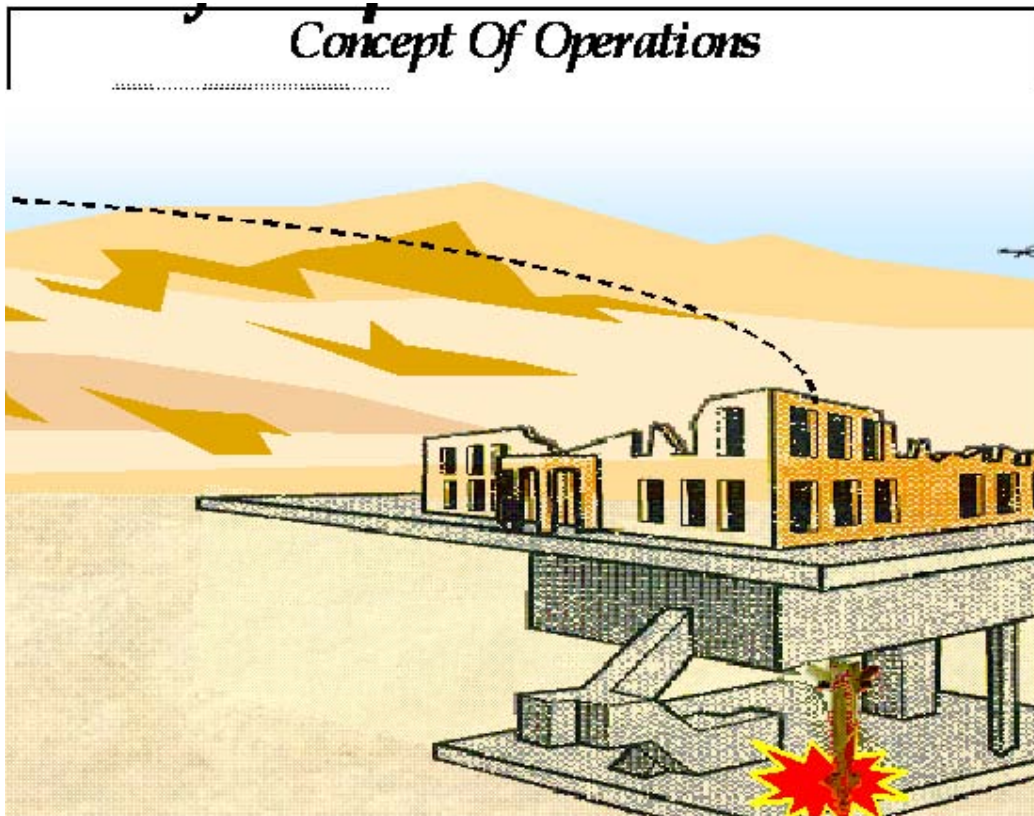
Figure 4.   HDBTD Concept of Operations

2.   Hard and Deeply Buried Targets

Hard and Deeply Buried Targets (HDBTs) are underground command and control bunkers, leadership quarters, garrisons, etc built out of reinforced concrete or tunneled into mountains. Due largely to the Gulf War and the present war in Afghanistan, U.S. military planners are particularly keen to find ways to destroy HDBTs. It is estimated that there are as many as 10,000 HDBT s worldwide, not all of which can be destroyed by conventional weapons. HDBTs involve all types of hardened above ground, shallow underground, and deep underground structures. Deeply buried facilities are extremely challenging targets. HDBTs differ with respect to function, which ranges from C4I operations; basing for surface-to-surface missiles; aircraft, artillery and other systems; and production and storage of Weapon of Mass Destruction (WMD) related or conventional munitions [6]. The main challenges posed by HDBTs are as follows:

- Depth of burial or other protective cover such as reinforced pre-stressed steel tendon

- Physical extent of layout

- Infrastructure features (external and internal)

- Active and passive defenses

- Camouflage, concealment, and deception (CC&D) measures

- Proximity of civilian populations, cultural sites, and other juxtapositions impacting collateral damage assessments

- Susceptibility to hard, functional, and full-dimensional defeat

- Sensitivity to time of delivery

D.   PROBLEM STATEMENT [7], [8]

Operation Iraqi Freedom (OIF) reinforced the need to hold hard and deeply buried targets at risk. A reliable fuze that survives penetration and detonates the warhead in the desired location is critical to successfully doing that. Post OIF analysis indicates the intelligence available was less accurate than required for successful weaponeering. Additionally, the post OIF Combat Weapons Evaluation Assessment Team (CWEAT) report and other sources indicate that there is a trend toward harder/deeper targets exceeding the design parameters of existing fuzes and warheads. Finally, development and operational test as well as post OIF analysis show that current fuzes are unreliable at long time delays. Fuzes such as FMU-143 and FMU-152 are sensitive to intelligence uncertainties and not designed for very hard targets. These limitations dictate a reliable, void sensing fuze capability designed for $\geq$10,000 psi concrete is required if hard and deeply buried targets are to be held at risk. At the HTVSF JCTD level, two main problems that are often faced by decision-makers are as follows:

1.   What are the Technological Risks Involved?

Mature technology exists to sense voids in hardened targets. Hard Target Smart Fuze (HTSF) [9] and Multi-Event Hard Target Fuze (MEHTF) both use hardened accelerometers to report data during hard target penetration. Numerous market sources have tested prototype hardware in high psi concrete targets, so the leap to greater than 10,000 psi seems an achievable increment in technology. However, some of the risks involved that require addressing are as follows.

- A problem exists in the ability to mass produce. Solving this problem is a focus of this JCTD.

- There are other alternatives available to address the problem mentioned above, such as simpler, cheaper strain gauge technology (replacing more complex accelerometers) combined with void sensing algorithms that could be used to detect layers in hard targets. Current strain gauge configurations have been shown to survive and record target layers/voids, but are at a lower Technology Readiness Level (TRL) than the HTSF and MEHTF fuzes have demonstrated. However, if strain gauge technology is successful, it may provide a cheaper and more reliable technology for void sensing in later generations of fuzes.

- Challenges to developing potential technologies for HTVSF remains. Figures 5 and 6 show the TRL of HTVSF core technologies and its definitions, respectively.

Figure 5.   TRL of HTVSF Core Technologies (From: [7])

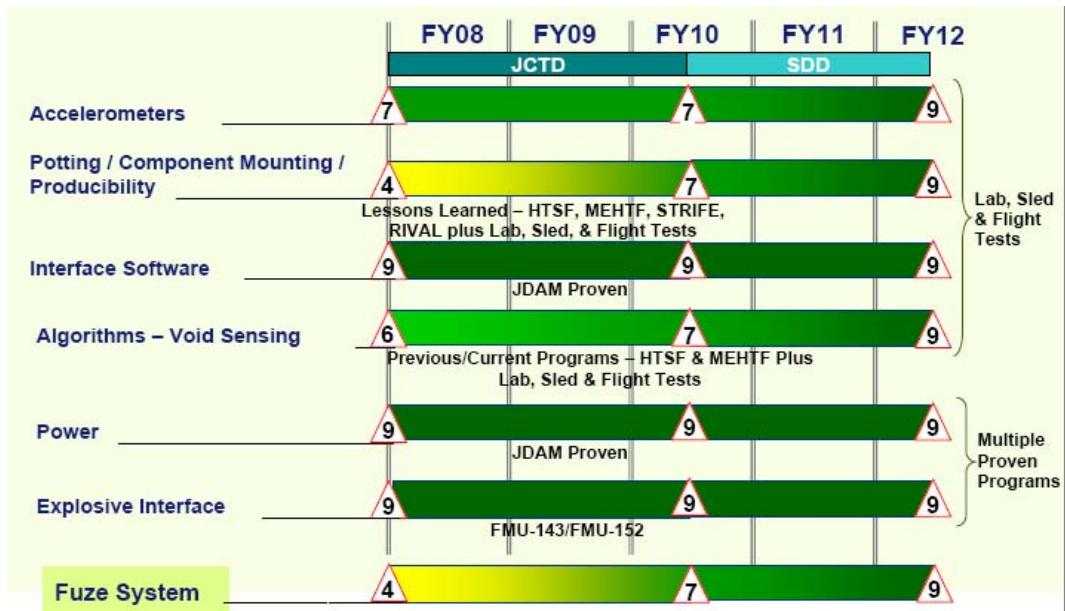| Technology readiness level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard. Validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for technology readiness level (TRL) 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system "flight proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Figure 6.   TRL and its Definitions (From: [10])

2.   Does the HTVSF Supplement, Complement or Replace an Existing Program?

HTVSF would complement existing fuzes. The FMU-143 and FMU-152 are still appropriate for BLU-109 applications against 5,000 psi targets where void sensing is not required. HTVSF would be used for ≥10,000 psi targets with high intelligence uncertainty. The Joint or Combined forces will benefit from this capability because HTVSF will be compatible with legacy hard target weapons, such as the BLU-113 and the BLU-109 (BLU-109 is used by USAF and USN). Future penetrators e.g., boosted penetrators, massive ordnance penetrator, or possibly high speed weapons could also take advantage of this fuze [11].

E.   RESEARCH METHODOLOGY, LIMITATIONS AND ASSUMPTIONS

To achieve the objectives set out in Section A, the author will develop and recommend an analytical structure for performing business case analyses (BCA). The BCA for the HTVSF JCTD will then be conducted based on that structure, results reported, with appropriate recommendations reported for decision makers. The

comprehensiveness of the BCA presented is necessarily limited to the data and information made available to the author. However, the method that estimates cost saving and benefits obtained specific to this operational scenario can also be used to derive the savings and benefits for other, reasonably similar cases. Key assumptions made while performing the BCA are as follows:

- A conservative approach is adopted, i.e., whenever a choice had to made between higher and lower costs due to ambiguity in the data, the higher cost is used.

- Where information is not available, or cannot be made available to the author, estimates are used and reasonable assumptions are made and described in regards to how they are derived.

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II. BACKGROUND

This section provides an overview of the current technologies that are currently employed in PGMs. It also includes new technologies that are being developed to enhance the survivability of fuzes after penetration, as well as addressing the problem of detonation by preset delay. A summary of the Joint Capability Technology Demonstration (JCTD) Program is also provided here, with details on the history and development of the HTVSF JCTD Program. Finally, the section concludes with an overview of the Business Case Analysis (BCA) methodology.

A. CURRENT TECHNOLOGIES

1. Current Technologies

Standard fuzes found in penetrator warheads are equipped with preset delay mechanisms for detonation and are designed to penetrate and survive ~5000 psi concrete. However, as construction techniques and materials progress, targets are getting harder. A new smart fuze, designed to function reliably after penetrating ≥10,000 psi concrete, is required to counter the next generation of hard targets. It ignites the warhead at a desired time when the weapon is at its optimal location. The smart fuze will feature several modes of operation. However, the key capability is counting the number of voids based on sensing changes in acceleration, as there is limited intelligence on target protection levels. The development initiative of this smart fuze is termed as Hard Target Void Sensing Fuze (HTVSF).

2. Legacy and Current Trends of Fuzes

"Some of us worry that we're not working on the new technologies of the future that we need to be … fuzes on hand are not smart enough ... not rugged enough ... not durable enough at the price we've been paying for them, and we're not putting enough money into the R&D of making them better," as stated by Maj. Gen. Robert W. Chedister [12]. Improving Coalition Forces' ability to hold hard or deeply buried targets at risk requires a reliable fuze that can sense when it enters a void. The void-sensing capability mitigates a substantial part of the intelligence uncertainty surrounding targets because the weaponeering no longer needs to select a single time

delay based on the estimated thicknesses of target layers and estimated concrete strength. The previous projects, Hard Target Smart Fuze (HTSF) and Multi-Event Hard Target Fuze (MEHTF) successfully tested void sensing/layer counting ability [13]. HTSF and MEHTF both used hardened accelerometers to report data during hard target penetration. Numerous sources have tested prototype hardware in high psi concrete targets, so the leap to greater than 10,000 psi seems an achievable increment in technology. Both fuzes show that fuze initiation within a specific void or floor layer is technically feasible.

3. Types of Legacy Fuzes in BLU-10 and BLU-113

a. FMU-157/B Hard Target Smart Fuze (HTSF)

A predecessor of HTVSF, the Hard Target Smart Fuze (HTSF) enables precision bombs with penetrating warheads to detonate at a desired point inside buried or reinforced concrete targets, such as underground bunkers and command centers. Similar to HTVSF, detonation occurs after a sensor tells the fuze that the weapon has passed through a pre-programmed number of hard layers or voids in the target. The HTSF, designated the FMU-157/B, is an active decision-making, accelerometer-based fuze system capable of counting layers and voids (floors), as well as calculating distance travelled. When the weapon reaches the pre-determined floor, it tells the bomb to explode. The HTSF is compatible with a variety of penetrating warheads.

b. FMU-143B/B

The FMU-143B/B Fuze System is an electromechanical fuze system that provides impact delay detonation for penetrating warheads. The fuze contains an explosive train, which is mechanically and electrically out-of-line until specific weapon launch cycle events have occurred. Once a valid launch has occurred, the fuze will arm in the selected arm time. This configuration has a selectable arm time of 5.5 and 12 seconds. It has a fixed detonation delay after impact of 60 milliseconds. The fuze is powered by an air-driven turbine generator power supply called the FZU-32 fuze initiator. The initiator is non-explosive and has no specific safety requirements. The fuze is equipped with a safety release assembly (housing and safety release shaft), and a connector to accept operating power. The fuze has a screwdriver-adjustable selector feature to select arming delay times. The fuze is threaded into the fuze well,

which is located at the aft end of the penetrator warhead. Prior to operational use, the fuze may be stored, transported worldwide, installed in a weapon, loaded on an aircraft, and flown during captive carriage without release [14].

c. FMU-152A/B (JPF)

The FMU-152A/B, Joint Programmable Fuze (JPF) is a multifunction, multi-delay tail fuze system with hardened target capability for use in general purpose and penetrating unitary warheads. The JPF operates with a wide variety of guidance kits, high and low drag fins, and with all configurations of the DSU-33 proximity sensor to provide an airburst capability. When used with the Joint Direct Attack Munition (JDAM), the JPF operating mode and other settings may be selected in flight from the cockpit through a serial RS-422 interface between the weapon and fuze [15].

B. JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

The Joint Capability Technology Demonstration (JCTD) Program is partly related to the Advanced Concept Technology Demonstration (ACTD) Program, which had its inception in 1994 by the Department of Defense (DoD) [16], [17], [18], [19].

1. The ACTD Program [19]

The Deputy Under Secretary of Defense (Advanced Technology) (DUSD/ AS&C) has oversight responsibility for the ACTD program. He is responsible for developing and promulgating guidance regarding the ACTD program, for evaluating candidates and approving new ACTDs, and for providing oversight, support and evaluation of ongoing ACTDs.

ACTDs exploit mature advanced technologies to develop solutions for important military problems. Declining budget, significant changes in threats and acceleration in the pace of technology have created challenges to our ability to address significant military needs. In addition, global proliferations of military technologies, and potential adversaries with relatively easy access to these technologies, have increased the need to rapidly transition new technology from the developer to the user. The ACTDs are structured to address the needs of the warfighter by providing needed capabilities, addressing deficiencies, and reducing

costs or manpower requirements. Each ACTD is aimed at one or more warfighting objectives and is reviewed by the Services, Defense Agencies and the Joint Staff. Candidates will be proposed for initiation in each fiscal year. These candidates are reviewed for technical maturity and projected effectiveness. Those with the greatest potential will be submitted to the Joint Staff/Joint Requirements Oversight Council (JROC) for prioritization.

ACTDs can be characterized by their employment of mature technologies over a fixed period of activity. They can also leverage existing technological investments. There is also a residual capability after the completion of the ACTD demonstration. In addition, ACTDs have a heavy focus on joint operations with Combatant Command warfighter participation, as well as a significant level of cross-service, cross agency/organization involvement.

The guidelines developed to provide guidance for the selection criteria for ACTD candidates are given as follows:

- The time for complete evaluation of military utility is about 2–4 years
- The technology should be sufficiently mature
- The project shall provide a potentially effective response to a priority military need
- A lead service or agency has been designated
- The risks have been identified, are understood, and accepted
- Demonstrations or exercises have been identified that will provide an adequate basis for the utility assessment
- Funding is sufficient to complete the planned assessment of utility and to provide technical support for the first two years of fielding the interim capability
- The developer is ready to prepare a plan that covers all essential aspects. These include affordability, interoperability, sustainability, and evolutionary capability, vis-à-vis technology and threat changes.

The objectives of ACTDs are to conduct meaningful demonstrations of military utility, develop and test concepts of operations to optimize military effectiveness, and prepare to transition to acquisition without loss of momentum. Another major ACTD goal is to promote operational "jointness" to reach beyond individual Service interests and capabilities for integrated, joint missions. The interests of the warfighter are paramount and, therefore, "guidelines" regarding

ACTDs mentioned above are considered flexible. Last but not least, the ACTD is to provide a residual capability to further refine Concept of Operations (CONOPS) and to permit continued use prior to formal acquisition, as well as to provide the ability to proceed into formal acquisition for additional capability, if required.

Possible outcomes after the ACTD operational demonstration are as follows [16]:

- The user-sponsor may recommend acquisition of the technology and field the residual capability that remains at the completion of the demonstration phase of the ACTD to provide an interim and limited operational capability

- If the user's need is fully satisfied by the residual capability remaining at the conclusion of the ACTD, there is no requirement to acquire any additional units of the system

- If the capability is deemed to not demonstrate sufficient military utility, the project is terminated or returned to the technology base for further development

2. The JCTD Program [19]

Since FY2006, a new business process called the JCTD model was initiated that takes the successful ACTD program and modifies it to better meet the Department's transformational goal of becoming capability based. This capability based approach is intended to provide a faster and more integrated joint response that will meet emerging asymmetrical threats. The JCTD model includes many positive aspects of the ACTD program and is integrated with the Joint Capability Integration and Development System (JCIDS) developed by the Joint Chiefs of Staff (JCS). Current ACTD processes will be transited to the improved JCTD program over a 3-5 year period, with the intent of having JCTDs replace ACTDs. It will focus on joint and transformational technologies that are initiated in Science and Technology (S&T), and carried through the difficult transition stage. The new JCTD business model will also include a Defense Acquisition Executive (DAE) pilot program that will take a limited number of "joint peculiar" JCTDs past Milestone B, into procurement, followed by initial sustainment, which is essentially a "cradle-to-grave" approach.

The JCTD program comprises three possible transition models post-demonstrations, as follows:

- Transition to Program of Record (POR). Once the military utility of the program has been successfully demonstrated, the concepts will be adopted by the warfighters. Technology or system will be transferred to a new/current POR or GSA (Government Services Administration) schedule. The acquisition of additional capability will also be funded.

- Interim Capability to Meet Needs of the Warfighter. Same as above. However, the technology and system may or may not have been sent to a POR. This interim capability fully meets the warfighter's needs and is being maintained.

- Return to Technology Base. The military utility is deemed to be not successfully demonstrated. Relevant components or capabilities may be incorporated into other systems, returned to the technology base or terminated.

C.   THE HARD TARGET VOID SENSING FUZE JCTD

The 708th Armament Systems Group (708 ARSG), 308th Armament Systems Wing (ARSW), Eglin AFB, FL plan to fund a Joint Capabilities Technology Demonstration (JCTD) of a Hard Target Void Sensing Fuze System (HTVSF), a cockpit programmable system that will provide multi-delay arming and detonation, as well as void sensing functions for a BLU-113 or BLU-109 weapon to penetrate and destroy hardened targets protected by multiple layers of reinforced material. A quick overview of the HTVSF JCTD is illustrated the Quad Chart in Figure 7.
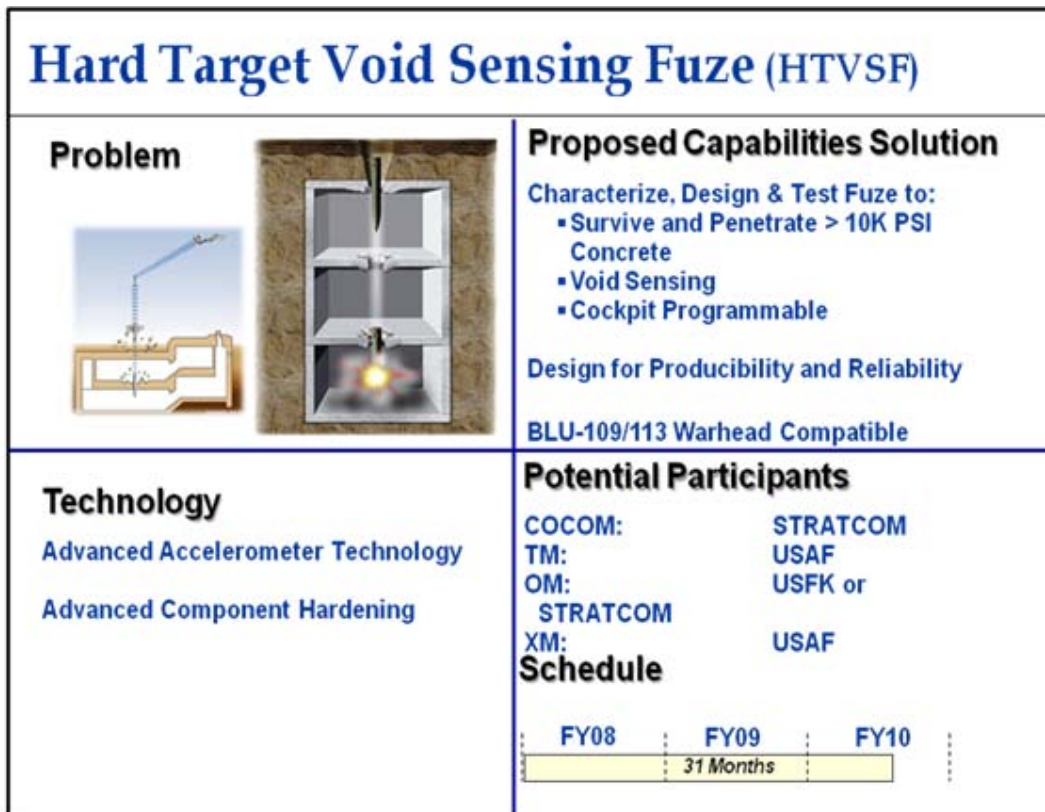
Figure 7.　HTVSF Quad Chart (From: [7])

1.　Program Schedule

The 27-month JCTD will engage two contractors with a firm fixed price contract of \$8.6m per contractor inclusive of 20 residual fuzes. A rolling-down select[2] method is used to select the award of a contract in both the SDD and production phase. A sole contractor will be selected from the winner of the JCTD at an estimated contract value of \$42.4m and \$195m for 33 months SDD and production phase from FY2013 onwards respectively [21].

2.　The JCTD Program

The demonstration will conduct the activities shown in Figure 8. The objective of these activities is to design, develop, and demonstrate a hard target ($\geq$10,000 psi

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[2] Rolling down select across multiple phases of a program is used to reduce the number of separate, formal source selections which would otherwise occur. When the risks and funding for a major program or a multi-phased laboratory effort justify multiple awards for the first segment of the acquisition, and a reduced number of industry participants for the follow-on segment, a rolling down select can be used effectively to avoid delays, which would otherwise occur from sequential use of a traditional selection process [20].

concrete) fuze with void sensing to survive and function with 2000- and 5000-lb systems. Two contractors will be selected for award of separate JCTD contracts to design, test, and demonstrate the capabilities of each of their proposed HTVSF systems. They will seek to meet the requirements specified in the System Requirements Document (SRD) [22]. On 31 March 2008, the contract was awarded to Alliant Techsystems Inc. [23] and Thales Missile Electronics LTD [24] at a contract amount of $8,737,741 and $8,770,000, respectively. During a planned 27 month period of performance, the two JCTD contractors will be evaluated against predetermined evaluation criteria, and one will be selected to deliver 20 residual HTVSF JCTD assets and will be awarded a follow-on System Demonstration and Development (SDD) contract. The single SDD contractor is expected to receive a sole-source follow-on production contract award for production of the HTVSF at an estimated contract value of $42.4 mil for 33 months. Pending a final determination regarding foreign source participation, the Government anticipates awarding one JCTD contract under full and open competition and the other under a competition restricted to U.S. sources only [25].

3. Program Exit Criteria

The exit criteria for the HTVSF JCTD are as follows:

- Survive and function during demonstration while penetrating 5000-15000 psi concrete
- Demonstrate successful capability for detecting and counting more than one void during target penetration
- Demonstrate Time-delay Capabilities
- Demonstrate Cockpit Programmability
- Demonstrate trend toward affordability goal
- Manufacturing capability to produce up to 100 fuzes per month

D. BUSINESS CASE ANALYSES [19], [26]

A Business Case Analysis (BCA) is a basic financial tool used by decision makers to evaluate alternative approaches and to decide on the best courses of action, with due regard for allocation of scarce resources. The BCA, which is a reasonably

well structured and systematic methodology, provides a best-value analysis that considers not only cost, but also other quantifiable and non-quantifiable factors that are relevant to the investment decision.

The BCA framework is an iterative process that is updated as the business and mission environment changes. It consists of the following elements:

- Determine objectives of the case
- Specify assumptions and constraints
- Identify possible alternatives, including the status quo
- Estimate costs and benefits of every alternative
- Perform sensitivity analysis and risk analysis
- Derive conclusions and make suitable recommendations

A sound and reliable BCA is an unbiased and objective analysis of the financial consequences of the various alternatives. The reliability of the BCA is crucial in aiding the decision maker to make an informed choice. It is based on facts, reasonable assumptions, and sound financial principles with its conclusions traceable and transparent whenever possible. As a decision-making tool, a high-quality BCA process provides the decision maker with the relevant insights as to how the project supports the strategic objectives and how it can help achieve these objectives. This assessment is structured such that important information on the scope, alternatives, costs and benefits are laid out clearly, with the potential risks highlighted so that the decision-maker can make an informed decision on whether to invest in the project.

As every BCA differs in the objectives, assumptions, constraints, risk and operating scenario, it is natural to expect that each BCA is customized for the particular case within a specific operating environment. However, a generic BCA methodology can be described as a 4-phase process, as shown in Figure 8.

Figure 8.   BCA methodology

The basic steps to the above mentioned process are as follows.

1. Definition

In the first phase, the scope, assumptions and constraints will be defined to guide the analysis. Alternative options are also explored to ensure that there is a minimum of two outcomes (one of which could be maintaining the current status quo) available at the end of the analysis.

2. Collection of Data

In the second phase, a data collection plan is devised, so that the types of data required, the data sources, and how they can be obtained, can be mapped out. Models will also have to be developed so that the data can be categorized and stored, while preserving the data integrity. Data normalization is also applied where required. Where the data is not available, estimates can be made, as long as they can be justified, and the methodology adopted explained clearly.

3. Analysis

The third phase is where most of the BCA calculations are being accomplished. Data analysis is performed to build the case for each alternative. Each alternative is compared against the baseline so as to determine which one provides the best value. Risk analysis must be performed to identify the set of risks associated with each alternative, along with proposed risk-mitigating strategies. Sensitivity analysis aims to provide insights to the BCA results if the input parameters change or if assumptions change or are proven invalid.

4. Presentation of Results

In this last phase, the BCA results are summarized into appropriate graphs and tables for representation to the decision makers. The information presented should be concise, with relevant supporting evidence from the previous phases. A conclusion and recommended course of action should also be provided to the decision maker based on the objectives defined in phase 1. The BCA should be able to determine the following.

- Relative costs and benefits of various alternatives

- Methods and rationale used to quantify benefits and costs

- Influence and value of Performance / Cost / Schedule / Sustainment tradeoffs

- Data required in support and justification of the decision

- Sensitivity Analysis of assumptions

- Risk Analysis of recommended decision

- Recommendation and summary of the implementation of the decision for proceeding with the best value alternative

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III.   HARD TARGET VOID SENSING FUZE (HTVSF)
BUSINESS CASE ANALYSIS

This section illustrates how the comparison of capabilities between HTVSF and legacy fuze (FMU-143) in a GBU-24 missile system carried by F15E will be conducted. Our hypothetical planning scenario describes the 24 hours strike operations on HDBTs using F15Es. The business case analysis will be performed based on the comparison of these F15Es performing strike operations using the two types of fuzes, namely HTVSF and FMU-143, in the GBU-24 missiles. First, the scenario on which the analysis is performed will be elaborated. The available data will then be analyzed. Next, a computation of return-on-investment (ROI), as well as sensitivity analysis on the key results, will be included. Finally, a general risk assessment for the HTVSF is made.

The purpose of this analysis is to compare the benefits that HTVSF brings, vis-à-vis the existing FMU-143 fuze used in BLU-109 warheads as part of the GBU-24 missile system. This analysis also factors in the platform support provided by F15E to perform HDBTD operations, and the considerations on aircraft attrition cost inflicted by the enemy's air defense layers. An operational advantage to using HTVSF that cannot be quantified is the element of surprise and denial of reaction time for the enemy forces when the enemy target is destroyed with a single GBU-24 using HTVSF. This is compared to multiple bomb attacks using FMU-143 where the enemy would be alerted and has sufficient reaction time to escape before the next attack.

A.   CAN HTVSF FILL THE GAP?

The February 2004 Defense Science Board Summer Study Task Force on Future Strategic Strike Forces looked ahead 30 years with the objective of providing the President with a broad range of strike options to protect the United States and her forces abroad, assure friends and allies of her future commitment, and deal with future adversaries on terms favorable to the United States. The Task Force identified currently planned systems that will still be relevant and recommended new systems for development.

The DSB Task Force recommended that USD (AT&L) immediately undertake an Advanced Concept Technology Demonstration (ACTD) for a bomber-delivered massive penetrator. A family of massive ordnance payloads (20-30 klb.), both penetrator and blast variants, would be developed to improve conventional attack effectiveness against deep, expansive, underground tunnel facilities.

A deep underground tunnel facility in rock geology poses a significant challenge for non-nuclear weapons. Such a target is difficult to penetrate, except possibly near an adit,[3] and the likelihood of damaging critical functional components deep within the facility from an energy release at the adit is low. Past test experience has shown that 2,000 lb. penetrators carrying 500 lbs. of high explosives are relatively ineffective against tunnels, even when skipped directly into the tunnel entrance.

Instead, several thousand pounds of high explosives coupled to the tunnel are needed to blow down blast doors and propagate a lethal air blast throughout a typical tunnel complex. This can be achieved either by an accurate blast weapon situated in front of the tunnel entrance or a penetrator that has burrowed directly into the tunnel. In both cases, the munition must be on the order of 20- to 30- klb to couple a sufficient amount of energy to the tunnel.

The penetrator requires sufficient weight for penetration; the blast weapon requires sufficient weight for carrying high explosives. Optimized penetrators of this size may penetrate about 5 to 8 times farther than an existing 2,000 lb. weapon and may also be suitable for housing a clean, low-yield nuclear weapon. Using the tactic of optimum dual delivery, where a second penetrator follows immediately behind the first penetrator and boosting the penetrator velocity with a rocket motor, a depth of up to 40 meters can be achieved in moderately hard rock. In view of the promise of such a massive penetrator for both conventional and nuclear payloads, the DSB Task Force recommended an immediate start on an ACTD-like demonstration of this capability [27].

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[3] An adit is a type of entrance to an underground mine which is horizontal or nearly horizontal [1]. Adits are usually built into the side of a hill or mountain, and often occur when a measure of coal or an ore body is located inside the mountain but above the adjacent valley floor or coastal plain [28].

B. HYPOTHETICAL OPERATION SCENARIO

1. Background

In early 2018, tension over Country A and Country B was growing again when Country B initiated massive campaigns to declare its independence from Country A. This move was supported by the U.S. and this highly escalated the situation between the two nations. U.S. facilities in the region sit within the conflict zone which is a swath of land and sea along Country A's coast. This is an area reachable by cruise missiles, jet-borne precision bombs and local covert operatives. There are five U.S. Air Force bases within this area. In a conflict over Country B, any nation allowing "an intervening superpower" such as the U.S. to operate inside its territory can expect a Country A attack. Hence, the U.S. air bases close to Country A's east coast region were subjected to immense threats from Country A as shown in Figure 9. When it comes to conflict with the U.S., Country A's military analysts favor age-old schoolyard wisdom: Throw the first punch and hit hard. It is designed to strike America's military suddenly, stunning and stalling the Air Force more than any other service.
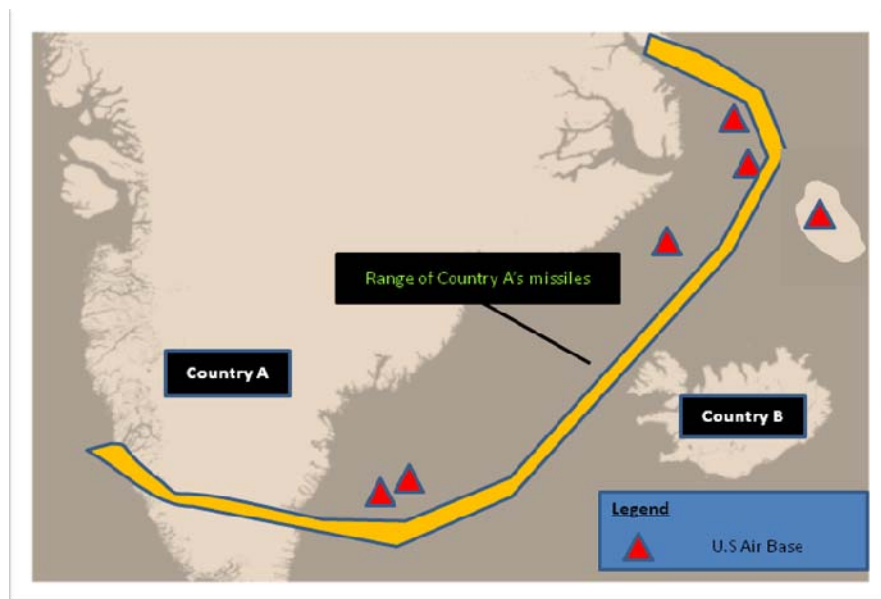
Figure 9.   Map of Country A missiles threat range near Country B

Based on confirmed military intelligence regarding Country A's course of action should a conflict arise, striking U.S. air bases around region of Country A/B

Straits, specifically command-and-control facilities, aircraft hangars and surface-to-air missile would be her first priority. As a countermeasure, suppose the U.S. Air Force would deem an efficient and responsive counter attack on Country A's critical yet deeply buried underground command and control facilities, missile storage sites and aircraft hangars as a viable course of action.

2.   Threats Posed by Country A

Suppose the U.S. clashes with Country A over Country B, Country A will employ its Strike First "Element of Surprise" Strategy. The following shows the various threats posed by Country A's current military power.

- Striking U.S. air bases such as command-and-control facilities, aircraft hangars and surface-to-air missile launchers could be Country A's top priority

- Country A could employ long-range anti-satellite missiles to destroy one or more American satellites

- Country A fighter jets could possibly scramble to intercept aerial refueling tankers and cargo planes sent to shuttle in fuel, munitions, supplies or troops. They could also deploy high explosive cluster bombs to target pilot quarters and critical installations with key personnel.

- Country A is designing ground-launched cruise missiles capable of nailing targets more than 900 nm away

- Country A could also launch a nuclear "e-bomb," or electromagnetic explosive, that would disable U.S. communication equipment while ionizing the atmosphere for minutes to hours

3.   Area of Operations

The 4th Fighter Wing at Seymour Johnson AF Base, in North Carolina (the largest F-15E Strike Eagle operator in the world) was ordered to have 10 sorties of F15Es to be ready to deploy to Alpha Air Base. It is assumed that each F15E can only carry four GBU-24 missiles at one time. The distance of the HDBTs in Country A is approximately 720 nm away from Alpha Air Base. There are three possible defense layers imposed by Country A as shown in Figure 10.
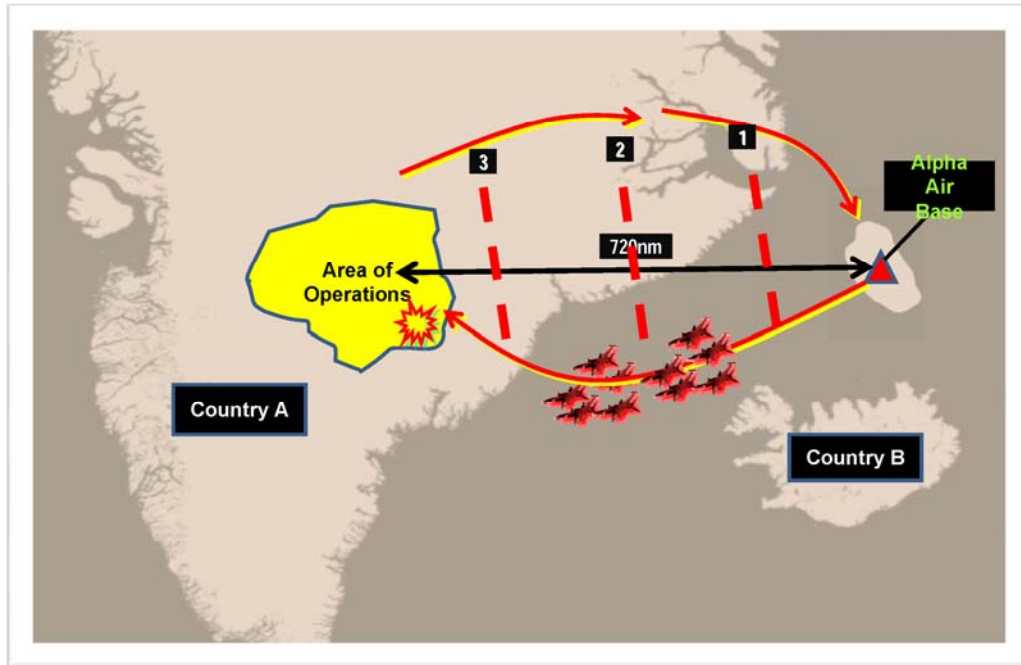
Figure 10.   Map of scenario Area of Operations (AO)

The F-15Es first began flying missions in the initial two weeks in support of all surveillance and reconnaissance missions as well as "Strike Familiarization" missions, which basically meant the air crews flew simulated missions against mock targets around Country B, so as to familiarize themselves with rules of engagements, local area procedures and flying over hostile territory. Based on intelligence reports, the Hard and Deeply Buried Targets such as senior leadership planning headquarters, ammunition and aircraft hangars, radars, radio relay stations, communications sites, and air defense positions are in located in central Country A as shown in Figure 11.
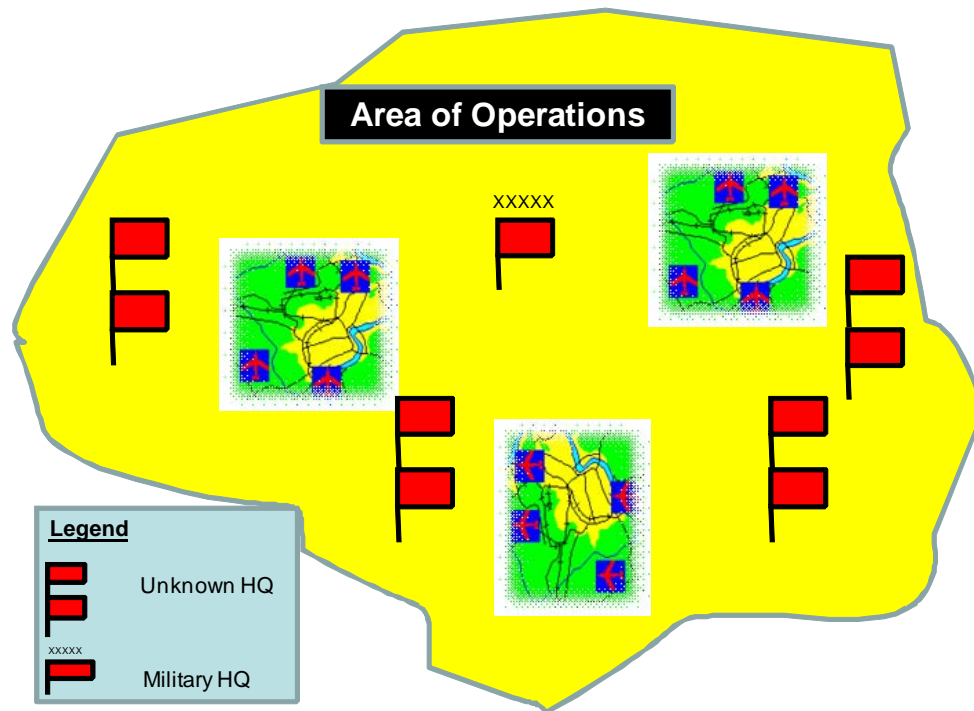
Figure 11.   Critical Installations in Country A

On March 25, the war began as Country A launched its first long war head to destroy one U.S. satellite. In response, the F-15Es dropped GBU-24s against key communication, command and control buildings, and leadership targets identified in the AO, but a few of the weapons missed their intended targets. The weapons are believed to have been affected by EA-6B Prowlers conducting jamming operations in the vicinity. As these missions are highly classified, only veteran F-15E crews participated in these missions. The F-15Es worked closely with Special Forces, operating deep inside the AO. The Special Forces provided rough damage assessment of the HDBTs intended for destruction as updated intelligence to the Strike Task Force.

4.   Model [29]

Based on lessons learnt from Operation Iraqi Freedom and military intelligence on Country A's air defense capability, the enemy forces have probably established three possible layers of air defense. The sorties are assumed to operate continuously in a circulation model with three possible layers of defense on ingress, as well as on egress, as shown in Figure 12.

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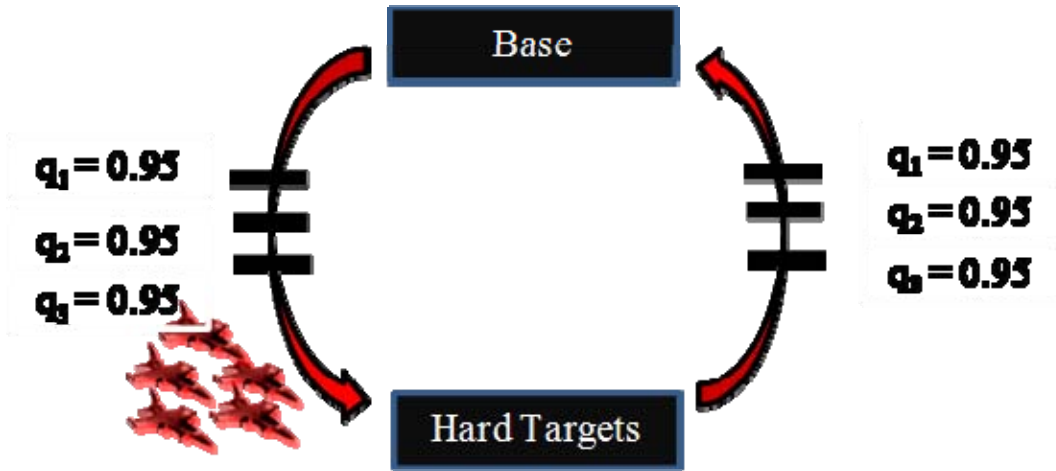
Figure 12.   Circulation Model

The probability (Ps) of the each F15E surviving each layer of air defense is **0.95** and the aggregate probability of survival q (3 layers) is calculated as follows.

$$q = q1 * q2 * q3 = (0.95) * (0.95) * (0.95) = 0.857$$

Suppose X is the number of successful attacks on HDBTs by each wave. This means that all 10 F15Es managed to penetrate the three layers of air defense on ingress, successfully hit all intended targets in the AO and survived the three layers of air defense on egress to return to base safely.

P[X = 0] = 1 – q

P[X=1] = q(1-q²)

The probability distribution function for mission success is given by the following.

$$P[X \leq n] = 1 - q + \sum_{i=1}^{n} q^{2i-1} (1 - q^2)$$

C.   EVALUATING HTVSF AS A POTENTIAL INVESTMENT

1.   Potential Cost Savings

The hard-target fuze technology is different from legacy fuzes. A hard-target fuze is designed to permit deep penetration of hard targets before detonation. The

hard-target fuze relies on a mechanical accelerometer receiving shock signals generated by the weapon system decelerating as it hits the surface of the ground and penetrates various layers of medium and voids, rather than on the standard time delay used in the legacy fuzes. The hard-target fuze programs require the development of software algorithms to read the impulses generated by the accelerometer, so as to distinguish between the various layers of medium and voids, and these algorithms must be performed sufficiently fast as to detonate the weapon effectively. The hard-target fuze must be shock-hardened in order to survive and continue to function despite penetrating multiple layers of hardened concrete, compacted soil, etc. In addition, the hard-target fuze, because it is in the direct firing sequence and includes the explosives which ignite the weapon, must satisfy a "Fuze, Safe and Arm" requirement. Finally, unlike other fuze technology, hard-target fuze technology has not yet been successfully developed. As such, significant research and development costs and production costs of HTVSF constitute a significant portion of HTVSF life cycle costs. The costs savings of employing HTVSF is given by the difference between the following two components and shown in the formula.

Net Present Value (NPV)[4] of employing FMU-143 in BLU-109 penetrator warhead as part of GBU-24 missile system

Net Present Value (NPV) of employing HTVSF in BLU-109 penetrator warhead as part of GBU-24 missile system

$$HTVSF\ Cost\ Savings$$
$$= NPV\ of\ employing\ FMU - 143$$
$$- NPV\ of\ employing\ HTVSF$$

The main cost components of the analysis are research and development costs, procurement costs, aircraft attrition costs and operations and maintenance costs. Table 3 shows an estimate of the various components of the HTVSF and FMU-143 employment costs in a particular scenario.

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[4] Inflation indices [30] are provided by the Naval Center for Cost Analysis (NCCA). The inflation index used to calculate from base year 2008 to target year 2018 is 1.219.

Table 3.   Cost Components of HTVSF and FMU-143 employment (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143
Research Development Test & Evaluation	164.57	0.00
Procurement	51.42	128.77
Sortie Attrition	67.72	171.47
Operations & Support	0.02	0.07
Total =	283.73	300.31
Cost Savings =	**16.58**	

2.   Research Development Test and Evaluation (RDT&E) Cost

Per [8] the RDT&E cost of a typical missile fuze program is $135M as shown in Table 4. All costs are in FY08$M.

Table 4.   HTVSF RDT&E Cost data

Phase	Cost	Remarks
RDT&E • JCTD • SDD	**$135M**	• HTVSF LCCE is about $400M- $450M • RDT&E Cost is about 25 – 35% of LCCE (Analysis assumes 30%)

3.   Procurement Cost

In this BCA, the procurement cost comprises mainly the payload cost (GBU-24 missile system). For all missions, it is assumed that since the 10 sorties of F15Es perform similar missions, they would carry similar payloads. Each F15E carries four GBU-24 missiles. Each GBU-24 missile is assumed to cost $65.7K (FY$18) [31] and the total payload cost for each sortie is $262.8K (FY$18). It is assumed that the cost includes FMU-143 as its delay fuze. Based on cost projections (FY08$) given by the Office of Secretary Defense (OSD) and HTVSF production cost data (provided to Dr. Daniel Nussbaum but not included in this thesis), a realistic production cost curve (Figure 13) is depicted as follows.
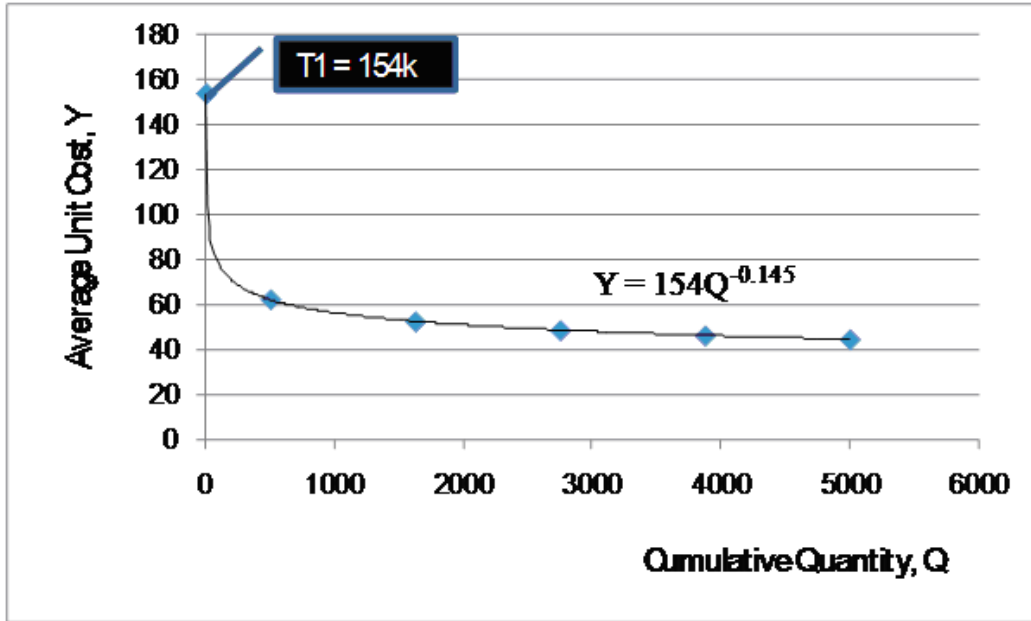
Figure 13.   HTVSF Production Cost Curve

From the plotted cost curve as shown above, the learning slope of HTVSF production b_{HTVSF} is estimated to be -0.1453 (90%). The theoretical First Unit Cost of HTVSF is approximately \$153k (FY08\$). The impact of changes in b_{HTVSF} and corresponding First Unit Cost on Return on Investment (ROI) will be discussed in detail later.

4.   Sortie Attrition Cost

Based on the scenario described above, the aircraft attrition cost is the main determinant of the investment potential of HTVSF. From the circulation model, it is clearly evident that as the probability of mission success, Pm decreases, the aircraft attrition cost increases. As a result, the associated cost penalty for the 10 F15Es for each wave is expressed as below.

$$Sortie\ Attrition\ Cost\ for\ each\ wave = 10 * (1 - Pm) * \$45.4M$$

For a fixed number of targets in the area of operations, it is assumed that the 10 sorties of F15Es using missiles equipped with FMU-143 would require more waves than F15Es equipped with missiles using HTVSF. The additional number of missiles or flights required to destroy the targets is determined by λ. For example, 10 sorties of F15Es can carry 40 missiles. Suppose there are 40 HDBTs, it would require one wave

for the 10 sorties using missiles equipped with HTVSF subjected to Pm $_{\text{HBTVSF.}}$ Assuming $\lambda = 4$, where it would require 4 waves for the 10 sorties using missiles equipped with FMU-143 subjected to a lower probability of mission success Pm $_{\text{FMU-143}}$, depending on the number of defense layers as discussed in the circulation model. The cost of each F15E is estimated to be $45.4M [32] (FY18$).

$$\lambda = \frac{\text{Number of missiles (FMU} - 143)\text{required to reach and destroy target}}{\text{Number of missiles (HTVSF)required to reach and destroy target}}$$

Pm $_{\text{HBTVSF}}$ and Pm $_{\text{FMU-143}}$ are calculated as follows. As defined earlier, X is the number of successful attacks on HDBTs by each wave. It is assumed that if a wave is successful, all 10 F15Es managed to hit all intended targets. Using the circulation model,

$P[X = 0] = 1 - q = 1- (0.95*0.95) = 0.0975$

$P[X=1] = q(1-q^2) = 0.167$

$P[X=2] = q^3 (1-q^2) = 0.136$

$P[X=3] = q^5 (1-q^2) = 0.111$

$P[X=4] = q^7 (1-q^2) = 0.0905$

The probability distribution function for mission success of one wave of 10 F15E sorties using missiles equipped with HTVSF is given by the following:

$$P[X \geq 1] = 0.9025 \ (\textbf{Pm HBTVSF}).$$

The probability distribution function for mission success of four waves of 10 F15E sorties using missiles equipped with FMU-143 is given by the following:

$$P[X \geq 4] = 0.4877 \ (\textbf{Pm FMU} - \textbf{143}).$$

5. Operations and Support Cost [19], [33]

The O&S cost is made up of Operations and Maintenance (O&M) costs as well as Personnel costs. To compute and compare the O&S cost of employing HTVSF vis-à-vis the FMU-143, the following key cost considerations will be used. Costs are computed in FY18$ [30].

- Launch and Recovery System (LRS), and Mission Control System (MCS) Costs
- Fuel Cost
- Maintenance and Repair Costs

a. Launch and Recovery System, Mission Control System Costs

Taking into account the fact that the Launch and Recovery System (LRS) and the Mission Control System (MCS) do not follow a 1:1 relationship with the number of F15Es, it is assumed that the cost of the LRS and MCS for each F15E comes up to 2% of the individual platform cost per mission. Hence, the LRS and MCS costs are estimated to be $0.9M for each F15E.

b. Fuel Cost

The F15E is powered by JP-8, the standard aviation fuel used by all U.S. Air Force aircraft since 1996. A report from OUSD (AT&L) estimated the burdened cost of JP-8 to be about $17.50/gallon, or about $2.62/pound. It is estimated that the fuel capacity of the F15E is about 22,000 lbs of JP-8. Using the two formulas,

$Cost\ of\ Fuel\ per\ F15E$

$= Burdened\ Cost\ of\ Fuel\ per\ pound * Fuel\ Capacity\ of\ F15E$

$Cost\ of\ Fuel\ per\ mission$

$$= 10 * Cost\ of\ Fuel\ per\ F15E * Number\ of\ flights\ per\ mission$$

The burdened cost of fuel per F15E is about $57,640. The cost of Fuel per mission depends on the number of flights that is required for each mission. For example, a mission of one wave for the 10 sorties of F15Es (which comes up to a fuel requirement of 0.22 million lbs. of JP-8) would cost about $0.58M.

c. Maintenance and Repair Costs

The operations maintenance and repair cost is estimated to be about 1% of the cost of the respective platforms per mission, i.e., $0.45M for each F15E.

6. Return on Investment (ROI)

The Return on Investment (ROI) of using a GBU-24 missile system equipped with HTVSF is given by the formula below.

$$ROI =$$
$$\frac{NPV \ of \ employing \ BLU-109 \ (FMU-143 \ fuze) - NPV \ of \ employing \ BLU-109 \ (HTVSF)}{Investment \ Cost \ of \ HTVSF}$$

D. BASE CASE

As discussed earlier, 10 sorties of F15Es are tasked to perform strike operations on identified HDBTs in the AO. The sorties will be dispatched from Alpha Air Base, 720 nm away from the AO. The analysis aims to compare and evaluate the cost of employing missiles equipped with HTVSF against missiles equipped with FMU-143.

Several assumptions were made in the analysis and discussed as follows:

- The RDT&E cost of HTVSF estimated by Air Mobility Command is $164.57M (FY18$)

- The learning slope of HTVSF production is assumed to be 90% with a First Unit Cost of $154k (FY08$)

- Intelligence reports have identified 40 targets in the area of operations

- Country A has placed two lines of defense by AA batteries against the 10 sorties F15Es, and the F15Es are only subjected to AA batteries attacks when both flying in and out of AO

- The probability of survival of each sortie in a wave through a single line of defense is 0.95. Hence the probability of survival of each sortie in a wave through two lines of defense is $(0.95)^2 = 0.9025$.

- Once the wave of 10 sorties managed to pass through the two lines of defense, it is assumed that all the missiles hit their intended target. The missile equipped with HTVSF is able to penetrate and detonate at the desired location. However, the missile equipped with FMU-143 may and may not be able to survive the impact and penetrate to the desired location to achieve the same kill as the former case. Hence, it is assumed that $\lambda = 4$ in the base case i.e., for every missile equipped with HTVSF, four missiles equipped with FMU-143 are required to effectively reach and destroy designated targets.

- The Launch / Recovery / Missile System Cost is assumed to be 2% of F15E platform cost per mission.

- The maintenance and repair cost of a F15E and missile system is assumed to be 1% of F15E platform cost per mission.

- The operational impact of the attrition rate of the aircraft is not considered in the analysis but it is certainly comparable to the cost effectiveness of employing HTVSF.

Table 5 shows the various cost components of the base case of the analysis using the circulation model.

Table 5.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (Base Case) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	45.18	237.41	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 2 Pm $_{HTVSF}$ = 0.9 Pm $_{FMU-143}$ = 0.4877
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	221.29	249.15	
Potential Cost Savings =	27.86		
ROI[5] (%) =	16.92		

From the analysis and table above, it is evident that more waves are required to achieve the intended target kill when using legacy fuze (FMU-143) with a Probability of Mission Success (Pm) of 0.4877 and hence a higher aircraft attrition cost incurred. The higher aircraft attrition rate will also result in a detrimental impact on other operations that require these F15Es, should the need arise.

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[5] Return On Investment for Base Case is calculated as follows: ROI = (221.29- 249.15) / 164.57 = 16.92%.

E. SENSITIVITY ANALYSIS

1. RDT&E

Suppose there is an unexpected technical difficulty in the development of HTVSF, which results in the RDT&E cost of HTVSF increasing from 165M to 192M (FY$18), which is a 16% increase; given the same scenario, HTVSF cost savings and ROI would remain positive as shown in Table 6.

Table 6.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (RDT&E) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	**192.00**	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost = $65.6k (FMU-143 inclusive)
Aircraft Attrition	45.18	237.41	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 2 Pm $_{HTVSF}$ = 0.9 Pm $_{FMU-143}$ = 0.4877
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	248.72	249.15	
Potential Cost Savings =	0.43		
ROI (%) =	22%		

2.   Subsequent Missions in 2018

Suppose we employ the GBU-24 missiles again in an immediate mission after the base case during 2018, the RDT&E costs would be considered as non-recurring costs. Hence, given the same scenario and holding everything else constant, HTVSF cost savings would increase by about 700% as shown in Table 7.

Table 7.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (Subsequent Missions in 2018) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	0.00	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	45.18	237.41	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 2 Pm_{HTVSF} = 0.9 $Pm_{FMU-143}$ = 0.4877
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	56.72	249.15	
Potential Cost Savings =	**192.43**		Note: ROI is not calculated since there is no RDT&E Cost in this case

If we employ the GBU-24 missiles again in any immediate mission after the base case during 2018, the RDT&E costs would be considered as non-recurring costs. If we increase the Probability of survival of the F15Es to 0.98 with only a single line of defense, HTVSF cost savings would increase by about 180% as shown in Table 8.

Table 8. Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (Subsequent Missions in 2018) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	0.00	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	9.27	61.13	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Line = 1 Pm $_{HTVSF}$ = 0.98 Pm $_{FMU-143}$ = 0.8681
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	20.81	72.87	
Potential Cost Savings =	**52.06**		Note: ROI is not calculated since there is no RDT&E Cost in this case

3. Number of Defense Layers

Suppose Country A employs three layers of defense, the aircraft attrition costs would increase for repeated waves of sorties. Hence, given the same scenario, HTVSF cost savings and ROI would increase by 270%, as shown in Table 9.

Table 9.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (Number of Defense Layers = 3) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	66.27	306.09	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 3 Pm_{HTVSF} = 0.9 $Pm_{FMU-143}$ = 0.4877
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	242.38	317.83	
Potential Cost Savings =	75.45		
ROI (%) =	45.85		

If Country A employs three layers of defense and the probability of survival for the F15E increases from 0.95 to 0.98, the aircraft attrition costs for F15Es employing missiles equipped with HTVSF (60%) reduces at a higher rate than missiles equipped with FMU-143 (47%). Although there is a 110% deficit in HTVSF cost savings as shown in Table 10, it is noted that HTVSF will pay for itself in subsequent missions.

Table 10.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 (Number of Defense Layers = 3, Ps = 0.98) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	11.72	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost = $65.6k (FMU-143 inclusive)
Aircraft Attrition	27.25	160.21	Number of Targets = 40, λ = 4 Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 3 Pm_{HTVSF} = 0.9 $Pm_{FMU-143}$ = 0.4877
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	203.36	171.95	
Potential Cost Savings =	**-31.41**		
ROI (%) =	**-19.08**		**Note: ROI will be positive in subsequent missions**

4.   First Unit Cost (T1 $_{HTVSF}$)

Figure 14 shows the variation of ROI with respect to T1 $_{HTVSF}$. Suppose there is an unexpected increase in production cost of HTVSF due to economic reasons or technological upgrade, which results in the theoretical First Unit Cost (T1 $_{HTVSF}$) increasing from 154k to 635k, given the same scenario, HTVSF cost savings and ROI would remain positive. If T1 $_{HTVSF}$ is low at about 20-40K (FY18$), ROI is high at about 20%.
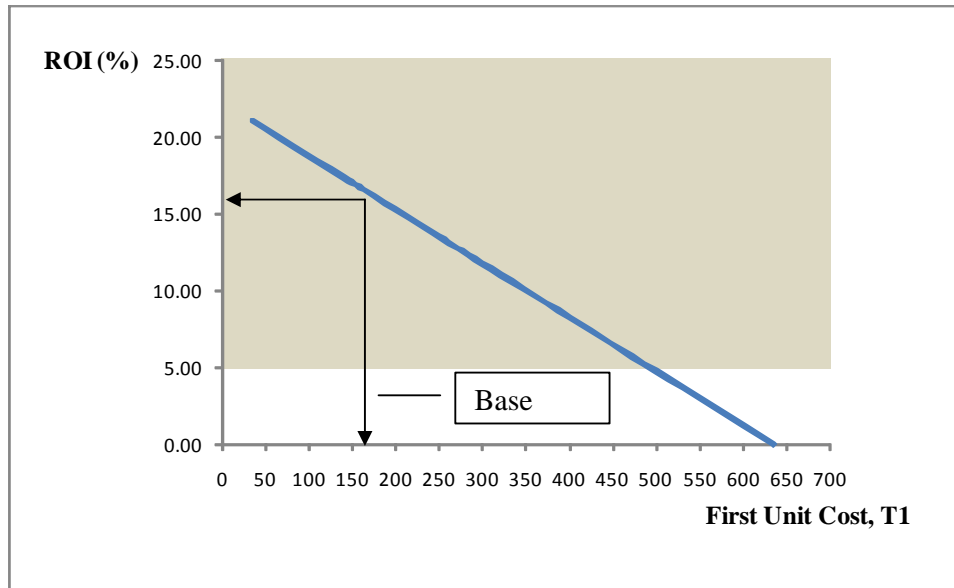
Figure 14.　　Graph of ROI (%) against $T1_{HTVSF}$

5.　　Learning Slope of HTVSF Production

Suppose there is a consistently high production cost of HTVSF due to shortage of skilled workers or poor retention of skills which results in no learning rate (100% learning slope); given the same scenario, HTVSF cost savings and ROI would remain positive as shown in Table 11.

Table 11.   Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 ($b_{HTVSF} = 0$) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research & Development	164.57	0.00	Program Office Estimate (POE)
Procurement	33.41	11.72	$b_{HTVSF} = 0$ (100% learning slope) $b_{FMU-143} = -0.2001$ (87% learning slope) $T1_{HTVSF} = 154k$ GBU-24 Missile cost $= $65.6k$ (FMU-143 inclusive)
Aircraft Attrition	45.18	237.41	Number of Targets = 40, $\lambda = 4$ Number of waves HTVSF = 1 Number of waves FMU-143 = 4 Number of Defense Lines = 2 $Pm_{HTVSF} = 0.9$ $Pm_{FMU-143} = 0.4783$
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	243.17	249.15	
Potential Cost Savings =	5.98		
ROI (%) =	3.63		

6.   **Values of λ**

The values of λ are given by the following expression.

$$\lambda = \frac{\text{Number of missiles (FMU} - 143) \text{required to reach and destroy target}}{\text{Number of missiles (HTVSF) required to reach and destroy target}}$$

As shown in the Base Case, it is evident that the HTVSF cost savings and ROI is dominated by the aircraft attrition costs. The Base Case assumes $\lambda = 4$ i.e., for every missile equipped with HTVSF, four missiles equipped with FMU-143 are required to effectively reach and destroy designated targets. As such, more waves of F15Es are required to be dispatched to destroy all the targets if missiles equipped with FMU-143 are used. The increased exposure time of the F15Es sorties results in higher

aircraft attrition costs. Hence, it follows that an increase in λ will lead to even higher attrition costs while a decrease in λ, i.e., $\lambda = 3$, will result in lower aircraft attrition costs if missiles equipped with FMU-143 are used. Table 12 shows that $\lambda = 3$ results in negative cost savings and ROI if HTVSF is used in the first mission. However, it must be highlighted that in subsequent missions, cost savings and ROI will increase and make using missiles equipped with HTVSF worthwhile. Table 13 shows that $\lambda = 5$ results in higher positive cost savings and ROI if HTVSF is used in the first mission.

Table 12. Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 ($\lambda = 3$) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	9.10	$b_{HTVSF} = -0.1453$ (90% learning slope) $b_{FMU-143} = -0.2001$ (87% learning slope) $T1_{HTVSF} = 154k$ GBU-24 Missile cost $= \$65.6k$ (FMU-143 inclusive)
Aircraft Attrition	45.18	185.97	Number of Targets = 40, $\lambda = 3$ Number of waves HTVSF = 1 Number of waves FMU-143 = 3 Number of Defense Lines = 2 $Pm_{HTVSF} = 0.9$ $Pm_{FMU-143} = 0.5987$
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	221.28	195.08	
Potential Cost Savings =	-26.20		
ROI (%)=	-15.92		Note: ROI will be positive in subsequent missions

Table 13. Cost Savings comparison between missiles equipped with HTVSF and missiles equipped with FMU-143 ($\lambda = 5$) (All costs in FY18$M)

Work Breakdown Structure (Cost Component)	HTVSF	FMU-143	Basis of Estimates
Research Development Test & Evaluation	164.57	0.00	Program Office Estimate (POE)
Procurement	11.53	14.35	b_{HTVSF} = -0.1453 (90% learning slope) $b_{FMU-143}$ = -0.2001 (87% learning slope) $T1_{HTVSF}$ = 154k GBU-24 Missile cost =$65.6k (FMU-143 inclusive)
Aircraft Attrition	45.18	279.35	Number of Targets = 40, $\lambda = 5$ Number of waves HTVSF = 1 Number of waves FMU-143 = 3 Number of Defense Lines = 2 Pm $_{HTVSF}$ = 0.9 Pm $_{FMU-143}$ = 0.3972
Operations & Support	0.01	0.02	Launch / Recovery / Missile System Cost = 2% platform cost per mission Maintenance and Repair Cost = 1% platform cost per mission
Total =	221.29	293.72	
Potential Cost Savings =	72.43		
ROI (%)=	44.01		

7. Cost Savings, Probability of Survival of F15E and Number of Lines of Defense

Figure 15 shows the interactions between Cost Savings, Probability of Survival of F15Es (Ps), Number of Lines of Defense and Number of missions. The following observations are made.

> **a.** ***For the Base Case (First Mission) with Three Lines of Defense, the Maximum Potential Cost Savings is about 123M (FY18$)***

(1) Mission 2 and Subsequent Missions. The Cost Savings remains positive for all numbers of defense lines and Ps. This is intuitive as the RDT&E cost of HTVSF is considered as non–recurring from Mission 2 onwards.

(2) For Both Missions. Cost Savings for Ps=0.9 starts to decrease at around three lines of defense lines. Cost Savings for Ps=0.95 starts to decrease at about seven lines of defense. This shows that the returns of employing HTVSF diminish rapidly if Ps is low where aircraft attrition is high, regardless of the fuze employed.
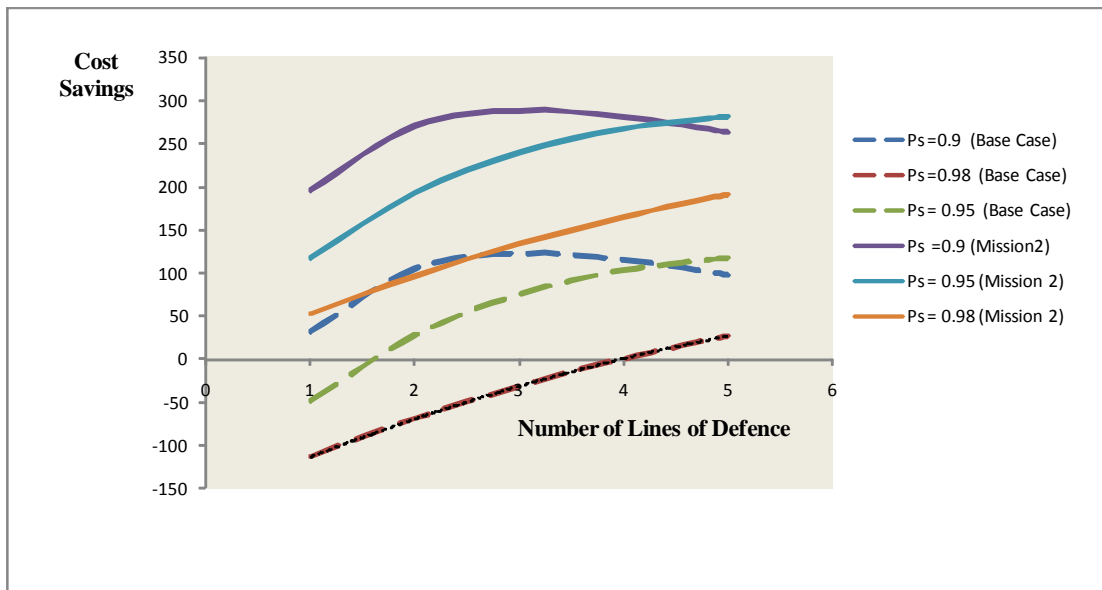
Figure 15.   Interaction Plot between Cost Savings, Ps and Number of Lines of Defense

F.   RECOMMENDATION

It is shown that the higher the number of waves sent to achieve the intended target kill, the higher the aircraft attrition cost incurred. Hence, the importance of the employment of missiles equipped with HTVSF. Besides, the high attrition rate of aircraft using the legacy fuze has a direct impact on the overall operation effectiveness as well.

A low Ps of F15E will result in a high aircraft attrition rate for missiles equipped with both types of fuzes. The Return On Investment (ROI) for HTVSF diminishes rapidly with decreasing probability of F15E sorties crossing the enemy's lines of defense. Hence, preserving the Ps of the F15Es is as important as employing missiles equipped with HTVSF.

The HTVSF with programmable void sensing capability appears to be a critical investment that can provide the DoD with a new capability in Hard and Deeply Buried Target Defeat globally.

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