Fuzed Insensitive General Purpose Bomb Containing AFX-645

Mr. John D. Corley and Mr. Gary H. Parsons
Major (CAF) Alan C. Stewart

WL/MNME
2306 Perimeter Road, Ste 9
Eglin Air Force Base FL 32542-5910
Phone: (904) 882-9532
FAX: (904) 882-3540

Introduction

The U.S. Air Force Wright Laboratory, Armament Directorate recently completed an in-house technology demonstration program.[1] The program objective was to develop a general purpose bomb which can be stored as an Insensitive Munition (IM). The system developed integrates a modified FMU-139 fuze and a modified Mk-82 (500 lb.) bomb containing the insensitive high explosive AFX-645. Goals of the program include demonstration of a fuzed bomb which achieves 1.2 hazard classification and a non-fuzed bomb which achieves 1.6 hazard classification while maintaining the lethality of tritonal.

The goals of this technology demonstration program have been achieved. Wright Laboratory has developed an insensitive high explosive for general purpose bombs, designated AFX-645, which is readily initiated by a modified version of the FMU-139. AFX-645 is a qualifiable insensitive high explosive bomb fill. Explosive performance is approximately 95% that of tritonal. Fully assembled, fuzed bombs can be safely stored and transported using this explosive fill. This paper discusses improvements to baseline AFX-644 which led to the development of AFX-645. The results of an extensive series of performance and safety tests are documented as well as the initiation experiments to produce a viable explosive train. The paper also details the FMU-139 fuze and Mk-82 bomb modifications required to achieve a Fuzed, Insensitive, General Purpose Bomb (FIGPB).

Baseline AFX-644 Formulation Characterization and Evaluation

The development of the baseline AFX-644 (also referred to as TNTO IV) insensitive high explosive is detailed in Reference 2. AFX-644 is a melt-castable, wax-desensitized, nitrotriazolone (NTO)-based explosive formulation which employs TNT as an energetic binder material and aluminum powder to enhance blast performance. TNT, NTO, Wax, and Al powder are mixed in proportions of 30, 40, 10 and 20%, respectively. As shown in Table I, Baseline AFX-644 meets the United Nations' (UN) criteria for Extremely Insensitive Detonating Substances (EIDS) and full scale testing requirements for fast cook-off, slow cook-off and bullet impact. Mixed results were obtained in full-scale sympathetic detonation testing with the baseline formulation. Mk-82 pressure arena tests for baseline AFX-644 yielded performance parameters similar to those obtained for tritonal-filled bombs.

Reformulation of Baseline AFX-644

A reformulation strategy for TNTO IV (baseline AFX-644) was developed to: minimize exudation, improve processing parameters, and improve survivability for sympathetic detonation scenarios. Two reformulation efforts were undertaken. The first effort sought to replace the low melt wax (D2) and the nitrocellulous surfactant. The product of this work was AFX-644 Mod 0 which was an extremely insensitive yet poor performing explosive. The performance parameters of this formulation were enhanced in the second reformulation effort by increasing the percentage of energetic ingredients to as high as possible and still pass insensitivity tests. The product of this work was AFX-645.

AFX-645 is a melt castable formulation which could be easily processed in existing high-rate loading facilities. It employs a well specified grade of nitrotriazolone (NTO), and other components for which detailed material specifications already exist. The AFX-645 wax/surfactant system is suitable for use in military environments. When compared with the conventional D2 wax system, the I-800/Ganex mix in AFX-645 minimizes exudation and off-gassing and enhances the TNT/wax emulsion characteristics. It also dramatically effects the shock sensitivity, critical diameter and energy of the aluminized TNT/NTO formulation. AFX-645 was developed by balancing energy and sensitivity requirements for surviving sympathetic detonation in the new standard metal pallet. AFX-645 blast performance measured in Mk-82s approaches that derived from tritonal filled Mk-82s.

AFX-644 Shock Sensitivity

The shock sensitivities of several TNT/NTO compositions were measured using the Modified Expanded Large Scale Gap Test[3] (ELSGT). The results of this testing is presented in Table II.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**
4. TITLE AND SUBTITLE **Fuzed Insensitive General Purpose Bomb Containing AFX-645**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **WL/MNME,2306 Perimeter Road, Ste 9,Eglin AFB,FL,32542-5910**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Table I: Baseline AFX-644 Formulation Results[1,2]

Screening		
Test	**Criterion**	**Result**
Impact Sensitivity (H-50%, 5 Kg)		> 200.5 cm
Friction Sensitivity (BAM)		6.2 Kg
Thermal Stability (CRT)		0.37 cm^3/g
Electrostatic Discharge		0.040 Joules
Small Scale Burn (TNT/NTO/Wax 42/52/6)		Mild Burn
United Nations Criteria for Extremely Insensitive Detonating Substance (EIDS) for 1.6 Hazard Classification		
Test	**Criterion**	**Result**
Cap	No Detonation	No Reaction
Gap (Comp B Donor)	No Go @ 82 mm*	No Go @ 41 mm
Susan	Pressure < 27 kPa	Pressure = 17 kPa
Friability	dP/dt < 15 MPa/s	dP/dt = 0.3 MPa/s
Bullet Impact	No Explosion	No Reaction
External Fire	No Violent Reaction	Pressure Rupture
Slow Cook-off	No Fragment Throw	Deflagration
United Nations 1.2 and 1.6 Hazard Classification Article Tests in Mk-82 Bomb		
Test	**Criterion**	**Result**
Slow Cook-off	No Detonation (1.6)	Burn only (2X)
Fast Cook-off	No Detonation (1.6)	Burn only
	No Mass Explosion (1.2)	
Bullet Impact	No Detonation (1.6)	Burn only (6X, 3 round bursts)
Sympathetic Detonation	No Propagation (1.2 and 1.6)	Adjacent: No Go (5X) @ 0.5 inches Diagonal: No Go (2X) @ 5.16 inches Go (2X) @ 5.16 inches

*Gap thickness criterion is a function of donor output pressure:
P(70mm, Pentolite)=P(82mm, Comp B)= P(76mm, RDX/Wax) = 34 Kbar.

Table II: Expanded Large Scale Gap Test Results for Various AFX-644 Formulations

AFX-644 Variants	**Formulation**				**Density**		**ELSGT**	
	TNT	NTO	Wax and Type	Al	g/cc	TMD	Go (Inches)	No Go (Inches)
Baseline	30%	40%	10% D2 [3]	20%	1.68	94.4%	1.91	1.94
Mod 0 [1]	30%	40%	10% I-800 [4]	20%	1.71	97.2%	1.50	1.63
Mod 0 [2]	30%	40%	10% I-800 [4]	20%	1.75	99.4%	1.25	1.31
Mod 1 [1]	30%	45%	10% I-800 [4]	15%	1.68	97.4%	1.76	1.81
Mod 2 [1]	32%	45%	8% I-800 [4]	15%	1.64	93.4%	1.94	2.00
AFX-645 [1]	32%	48%	8% I-800 [4]	12%	1.63	93.6%	1.95	2.01

Notes:1: Vacuum Mix, Ambient Cast ($V_D = 6.82 \pm 0.12$ km/sec, 2.0 in $\leq D_c <$ 2.5 in.) 2: Vacuum Mix, Vacuum Cast 3: D2 wax is 84% Indramic 170C, 14% Nitrocellulose and 2% Lecithin (melting point 62.7°C) 4: 98.5% Indramic 800 wax and 1.5% Ganex surfactant (melting point 83.9°C)

New Metal Pallet

Suppression of sympathetic detonation is achieved through optimization of candidate explosive formulations and container design. During the course of the FIGPB program, a new standard metal pallet was introduced. The new design was accomplished to enable munition handlers using forklifts to dissect bomb pallets for maneuvering as "three-packs" or "six-packs." The separation distance between rows and columns in the old standard metal pallet is approximately 0.5 inches. The new pallet provides a horizontal distance between bombs of approximately 0.75 inches and the top row of bombs has been raised to a spacing of approximately 2.88 inches . The survivability of the bombs is aided by the change.

HULL calculations were performed for donor bombs containing a 30/40/2/28 -- TNT/NTO/wax /Al AFX-644 formulation[4]. Although this particular formulation was not explored further, the trends of pressure distribution within the pallets during a sympathetic detonation test are valid. The pressure and velocity distributions in the old standard pallet and the new standard pallet are shown in Table III. The peak pressure distribution is much more uniform in the new standard pallet configuration. The critical position for surviving sympathetic detonation has shifted to the adjacent bombs. The donor casewall impacts these items first. The expansion at impact with these acceptors is smaller than the expansion at the point the donor casewall impacts the top center bomb or the diagonal bombs. Also, the casewall is somewhat thicker at the point of impact with the adjacent bomb, creating a longer duration pulse in this location.

Table III: 2% Wax AFX-644 Pressure/Velocity Distributions for Acceptors in Old And New Standard Metal Pallet Configurations[4]

Pallet and Acceptor Position	Distance (mm)	Casewall Velocity (mm/usec)	Peak Pressure (kbar)	Impulse (kbar*sec*10^5)
Old Pallet Adjacent Bomb	13	1.29	58	2.76
Old Pallet Top Bomb	13	1.29	58	2.76
Old Pallet Diagonal Bomb	133	1.69	92	2.11
New Pallet Adjacent Bomb	19	1.47	73	2.74
New Pallet Top Bomb	73	1.60	72	2.24
New Pallet Diagonal Bomb	179	1.73	75	1.72

Four-Inch Diameter Copper Cylinder Expansion Tests

Copper cylinder expansion tests (4-inch diameter) were conducted for the baseline AFX-644, AFX-644 Mod 0, AFX-644 Mod 1 and AFX-645 in addition to tritonal. Procedures described in Reference 5 were employed in these tests. Gurney constants were derived from the curve fit velocities at a casewall displacements of 24 mm, 76 mm and 120 mm using:

$$\sqrt{2E} = G_{76} = V_{76}\sqrt{M/C + .5}$$

where G_{76} is the Gurney Characteristic Velocity (km/sec), also called $\sqrt{2E}$ calculated using the velocity at 76 mm (equivalent to 19 mm for the 1 inch diameter test), V_{76} is the wall velocity at 76 mm of expansion and M/C is the mass ratio of metal to explosive. Gurney energies were calculated using:

$$E_{g76} = ME_{76}\left[\frac{1+\rho_0\dfrac{W}{2M}}{W}\right]$$

where E_g is the Gurney energy (kJ/cm^3), E_{76} is the specific kinetic energy of the casewall (1/2 V_x^2) at 76 mm of expansion, M is the mass of the cylinder wall per unit length, W is the volume of the cylinder wall per unit length, and ρ_0 is the initial density of the explosive. Data for each of the formulations tested is provided in Table IV. A comparison of the performance for each formulation with the performance of tritonal is also provided.

Balancing Performance with Sensitivity

Development of an insensitive high explosive requires achieving the appropriate balance of sensitivity and performance while maintaining a reasonable level of initiability. All AFX-644 Mods are readily initiated. Maximum performance is desired while still achieving the criteria for passing the sympathetic detonation test. Energy/Sensitivity ratios for various formulations were determined using the Gurney Energy at a case wall expansion of 76mm, Eg_{76} and the calibrated pressure corresponding to the minimum barrier thickness in the modified expanded large scale gap test required to prevent detonation of the acceptor charge, P_{NOGO}. Given two formulations within the same family of formulations which yield different sympathetic detonation results, (i.e. one propagates and one does not propagate) one can add energetic material to the non-propagating formulation until the energy/sensitivity ratio approaches that of the propagating formulation. This is the approach used to develop AFX-645 as shown in Table V. AFX-645 was selected based on its energy/sensitivity ratio of 0.0543.

Table IV: 4-inch Diameter Copper Cylinder Expansion Data for Tritonal and AFX-644

Formulation	Casewall Velocity (Km/sec)			Gurney Energy (KJ/cm)	Gurney Velocity (Km/sec)	Ratios with Tritonal	
	V_{24}	V_{76}	V_{120}	E_{g76}	G_{76}	$E_{g76}/E_{g76}(T)$	$G_{76}/G_{76}(T)$
Tritonal	1.12±0.02	1.34±0.00	1.41±0.01	4.23±.01	2.23±0.00	1	1
Baseline AFX-644	1.10±0.01	1.29±0.03	1.35±0.04	3.94±.19	2.16±0.06	0.93±0.05	0.97±0.03
AFX-644 Mod 0	1.01±0.03	1.14±0.04	1.18±0.04	3.09±.19	1.90±0.06	0.73±0.05	0.84±0.03
AFX-644 Mod 1	1.04±0.02	1.19±0.01	1.24±0.00	3.35±.05	1.99±0.01	0.79±0.01	0.89±0.01
AFX-645	1.10±0.01	1.28±0.03	1.33±0.03	3.85±.16	2.14±0.05	0.91±0.04	0.95±0.02

Table V: Energy to Sensitivity Ratios for Various AFX-644 Formulations

AFX-644 Variants	Formulation				Density		Symp. Detonates	Eg_{76}/P_{NOGO}
	TNT	NTO	Wax and Type	Al	g/cc	TMD		
Tritonal	80%	none	none	20%	1.73	96.6%	Go	0.2213
Baseline	30%	40%	10% D2	20%	1.68	94.4%	Mixed	0.0533
Waxless	30%	40%	None	30%	1.92	96.0%	Go	0.0624
Mod 0 **	30%	40%	10% I-800	20%	1.71	96.2%	No Go	0.0358
Mod 1 *	30%	45%	10% I-800	15%	1.68	97.4%	not tested	0.0423
AFX-645*	32%	48%	8% I-800	12%	1.63	93.6%	No Go	0.0543

Blast Pressure Testing

Mk-82 pressure arena tests were conducted for the baseline AFX-644 formulation, AFX-644 Mod 0, AFX-645, H-6 and tritonal. The transducers were placed in two radial arrays at ten feet intervals in a range of 25 to 65 feet. The sample size for this data is very low: two bombs each with two rows of pressure gauges. A summary comparison of the data obtained for the formulations tested ratioed with that obtained for tritonal is provided in Table VI below. The ratios presented in Table VI were calculated by ratioing the results from each of the 12 gauges and then bulk averaging these results.

AFX-645 Sympathetic Detonation Test

A full-scale (MK-82) sympathetic detonation test of AFX-645 (TNT/NTO/I-800 Ganex/Al-32/48/8/8/12) was conducted. All of the bombs in the standard metal pallet were filled with explosive. The donor bomb was placed in the bottom, center position of a the pallet. There was no evidence of detonation from four of the five acceptor bombs; however, the fifth item reacted violently or partially detonated after a substantial run-up. The results of this test are considered as a positive indication of the low vulnerability of this formulation.

Initiation System for the Fuzed Insensitive General Purpose Bomb

The program goals included the demonstration of advanced insensitive high explosive (IHE) technology in an existing weapon system. An objective was to use the FMU-139 fuze with as few modifications as possible to detonate the IHE. The strategy for achieving this was to first determine the booster size and material needed to detonate the AFX-644 and then determine the best fuze configuration to house this booster. This strategy was followed by first testing several inventory boosters against the IHE. After these tests proved unproductive, a booster material was chosen such that it could be stored in the weapon if needed and maintain the desired 1.6 hazard classification. A series of tests, supplemented with hydrocode modeling were performed to size this booster. This was followed by a series of detonation tests of this insensitive booster material to size and select a lead material and configuration. The fuze hardware was examined to configure a system which would be compatible with the FMU-139 fuze. These steps are summarized in Table VII.

Table VI: Mk-82 Performance Comparison with Tritonal

Parameter	H-6	Baseline AFX-644	AFX-644 Mod 0	AFX-645
Detonation Velocity	1.11	0.97	0.99	1.01
Peak Pressure	1.33±0.14	1.40±0.18	0.82±0.07	0.92±0.09
Impulse	1.15±0.12	1.13±0.19	0.87±0.10	0.85±0.07
Time of Arrival	1.06±0.02	0.99±0.01	0.91±0.02	0.93±0.02
Positive Phase Duration	1.10±0.13	1.06±0.09	0.98±0.05	1.00±0.08
Fragment Velocity				0.95*

* Compared to old test data

Table VII: Summary of AFX-644 Initiation Test Results

Test Item (Donor)	Tested Against (Acceptor)	Test Condition*	Result
FMU-139 (Annular--125g CH-6)	Baseline AFX-644	Ambient	NO GO
T-147 Auxiliary Booster (Annular 284g Tetryl)	Baseline AFX-644	-65°F	NO GO
PBX-9502 (Cylindrical 3" X 3") Flat Bottom Fuzewell	Baseline AFX-644	Ambient	GO
PBX-9502 (Cylindrical 2.7" Dia X 3")	Baseline AFX-644	-65 °F	GO
PBX-9502 (Cylindrical 2.4" Dia. X 1")	Baseline AFX-644	-58°F	NO GO
PBX-9502 (Cylindrical 2.4" Dia. X 1.875")	Baseline AFX-644	-65°F	NO GO
PBX-9502 (Cylindrical 2.4" Dia. X 2.5")	Baseline AFX-644	-65°F	GO
PBX-9502 (Domed Shape 2.4" Dia. X 2.25")	Baseline AFX-644	-65°F	GO
PBXN-7 (Cylinder 2.44 Dia X 1) Through Metal Plate	PBX-9502	-65°F	NO GO
PBXN-7 (Cylindrical 1" X 1") with 0.01 Flyer Plate and 0.04 Air Gap	PBX-9502	-65°F	GO
PBXN-7 (Cylindrical 1" X 1") with 0.03 Flyer Plate and 0.125 Air Gap **	PBX-9502	Ambient	GO
Modified FMU-139 and PBX-9502 Aux Booster	AFX-644 Mod 0	-67°F	GO

* Cold test conditions were achieved by soaking the test items until equilibrium was reached with the pre-set freezer temperature. 65 below was the goal on all cold tests. However, some tests were conducted in the heat of summer where the freezer was incapable of getting that cold.

FMU-139 Modifications

The initiation train for the FIGPB is derived from the FMU-139 fuze which, at program start, had only recently entered the munitions inventory. The electronic safe/arm mechanism, rotor, detonator and lead were not changed in this program. However, a new configuration is required to initiate reliably less sensitive explosives having larger critical diameters and initiation pressures than the current bomb fills. Specifically, the output from the booster explosive must be greater than the initiation pressure of the main charge explosive when the generated shock wave grows to the critical diameter of the main charge explosive. The re-design of the FMU-139 involved replacement of the annular CH-6 booster with a smaller, cylindrical PBXN-7 'flyer plate' lead. The large solid cylindrical PBX-9502 auxiliary booster requires the relocation of the fuze electrical connector to the face plate of the fuze at the rear of the bomb.

The baseline AFX-644 formulation had a critical diameter approaching 40mm and cannot be initiated by the standard FMU-139 fuze. AFX-644 Mod 0 has a critical diameter approaching 50mm. The critical diameter of AFX-645 is estimated to be 40mm and it is less sensitive than baseline AFX-644. A 2.44 inch diameter, 3.0 inch long booster of PBX-9502 can detonate baseline and AFX-644 Mod 0. AFX-645 is between these two in gap test results. Thus by interpolation, it too can be detonated by this booster at service conditions.

The detonator and small lead in the FMU-139 can be easily augmented with a PBXN-7 booster to launch a small flyer plate capable of detonating the large PBX-9502 auxiliary booster. This concept is tolerant to dimensional inaccuracy in assembly. The electrical connector for the FMU-139 can be relocated to the fuze face-plate. This is required to employ a cylindrical (vs. toroidal) booster. The relocated electrical connector allows the charging tube to be moved to the aft closure of the bomb which has several advantages: it simplifies explosive loading procedures as the fuzewell can be inserted after filling; the flat bottomed fuzewell provides for better shock matching between the booster and main charge; and the blind cavity provided by the fuzewell could be used as the storage can for the fuze as it is easily hermetically sealed. This last feature is a key element in achieving an all-up round general purpose bomb.

Bomb Modifications

The bomb's rear internal charging tube must be moved such that it tunnels from the charging well to the aft closure of the bomb. Prototype versions of a modified Mk-82 bomb aft closure have been fabricated. Explosive loading with this bomb is accomplished by filling the bomb through the large hole in the aft closure to a predetermined level and then inserting the new fuzewell into the molten explosive and attaching it to the aft closure with a screw locking ring.

All-Up Round Fast Cook-off (Wood Bonfire) Test

A fast cook-off (wood bonfire) test was conducted on three All-Up Round (AUR) Mk-82 bombs containing AFX-644 Mod 0 and a modified FMU-139. The results of this test met the 1.2 Hazard Classification criteria prescribed by the United Nations.

All-Up Round Sympathetic Detonation Test

An all-live, fuzed, full-scale (Mk-82) sympathetic detonation test of AFX-645 was conducted to demonstrate the survivability of this system as a fully assembled munition in a standard storage configuration. In this test all of the bombs were filled with AFX-645 and placed in the new standard metal pallet. All of the acceptor bombs contained prototype fuzes and auxiliary boosters. There was no evidence of detonation from four of the five acceptor bombs; however, the fifth item reacted violently or partially detonated after a substantial run-up. The results of this test were essentially identical to those reported for the unfuzed, all-live, sympathetic detonation test of Mk-82s containing AFX-645.

Conclusions

Baseline AFX-644, an insensitive high explosive for general purpose bombs, has been tailored to provide a qualifiable explosive designated AFX-645. This new formulation eliminates the poor processing characteristics of baseline AFX-644 and improves upon the performance of AFX-644 Mod 0. AFX-645 provides the proper balance of insensitivity, performance and initiability required for safe storage, safe handling, reliability and lethality in operational environments.

AFX-645 has been successfully integrated with a Mk-82 bomb and a fuze system derived from the FMU-139. The fuzed insensitive general purpose bomb (FIGPB) system integrates an insensitive booster, allowing fully assembled munitions to be safely stored and transported.

The objectives of this technology demonstration program have been achieved. Full scale testing results for AFX-644 and subsequently AFX-645 have demonstrated the feasibility of fielding a Mk-82 bomb with a hazard classification of 1.6 and a fully assembled Mk-82 bomb with a 1.2 hazard classification. Minor modifications to existing fuzes can allow reliable initiation of insensitive high explosives without degrading the response to hazardous stimuli. Although the blast/fragmentation performance of the system is slightly less than that of tritonal filled bombs, the effectiveness in terms of single shot probability of kill should be unchanged especially if used in a precision strike manner. The operational and safety benefits of an all-up round system derived from larger quantity per distance allowances and minimal build-up activities will far out-weigh the small loss in performance. The technologies developed in this program are ready for transition into the next generation of munition systems.

References

1. Corley, J.D., et. Al., Fuzed Insensitive General Purpose Bomb Containing AFX-645-Final Report, WL-TR-95-019, May 1995

2. Aubert, S.A., et. al., Development of TNTO Composite Explosives , WL-TR-92-7073, June 1993

3. Aubert, S.A., et. al., Calibration and Correlation of a Modified Expanded Large-Scale Gap Test with the Large-Scale Gap Test and the 8-Inch Gap Test, AFATL-TR-89-46, August 1989

4. Unpublished Calculations by M. Gunger 1993 and 1994

5. Aubert, S., Characterization of the Hydrodynamic Performance Properties of NTO and TNTO Composite Explosives, WL-TR-94-7307, May 1994.