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TECHNICAL REPORT 4301

A STUDY FOR AN IMPROVED VELOCITY 2.75-INCH ROCKET MOTOR (U)

WILLIAM G. MUTH

IRWIN SPIESS

NOVEMBER 1971

PICATINNY ARSENAL
DOVER, NEW JERSEY

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IRWIN SPIESS

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(C) SUMMARY (U)

(U) A limited study was conducted by the Ammunition Engineering Directorate's Solid Rocket Propulsion Laboratory to determine the velocity improvement that could be obtained by substituting a high-energy, smokeless propellant for the N-5 Propellant in the 2.75-inch rocket motor which was developed nearly 20 years ago. Developed by Picatinny Arsenal, this high energy propellant incorporates RDX within the double-base matrix to achieve both a higher density and higher energy level than standard double-base propellants while still retaining their desirable characteristics: smokeless and non-toxic exhaust, low sensitivity of burning rate to pressure and temperature variations, excellent stability characteristics and low cost.

(U) Various production size mixes were made to arrive at a formulation that could be adapted to the production facilities now used for manufacturing the standard N-5 Propellant grain. The selected formulation was fabricated both in a 2-inch test motor grain configuration and the standard 2.75-inch rocket motor grain configuration. Both types of grain were statically test-fired to evaluate the ballistic properties of the propellant with the test motor and to demonstrate full-scale motor performance in the tactical motor.

(U) The overall static test results confirmed the predicted energy increase (in the form of total impulse). In addition, the structural integrity of the present aluminum motor case was demonstrated for this higher flame temperature propellant throughout the range of -65°F to 165°F. Ballistically, the results of the full-scale firings proved to be within the tolerance level of the original rocket motor design criteria. The firings yielded smooth pressure and thrust vs. time traces with less indication of irregular burning than the standard propellant. The only adverse effect attributable to the high-energy propellant was to expose a potential weakness in the present method of holding the nozzles in place on the rear plate by staking. Although this is satisfactory for the N-5 Propellant, it is not suitable for the higher operating temperature of the high-energy propellant. This effect is minor and can be remedied in a full-scale development program.

(C) The 19% increase in impulse (17% computed increase in velocity) obtained by a straight propellant substitution confirmed the original prediction and also provided an experimental basis for the extrapolations resulting from the proposed optimized design studies. Using the test results as criteria, it was calculated that an optimized high-energy propellant design would result in a 30% increase (27% computed velocity increase) within the existing envelope and a 45% increase (36% computed velocity increase) if the motor were lengthened by five inches. The increase in burnout velocity will greatly increase the effectiveness of the various warheads currently in use without modifying the launch equipment.

(C) CONCLUSIONS (U)

(C) The velocity level of the 2.75-inch rocket motor can be increased by 17% by the straight substitution of a high-energy, RDX-filled propellant for the N-5 composition without a change in grain configuration or dimensions.

(C) The velocity level can be increased by 27% within the existing motor body by optimizing the grain configuration in addition to substituting high-energy filled propellant for the N-5 Propellant.

(C) Velocity improvement up to 36% can be obtained by increasing the motor length up to 5 inches and using the filled high-energy propellant in an optimized configuration. The outer diameter of this design is the same as the standard motor; thus, this rocket is compatible with existing launch tubes. The overall length may be retained if shorter alternative fin mechanisms are adopted.

(U) RECOMMENDATIONS

(U) A full-scale program should be initiated to replace the N-5 Propellant used in the 2.75-inch rocket with a high-energy high-density, RDX-filled propellant for the purpose of increasing the terminal velocity--enhancing the overall effectiveness of this weapon system.

(C) BACKGROUND (U)

(U) The 2.75-inch FFAR rocket was designed about 20 years ago. Its specific propulsion requirements at that time were based on launching a high explosive warhead forward from a high-speed aircraft. The aircraft velocity--added to the velocity imparted by the rocket motor--gave a total velocity to the round which translated into desirable range, terminal velocity and aircraft standoff values. In subsequent years, however, the role of this air-to-ground rocket has expanded to include firing from helicopters and low-speed aircraft. Furthermore, additional and heavier warheads, such as flechette and white phosphorous, were designed for this item. It became apparent that increased propulsion capability was desirable to permit the rocket to function effectively with slower aircraft, heavier warheads and at greater standoff ranges. However, the original design had been so well optimized with the characteristics of standard propellants then in use that there was no apparent area for improvement with conventional type propellant without seriously compromising some essential element of design such as length, diameter, or operating pressure. The new high-energy propellant formulations that have become available since the 2.75-inch rocket design was standardized cannot be utilized to improve the round's performance without seriously changing some essential elements. These propellant formulations are, for the most part, smoky and corrosive and emit toxic exhaust products. Obviously, such propellants could create serious problems when used in a helicopter-launched rocket. They could also drastically effect the launching mechanisms as well as the launching aircraft.

(C) To obtain a significant increase in ballistic performance of the 2.75-inch rocket system without compromising exterior rocket dimensions, it was necessary to formulate a propellant composition that could meet highly refined requirements. In addition to being free of the defects noted, the propellant formulation must possess suitable burning rate characteristics, be superior to the standard propellant by having a higher volumetric impulse and still remain compatible with 2.75-inch rocket hardware. Low-temperature sensitivity is also important to permit the round to function in a wide variety of environments. Compositions offering a promise of meeting these requirements--designated as nitramine propellants--were worked on for a number of years by Picatinny Arsenal (Reference 1). These compositions are of the double-base type with an organic oxidizer additive (such as RDX or HMX) incorporated into the matrix, which accounts for both the higher density and higher energy over the more conventional compositions. Due to the higher operating temperature characteristics of these propellants and the presence of the crystalline filler, the normal ballistic modifiers (used in most double-base rocket propellant compositions) do not perform well. As a result, considerable effort was expended to develop a suitable modifier. This led to the use of TDI-reduced lead stannate as a ballistic modifier with these high energy compositions. The results of this work are detailed in Reference 1. Thus, it was this type of propellant that was considered as the prime candidate to replace the standard propellant in the 2.75-inch rocket motor to achieve the goal of higher system performance.

(C) DISCUSSION (U)

Propellant Formulation and Manufacture

(C) A review of the work accomplished in the development of nitramine propellants disclosed a formulation which maximized volumetric impulse and had burning rate vs. pressure characteristics required for proper functioning within the envelope and ballistic constraints of the 2.75-inch rocket (Reference 1). This formulation was based on the use of a special ballistic modifier, designated TDI reduced lead stannate, which was fabricated in laboratory-scale quantities. It contained 54% HMX, a material in short supply in relation to the demands of high production items for which it is produced. The propellant was designed to be fabricated by the solvent/solventless extrusion process. Although the nitramine propellants have the higher energy and density required for the 2.75-inch rocket improvement application, the limited supply of some of their ingredients precluded their immediate use. The short supply of HMX and the miniscule quantity of the TDI reduced lead stannate are not compatible with production quantity of some 40 million lbs. of propellant per year. Consequently, an investigation was conducted to determine the possibility of substituting RDX for the HMX called for in the original formulation because it is more abundant in supply. In addition, the investigation included the development of a ballistic modifier that would be commercially available.

(C) Direct substitution of RDX resulted in a formulation having the same desirable burning rate properties obtained using HMX with only a minor reduction in volumetric impulse. As a result of the program on the ballistic modifiers, it was determined that a 4.2% mixture of lead and tin oxides gave excellent low slope burning rate characteristics in the region of burning rate required to be applicable in the 2.75-inch rocket motor (Reference 2). More important, these metallic oxides, with RDX, are available in sufficient quantities to meet the production requirements of the 2.75-inch rocket system.

(U) The exhaust products of this high-energy propellant formulation are similar in nature to those of the N-5 Propellant in that they are essentially mixtures of carbon dioxide, water, hydrogen, nitrogen and carbon monoxide. Thus the exhaust products are no more corrosive or toxic than are those of the standard propellant, and because of the high energy propellant's higher flame temperature, they are less smoky. They do not contain significant quantities of metallic oxides or solid particulate matter and consequently cannot cause deleterious effects such as grit buildup on the launcher detent or erosion of the launching aircraft.

(U) As mentioned, the high-energy propellant formulations are manufactured by the solvent/solventless extrusion technique. This process departs somewhat from the conventional solventless process in that the rolling of the sheet material for extrusion press feed is not possible due to the presence of explosive filler in granular form. To circumvent this situation, the propellant ingredients are mixed with solvent instead of being slurried with water, and the solvent mix is extruded into a granular configuration which is then dried. The granular feed stock is then placed in the solventless press. The process of extrusion is identical from that point on with the one now used. Thus the rolling process--one of the most costly and time-consuming elements of N-5 Propellant manufacture--is eliminated. Manufacture of granular propellant by the solvent process is the standard process used in the manufacture of artillery propellants. At Picatinny Arsenal, the solvent/solventless process is used for the production of gas generator nitramine propellant grains for the Hawk missile. The use of this process in the manufacture of propellant for the 2.75-inch rocket has a significant advantage compared to the solventless process used to manufacture N-5 Propellant because the result is a more uniform product. Unlike sheet propellant, huge lots of granular propellant may be cross blended to a high degree of uniformity prior to final extrusion.

Experimental Propellant Work

(U) A lot of propellant (IB-8145) was manufactured in a semi-production quantity based on the formulation discussed in Reference 2. This lot was solvent mixed, extruded into 1/8-inch-diameter granules and dried. A preliminary extrusion was carried out in a 4-inch solventless press prior to extrusion of full-scale grains in the 15-inch production press. It was immediately apparent that this composition was much too hard to successfully extrude in a larger press. The preliminary extrusion required the full pressure of the 4-inch press to extrude a 2-inch solid grain. This is equivalent to a basket-to-die area ratio of 4:1. In a 15-inch production press, extruding 2.75-inch rocket propellant grains, an area ratio in excess of 36:1 exists. It was therefore apparent that a modification must be made to soften the propellant composition prior to full-scale extrusion.

(C) To obtain a softer propellant composition without compromising its desirable ballistic properties, it was decided to modify only the nitrocellulose/plasticizer ratio while keeping the RDX content at its previous level of 54% (Reference 3). It was reasoned that this would provide a much softer propellant but one which still retained its high energy and high density properties. Accordingly, a semi-production lot of this modified propellant was manufactured (Lot IB-8309, Table 1) and a preliminary extrusion was carried out in the 4-inch solventless press. This mix was considerably easier

(C) TABLE 1

PROPERTIES OF HIGH ENERGY FORMULATIONS (U)

	LOT NO.		
(C) 1. Composition, %	IB-8145	IB-8309	IB-8419[2]
Nitrocellulose (12.6% N)	19.9	10.9	13.9
Nitroglycerin	16.7	23.7	21.2
RDX* (14 Micron Size)	54.0	54.0	53.9
Triacetin	4.2	6.2	5.6
2-Nitrodiphenylamine	1.0	1.0	1.0
Lead Oxide (Reagent Grade)**	0.84	0.84	0.84
Stannic Oxide (Reagent Grade)**	3.36	3.36	3.36
Carbolac I (added)	0.03	0.03	0.03
Candelilla Wax	----	----	0.20

* Cyclotrimethylenetrinitramine
** Screened through 200 mesh sieve

	IB-8419
(U) 2. Density	0.0626 lbs/in^3
(U) 3. Thermodynamic Properties of Propellant Gases[1]	
Mol. Weight	25.38
Cp, cal/gm	0.413
γ	1.23
T_v, ^oK	3664
T_p, ^oK	2971
C_d, 1/sec	0.00650
C_f	1.55
C*, ft/sec	4951
Q (exp), cal/gm	1166
Isp (1000 psi Ae/At = 4.0), sec	239

[1] Theoretical Data
[2] This Lot used in full scale firing tests

to extrude than the previous lot. Accordingly, arrangements were made to perform a limited extrusion of the full-scale 2.75-inch rocket motor grain in the 15-inch production type press. Successful extrusion of this full-size grain was not accomplished, however. The grains were much too soft and could not be processed further. In addition, the internal star perforation was very rough and ragged despite the pin being fabricated to a mirror finish. It was evident that modifications were required both to the formulation and tooling to obtain a satisfactory product.

(U) A further modification was made to the propellant formulation to reduce excessive softness and also to provide a smooth surface on extrusion. This modification consisted of slightly increasing the nitrocellulose/plasticizer ratio over that of the excessively soft formulation and adding 0.20% Candelilla wax (a die lubricant). Additionally, the pin for the 15-inch press was Teflon coated to reduce extrusion friction and provide a smooth internal surface. The modified formulation, designated as IB-8419 (Table 1), was fabricated by the standard solvent process, dried and successfully solventless extruded, first in the 4-inch press and then into full-size 2.75-inch rocket motor grains in the 15-inch press. Examination of these charges revealed them to be homogeneous, fissure-free and free of all other defects. The perforation surfaces were smooth with the points of the star sharply defined. Accordingly, these grains were machined on the outer diameter, trimmed to length, and inhibited and spirally wrapped for the conduct of full-scale motor tests. The physical and ballistic properties of this improved propellant formulation are in Table 1, while its burning rate vs. pressure data are plotted in Figure 1. Sensitivity and stability data for this composition are given in Table 2.

(c) BURNING RATE vs PRESSURE FOR
A TYPICAL HIGH ENERGY RDX FILLED PROPELLANT (U)

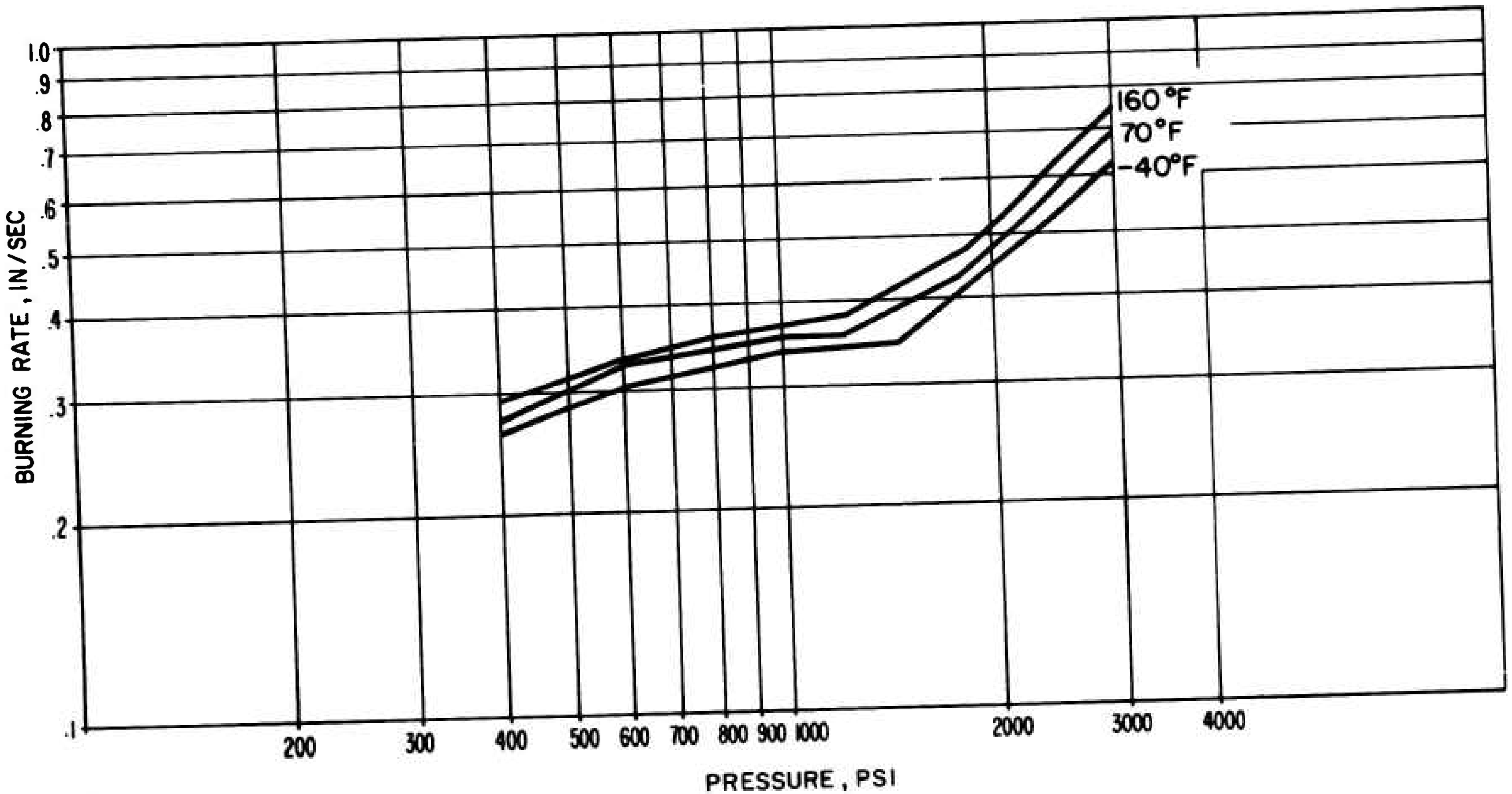

FIG. 1

LOT IB-8419

(U) TABLE 2

SENSITIVITY AND STABILITY DATA FOR HIGH ENERGY RDX-FILLED PROPELLANT

Sensitivity Data	
P.A. Impact Test	
2 Kilogram Weight, inches	10.0
Friction Sensitivity	
Steel Shoe	
Dry Propellant	No Action
Wet Propellant	No Action
Electrostatic Discharge, Joules	>11.025
Card Gap Test	
GO, No. of Cards	150
NO GO, No. of Cards	152
Differential Thermal Analysis	
Break Point	193°C
Stability Data	
120°C Heat Test	
Salmon Pink, minutes	50
Red Fumes, minutes	None
Explosion, minutes	500+
90°C Vacuum Stability	
Milliliters gas/40 hours	1.69
Taliani Test at 110°C (N_2)	
Slope at 100 Millimeters	*
Minutes to 100 Millimeters	*
Slope at 100 Minutes	0.10

* Curve did not reach 100 Millimeters Hg throughout test duration (300 minutes).

Static Test Program - Experimental Test Motors

(U) A static test program was initiated to fully characterize the high-energy propellant when fired in test and in standard tactical motors. Initially, tests were conducted in a 2-inch test motor using the grains obtained from the preliminary extrusions with the 4-inch press. These 2-inch test motor grains, having dimensions of 1.7 inches outer diameter, 0.6-inch inner diameter and 6.0 inches long, were loaded into standard test motors and statically fired to check out the ballistic properties of the propellant. The results of this test series are in Table 3. Twelve grains from Lot IB-8309 and three from Lot IB-8419 were fired to determine basic ballistic properties and the differences between these two batches. As mentioned, a slight modification was made between the two to enhance extrusibility. Only three firings from Lot IB-8419 were conducted because this particular lot was subsequently extruded into the full 2.75-inch rocket motor grain configuration and was scheduled for static tests with standard 2.75-inch motors.

(U) Soon after testing began, it became apparent that ordinary steel nozzles were affected by the higher flame temperature of this propellant to a much greater extent than by N-5 Propellant. An analysis of Round No. 8309-1 to 8309-5 shows that significant erosion took place in the throats of the individual nozzles. To prevent excessive erosion, the nozzle throats for the remainder of the firings were fitted with ATJ carbon inserts, a material successfully used to withstand erosion from high-energy propellant exhaust in short-burning time rockets. As a result, measurements of the individual nozzle throats made before and after firing for the remainder of the tests revealed that erosion was almost completely eliminated.

(U) Ballistically, the results of the 2-inch test motor program show good uniformity of parameters among the various rounds fired as well as close conformity to the predicted values. The specific impulse values obtained were expected to be pessimistic since this particular test motor, originally designed for many firings, is quite heavy in relation to the propellant weight. It was thought that the large heat sink represented by this motor would appreciably lower this parameter. In spite of this, the value of specific impulse obtained was very near the predicted value for the full-scale motor. In general, the tests proved quite satisfactory and preparation was made for full-scale tests in the standard 2.75-inch rocket motor.

Static Test Program - Tactical Motors

(U) A number of full-scale grains were fabricated from Lot IB-8419 into the identical propellant configuration of the standard N-5 grain. It was felt this would provide a firm basis for comparison

(C) TABLE 3

STATIC TEST RESULTS OF LOTS IB-8309 & IB-8419 FIRED IN

Round No.	8309-1	-2	-3	-4	-5	-6	-7
Temperature, °F	70	-40	160	70	70	70	70
Propellant Weight, lbs	0.787	0.766	0.766	0.796	0.770	0.781	0.775
Diameter Nozzle Throat, before, in	0.389	0.389	0.389	0.389	0.378	0.389	0.390
Diameter Nozzle Throat, after, in	------	0.403	0.430	0.429	0.410	0.390	0.391
Ignition Delay, sec	0.0100	0.0125	0.0114	0.0125	0.0099	0.0134	0.0178
Maximum Pressure, psi	1390	1027	2428	1640	1640	1418	1314
Maximum Initial Pressure, psi	------	481	3448	------	------	1120	1105
Mean Pressure, psi	1100	901	------	1204	1247	1155	1130
Maximum Thrust, lbs	------	193	458	304	268	250	226
Maximum Initial Thrust, lbs	------	83	------	------	------	194	192
Mean Thrust, lbs	------	164	------	255	218	204	190
Action Time, sec	0.871	1.036	------	0.731	0.774	0.846	0.863
Total Impulse, lb-sec	------	170	------	187	169	173	164
Specific Impulse, sec	------	220	------	235	220	221	212
Notes	(1)		(2)			(3)	(3)

Notes:

(1) Thrust gage malfunctioned. Thrust dependent data questionable.
(2) Evidence of Propellant Breakup near end of burning. An unknown quantity was expelled prior to burnout.
(3) These nozzles were fitted with carbon inserts. Rounds 1-5 were fired with steel nozzles.
(4) Propellant Dimensions: O.D. 1.75 in, I.D. 0.600 in, Length 6.0 in.

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(C) TABLE 3

LOTS IB-8309 & IB-8419 FIRED IN TWO INCH TEST MOTORS (U)

-5	-6	-7	-8	-9	-10	-11	-12	8419-1	-2	-3
70	70	70	70	-65	-65	165	165	70	70	70
0.770	0.781	0.775	0.773	0.764	0.780	0.774	0.786	0.797	0.802	0.804
0.378	0.389	0.390	0.396	0.396	0.396	0.393	0.390	0.392	0.392	0.396
0.410	0.390	0.391	0.396	0.396	0.393	0.393	0.392	0.393	0.395	0.397
0.0099	0.0134	0.0178	0.0145	0.0204	0.0110	0.0078	0.0094	0.0124	0.0129	0.0166
1640	1418	1314	1247	1614	1408	2380	2971	1132	1193	1143
------	1120	1105	1082	1116	1081	1641	1707	1281	1279	1265
1247	1155	1130	1072	876	838	1443	1816	1142	1142	1119
268	250	226	217	306	279	417	516	225	227	231
------	194	192	180	204	201	294	302	202	216	210
218	204	190	191	161	154	249	311	203	206	205
0.774	0.846	0.863	0.885	1.072	1.088	0.661	0.544	0.884	0.900	0.898
169	173	164	169	173	168	165	169	179	186	184
220	221	212	219	227	215	214	215	225	232	230
	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)

elled prior to burnout.
nozzles.

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since only the propellant composition would be different from the present rocket and differences in static test results from those with N-5 Propellant would represent only the difference due to propellant composition. It was recognized quite early that, because of the higher flame temperature of this high energy composition, it is vital for the obturation between the propellant grain and the thin aluminum case to remain intact throughout the burning time to prevent a motor failure. Since the flame temperature of this propellant is 5,400°R, and since the softening point of aluminum is considerably less than this value, it is quite obvious that every precaution must be taken to insure that no hot gases can reach the motor wall prior to propellant burnout. The obturator between the end of the propellant charge and nozzle assembly was originally designed for a much cooler propellant (N-5). However, no change was made in the parts used in tactical rockets except for the use of ATJ carbon inserts for all nozzles to prevent nozzle throat erosion. Accordingly, a group of three full-scale 2.75-inch rocket motors, loaded with Lot IB-8419-2 high-energy propellant, and incorporating the single nozzle design, was statically test-fired at 70°F (Table 4).

(C) TABLE 4

STATIC TEST RESULTS OF FULL SCALE 2.75 INCH MOTOR TESTS WITH HIGH ENERGY PROPELLANT-SINGLE NOZZLE CONFIGURATION (U)

Round No.	HE-1	HE-2	HE-3
Temperature, °F	70	70	70
Propellant Weight, lbs	6.04	6.19	6.05
Diameter Nozzle Throat, before, in	0.810	0.803	0.811
Diameter Nozzle Throat, after, in	0.808	0.805	------
Ignition Delay, sec	0.0082	0.0058	0.0082
Maximum Pressure, psi	1253	1495	1330
Maximum Initial Pressure, psi	1176	1198	1209
Mean Pressure, psi	911	959	919
Maximum Thrust, lbs	886	1118	1002
Maximum Initial Thrust, lbs	862	829	837
Mean Thrust, lbs	657	682	669
Action Time, sec	2.05	1.94	2.03
Total Impulse, lb-sec	1363	1320	1359
Specific Impulse, sec	226	214	224

Notes:
1. Propellant Lot: IB-8419-2
2. Nozzle Throat fitted with carbon inserts

(U) The results of this initial test of a high-energy, RDX-filled propellant in a full-scale production motor were extremely satisfactory. The obturation seal and the thin aluminum motor case functioned perfectly despite the high flame temperature. In addition to the excellent uniformity in mean pressure and thrust of the three rounds tested there was no indication of any significant resonance in spite of the fact that standard rounds do show evidence of resonant burning. Also, there was no evidence of erosive burning, which is always a possible problem with low port-to-throat area ratio rockets. Finally, the absence of any nozzle erosion confirmed the choice of ATJ carbon for a nozzle throat insert material.

(U) The success of the preliminary full scale tests led to a continuation of the static test program with grains of this same propellant lot loaded into standard MK40 motors, utilizing a four-nozzle configuration with the individual nozzles staked in place on a plate assembly. As in the previous tests with the single nozzle assembly, each throat section of the four nozzles was fitted with an ATJ carbon insert to preclude erosion. Unlike the single-nozzle design in which the approach to the throat is well protected by a plastic sleeve, the MK40 design has no such protection and hence the plate to which the four nozzles are staked is vulnerable to erosive gas attack. No provision was made to protect this area during this test phase. Again, other than the substitution of the high-energy propellant for the N-5 grain and the insertion of the carbon inserts, the rockets tested were standard MK40 motors taken from production stocks.

(C) A series of five rounds was initially static test-fired at 70°F (Table 5). Analysis of the first four firings, Rounds HE-4 to HE-7, showed an average impulse improvement of 19% which is very close to the original predicted value. Ballistic uniformity was good and nozzle erosion was minimal. It should be mentioned that the occasional nozzle listed as "plugged" on Table 5 does not represent a defect. This is caused by the melted inhibitor filling the nozzle cavity, which occurs after burning has terminated. This is of no consequence since it cannot affect the free flight of the projectile. The last round tested at 70°F (HE-8) did exhibit a significant deficiency. Two of the four nozzles blew out of the nozzle plate assembly just prior to burnout resulting in a shorter action time and consequently a low total impulse. This was not totally unexpected since the nozzle staking design is known to be marginal for high temperature operation. The same phenomenon occurred again during the firing of Round HE-10 at 130°F, at which time all four nozzles were ejected just prior to completion of burning.

(U) Since no major alteration to the nozzle assembly could be made at this time, an expedient fix was attempted to permit completion of the static test program. It was recognized that the basic design

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(C) TABLE 5

STATIC TEST RESULTS OF FULL SCALE 2.75 INCH
WITH HIGH ENERGY PROPELLANT IN STANDARD MK 40

Round No.	HE-4	HE-5	HE-6	HE-7	HE-8
Temperature, °F	70	70	70	70	70
Propellant Weight, lbs.	6.35	6.31	6.07	6.21	6.30
Diameter Nozzle Throat, before, in.	0.400+.002	-----	-----	-----	-----
Diameter Nozzle Throat, after, in.	0.414(3) Plugged(1)	0.426,0.420(2) Plugged(1)	0.412(3) 0.417(1)	0.412(3) Plugged(1)	0.412(2)
Ignition Delay, sec.	0.0118	0.0067	0.0118	0.0135	0.0135
Maximum Pressure, psi	-----	1225	1225	1306	1284
Maximum Initial Pressure, psi	-----	1000	980	1245	-----
Mean Pressure, psi	-----	938	928	916	-----
Maximum Thrust, lbs	995	827	827	964	842
Maximum Initial Thrust, lbs	781	796	735	916	-----
Mean Thrust, lbs	711	707	663	827	-----
Action Time, sec	2.06	1.96	1.98	2.03	-----
Total Impulse, lb-sec	1463	1384	1313	1377	-----
Specific Impulse, sec	231	220	217	222	-----
Notes	(3)				(4)

Notes:
(1) Propellant Lot: IB 8419-2
(2) Nozzle Throat fitted with carbon inserts
(3) Pressure Gage failed. No pressure data could be obtained
(4) Two of the four nozzles blew out of nozzle plate just prior to end of burning resulting in a shorter time and low
(5) All four nozzles blew out of housing just prior to burnout resulting in a shorter time and lower total impulse
(6) One nozzle blew out of housing just prior to burnout resulting in a shorter time and lower total impulse
(7) These rounds utilized welded nozzle assemblies

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(C) TABLE 5

RESULTS OF FULL SCALE 2.75 INCH MOTOR TESTS
RGY PROPELLANT IN STANDARD MK 40 CONFIGURATION (U)

HE-7	HE-8	HE-9	HE-10	HE-11	HE-12	HE-13	HE-14
70	70	-10	+130	+130	-10	+165	-65
6.21	6.30	6.14	6.20	6.30	6.31	6.28	6.27
0.412(3) Plugged(1)	0.412(2)	0.473,0.417	-----	0.418(4)	0.396(3)	0.414,0.415	0.409(4)
0.0135	0.0135	-----	0.0067	0.0149	-----	0.0147	0.0168
1306	1286	1141	1177	1045	942	1099	987
1245	-----	1092	1311	944	767	1597	1004
916	-----	851	903	773	-----	-----	748
964	842	847	875	1009	-----	1336	643
916	-----	722	826	917	-----	886	729
827	-----	589	624	669	-----	-----	521
2.03	-----	2.20	2.03	2.05	-----	-----	2.58
1377	-----	1298	1270	1368	-----	-----	1343
222	-----	212	-----	218	-----	-----	214
	(4)		(5)	(7)	(3,6)	(4,7)	(7)

ulting in a shorter time and low total impulse
time and lower total impulse
and lower total impulse

is marginal, that is, the failure only occurred occasionally and, in each case, almost at the end of burning. Thus, it was expected that a minor fix to reinforce the nozzle attachment might overcome the deficiency. A weld bead was therefore added to each nozzle in place without removing the nozzles from their staked position on the plate. Additional tests conducted at 130°F (HE-11) and -65°F (HE-14) utilized these welded nozzles. They functioned satisfactorily. However, at 165°F with Round HE-13, this expedient failed and all four nozzles were ejected near the end of burning. These results clearly demonstrated that staking the nozzles in place was marginal for the high-energy propellant motor. A redesign to provide firmer attachment and to eliminate gas leakage through the nozzle attachment would be required during development. Such work was beyond the scope of the present program. However, a promising approach to this problem was taken by the Air Force with a design incorporating phenolic nozzles molded in place on the nozzle plate around throat inserts. A similar solution would completely eliminate this problem.

(U) Aside from the nozzle attachment difficulty, the final static test results clearly demonstrate the benefits of incorporating a high-energy propellant charge into the 2.75-inch rocket system. The exploratory firing conducted at -65°F (Round HE-14) showed that the ignition system is entirely suitable for use with the new propellant charge. Also, the structural integrity of the metal parts assembly--particularly the thin aluminum shell--was satisfactorily demonstrated in the firing conducted at 165°F (Round HE-13). Finally, the ballistic performance was satisfactory in that the impulse improvement was close to that predicted.

Motors for Flight Tests

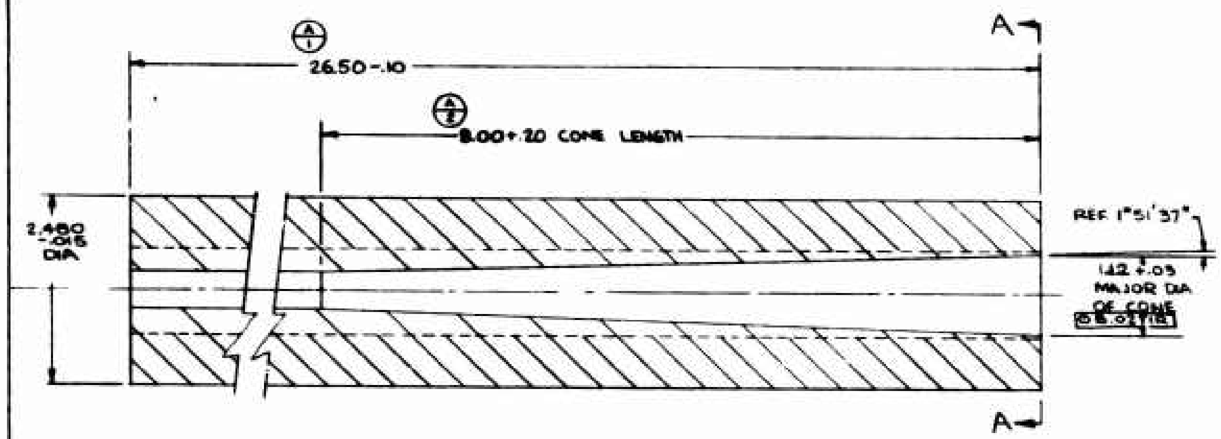
(U) A series of 10 additional full-scale motors were loaded with the remainder of the high-energy propellant grains from this lot. These motors were packed for shipment to Yuma Test Station for flight tests. It is planned to flight-test these rounds to determine the overall improvement in burnout velocity and range that will occur by merely replacing the N-5 Propellant with the high-energy propellant composition in the standard configuration. These tests are expected to be conducted in early 1972.

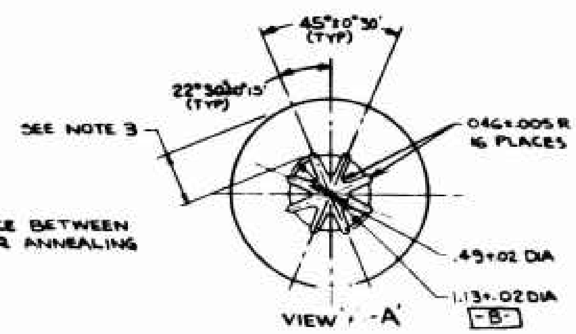
Proposed Designs and Future Work

(C) The object of this study was to demonstrate the overall improvement that could be obtained by substituting a high-energy propellant for the N-5 Propellant without any change in weapon configuration. Design studies were conducted to determine the improvement possible by using this same high-energy propellant with an optimized grain configuration, but restricted to the external envelope of the 2.75-inch rocket motor. The results of this study (in Table 6) revealed that a total impulse improvement of 30% (27% computed velocity increase) can be achieved within the existing motor case. This can be accomplished by redesigning the grain perforation to achieve a greater weight of propellant within the existing motor volume (Figure 2). The nozzle end of the grain perforation would be slightly tapered to maintain the present port to throat area ratio--a necessity to prevent erosive burning. The web thickness also would be increased. Despite the tapering of the perforation star points, the web would remain constant for the entire grain length to prevent deterioration of the motor tube by heat effects caused by one end of the grain burning out before the other This grain, like the N-5 Propellant grain, is designed to burn only internally and therefore uses the unburned propellant as its own insulator to protect the motor wall. This insulation must be maintained because the thin aluminum motor wall would be almost instantly compromised by exposure to excessive heat. The increase in velocity achieved by this optimized grain with both the M151 and M229 Warheads fired both from a helicopter and from ground level is plotted in Figures 3-6

(C) Although Table 6 details a number of impulse improvements that can be obtained by optimizing the grain configuration without a change in exterior dimensions, still further improvements are possible if the present grain can be lengthened. Among the investigations being conducted for the 2.75-inch rocket, two modifications are significant because they offer room for additional propulsion improvement. One design now being flight-tested uses a "short bent" fin which is three inches shorter than the present fin. Another device currently under consideration is a wrap around fin assembly which, if adopted, would decrease the length of the 2.75-inch rocket by five inches. These two devices could permit an increase in the length of the propellant charge by either three or five inches without increasing the missile length.

(C) Accordingly, it was decided to determine the maximum impulse improvement that could be obtained if either of the two fin designs were incorporated into the 2.75-inch rocket system. The results of these studies predict that a total impulse improvement of 40% (32% computed velocity increase) is possible with a 29.5-inch grain (+3.0 inches) and a 45% increase (36% computed velocity increase) can be obtained with a 31.5-inch grain (+5.0 inches). It should be noted that the latter figure is the maximum impulse improvement possible since any further increase in propellant length, without a corresponding increase in the present diameter, would not permit introduction of additional useful propellant. This is because additional internal venting area would be required to allow the generated gas to escape without causing severe erosive burning at the nozzle end. By increasing the internal diameter to the required size, the weight of the longer propellant grain and consequently its total impulse would actually decrease instead of increase.





NOTES:
1-SPEC MIL-A-2550 APPLIES
2-MATERIAL: PROPELLANT TYPE IB-8419
3-CONSIDERING EACH END SEPARATELY, THE DIFFERENCE BETWEEN THE THICKEST AND THINNEST WEB THICKNESS AFTER ANNEALING SHALL NOT EXCEED .040 INCH
4-ALL DIMENSIONS APPLY AT 70°±5°

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL
A-Z	CHANGED: (A) "26.50 -.10" WAS "26.60 -.10"; (B) "8.00 +.20" WAS "8.65 +.25"		

SOLID ROCKET PROPULSION LABORATORY
PICATINNY ARSENAL, DOVER, N. J.

GRAIN PROPELLANT 2.75 IMPROVEMENT

DATE APR 24 1969
SCALE NONE

C- SK-MGH-4492

(C) FIGURE 2

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(C) 2.75 INCH ROCKET STUDY
COMPARISON OF N-5 & HE PROPELLANTS
MK40 W/151 WARHEAD (U)

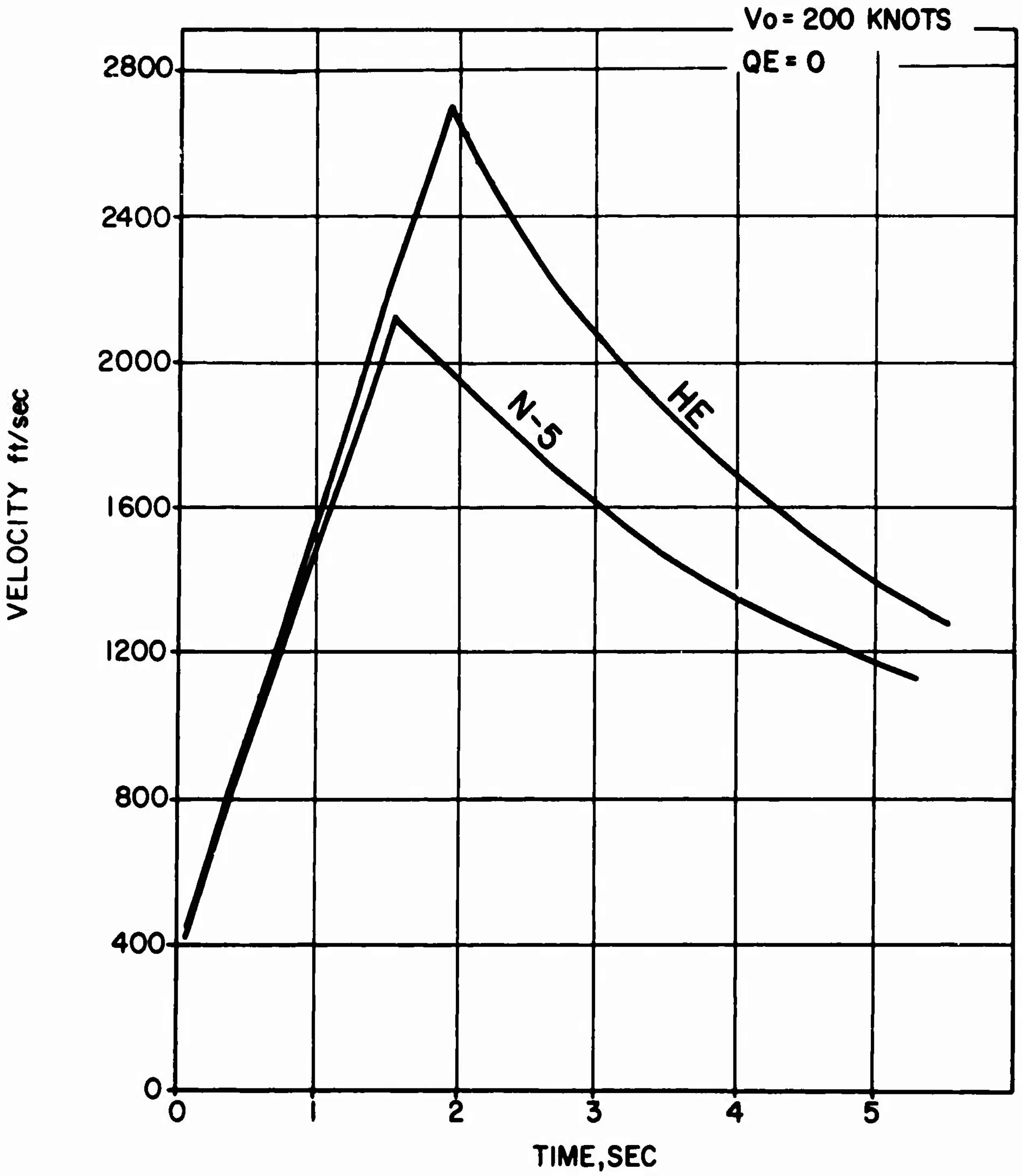

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FIG 3

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(C) 2.75 HIGH ROCKET STUDY-COMPARISON OF N-5 & HE PROPELLANTS
MK40 W/M151 WARHEAD (U)

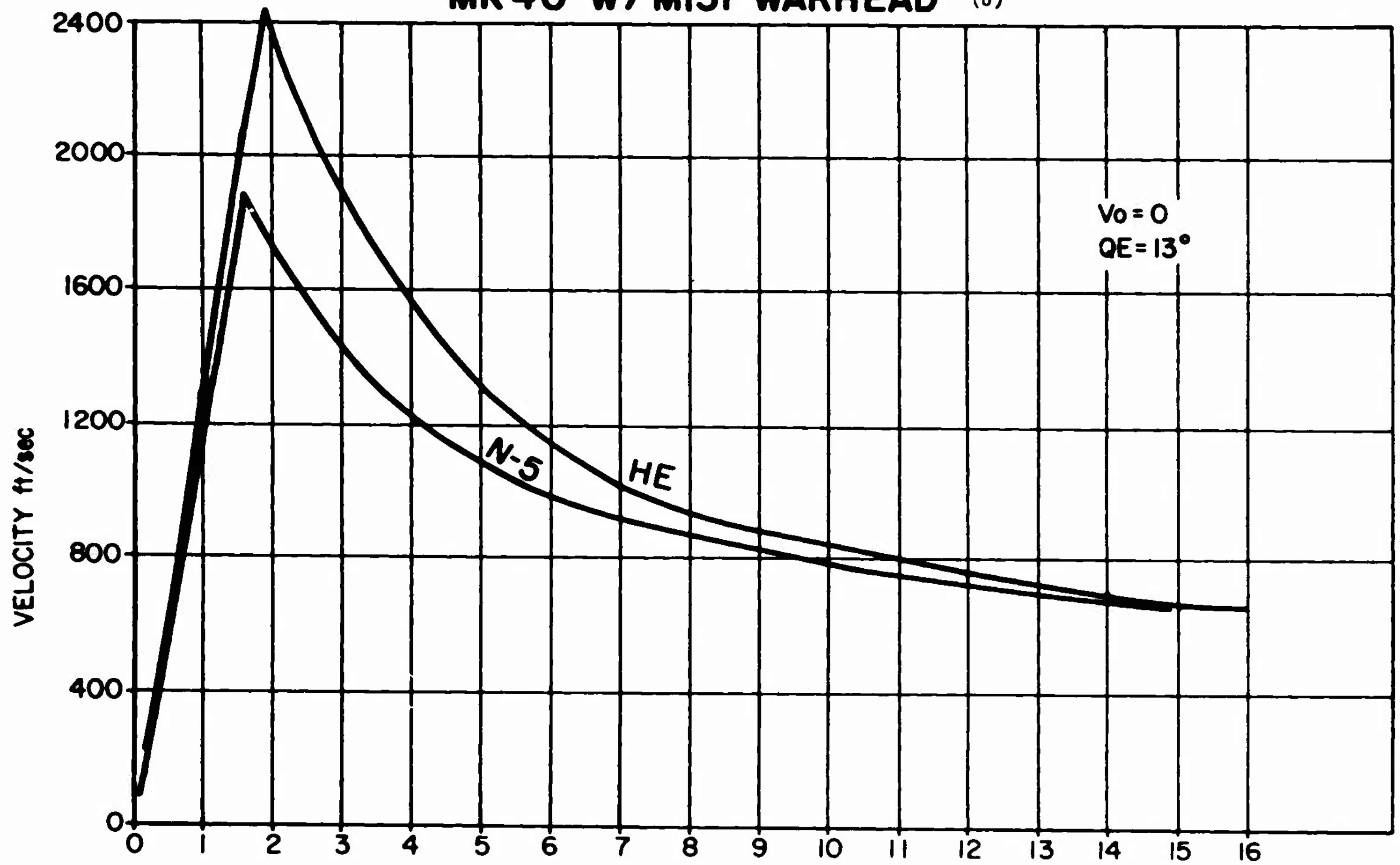

FIG 4

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(C) 2.75 INCH ROCKET STUDY
COMPARISON OF N-5 & HE PROPELLANTS
MK40 W/M229 WARHEAD (U)

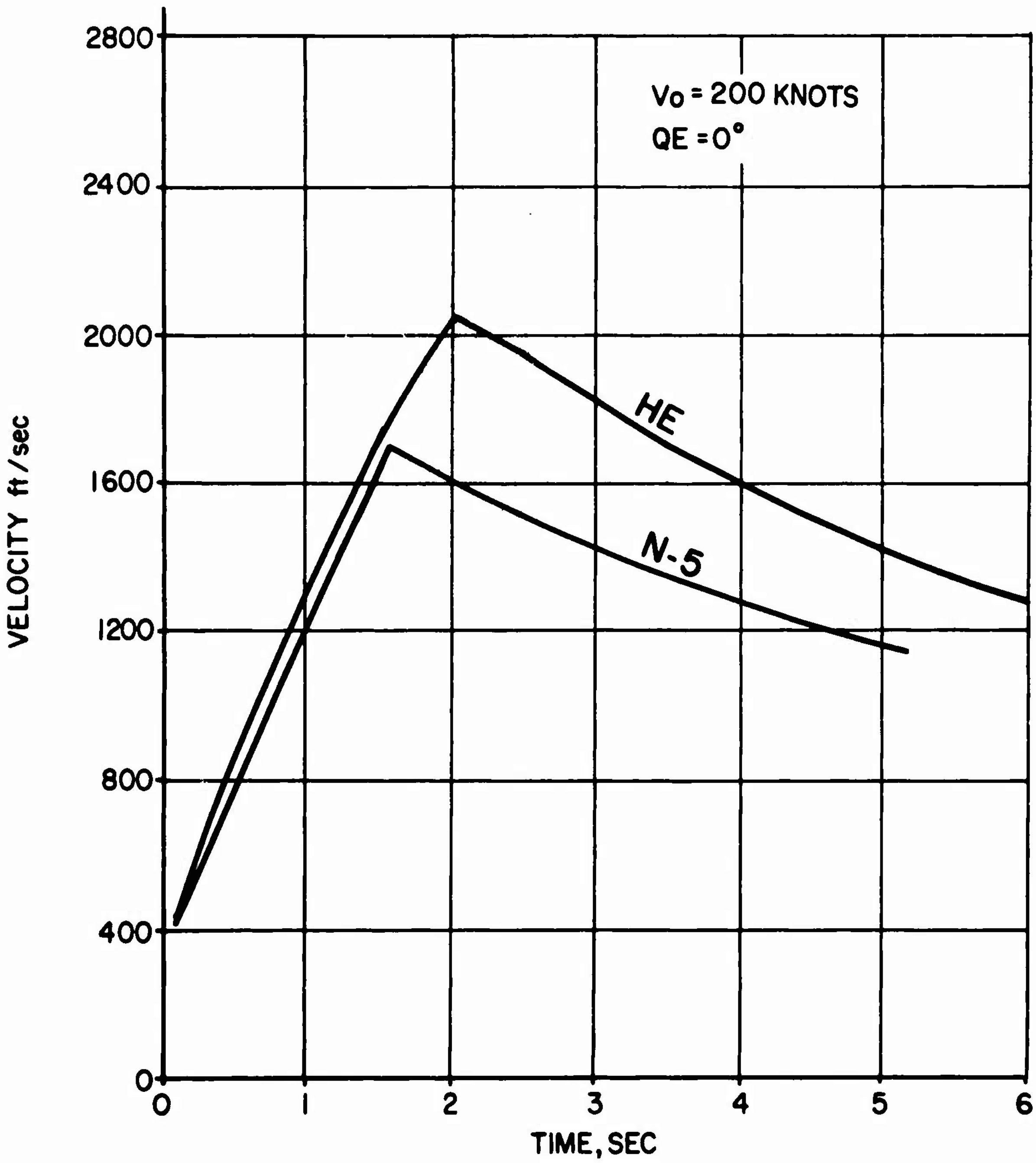

FIG 5

(c) 2.75 INCH ROCKET STUDY COMPARISON OF N-5 & HE PROPELLANTS MK40 W/M229 WARHEAD (U)

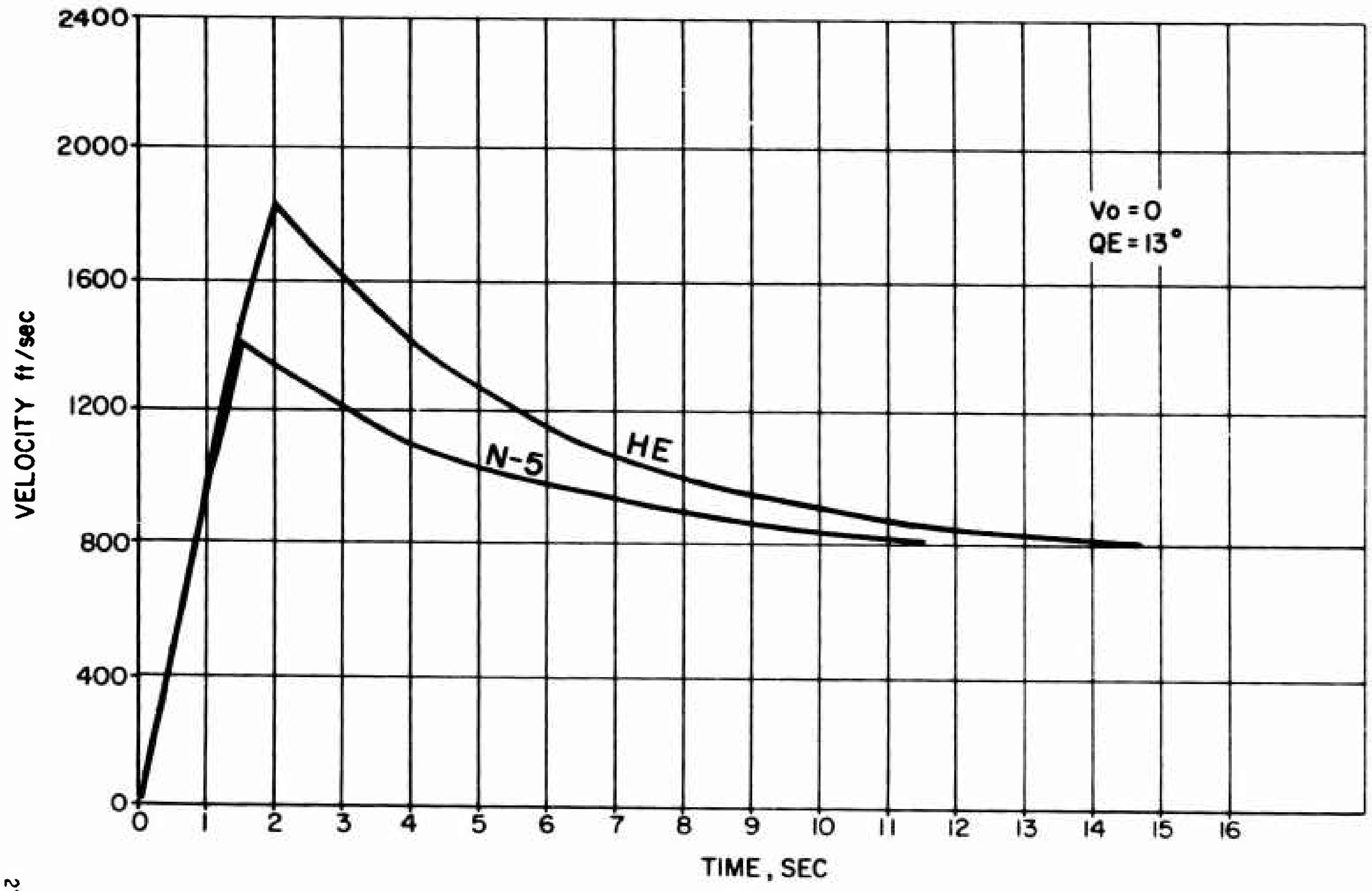

FIG 6

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(C) TABLE 6

COMPARISON OF NEW DESIGNS WITH STANDARD MK 40

Round Description Propellant Composition Propellant Configuration	Standard Round (1)(MK40) N-5 Standard		Standard Motor (2) H.E. (IB-8419) Standard		Standar H.E. (Optimi this
Temperature Range, °F	-65	+165	-65	+165	-65
Maximum Operating Pressure, psi		1467	1300	1700	1000
Mean Pressure psi			1000	1220	950
Minimum Pressure psi			820	1025	760
Mean Thrust, lbs			722	915	736
Burning Time, sec			1.89	1.53	2.10
Total Impulse lb-sec	1143	1183	1364	1400	1545
Specific Impulse, sec	194	200	216	222	216
Propellant Weight, lbs	5.9		6.3		
Area Nozzle Throat, in^2	0.422		0.502		
Port Area to Throat Area Ratio, Ap/At	1.79		1.76		
Length Prop. Grain, in	26.15		26.40		
Impulse Improvement over Standard Round, %	-----		19.0		
Velocity Improvement over Standard Round %					
Vo = 0	-----		17.4		
Vo = 90 Kts	-----		16.2		
Vo = 125 Kts	-----		15.8		

Notes:
(1) Acceptance Test Data
(2) This design was statically test fired in both single nozzle and standard 4 nozzle configuration (See

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(C) TABLE 6

OF NEW DESIGNS WITH STANDARD MK 40 MOTOR (M151 WARHEAD) (U)

Standard Motor (2) H.E. (IB-8419) Standard		Standard Motor H.E. (IB-8419) Optimized for this Length		Modified Fins H.E. (IB-8419) Increased Length (+3 In.)		Modified Fins H.E. (IB-8419) Increased Length (+5 In.)	
-65	+165	-65	+165	-65	+165	-65	+165
1300	1700	1000	1250	1300	1700	1300	1700
1000	1220	950	1150	1000	1220	1000	1220
820	1025	760	900	820	1025	820	1025
722	915	736	932	810	924	844	960
1.89	1.53	2.10	1.72	2.0	1.80	2.00	1.80
1364	1400	1545	1585	1620	1660	1685	1730
216	222	216	222	216	222	216	222
6.3		7.15		7.49		7.81	
0.502		0.530		0.597		0.604	
1.76		1.80		1.72		1.70	
26.40		26.50		29.50		31.50	
19.0		30.0		40.0		45.0	
17.4		27.2		31.7		35.9	
16.2		25.3		29.5		33.5	
15.8		24.5		28.7		32.5	

dard 4 nozzle configuration (See Table 2 and 3)

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(U) It is anticipated that the present ignition system and grain support system can be used without change. As for the remainder of the metal parts assembly, the only change that would be required--in addition to the insertion of carbon inserts into the nozzle throats--would involve an improved method of attaching the nozzles to the nozzle plate. The reasons for this were previously discussed. All the necessary manufacturing facilities for mass producing this propellant are in existence, since the process operations are identical to those used for the manufacture of granular propellant and for the standard N-5 grain. The only difference in facility requirements stems from the higher explosive classification of this propellant. The high-energy propellant was determined to have a Class 7 classification as compared to Class 2 for N-5 Propellant. Facilities exist at Radford Army Ammunition Plant to manufacture Class 7 granular propellant in production quantities. Solventless extrusion of the final configuration, however, will require additional barricades between the production presses now used for N-5 Propellant production. Although the extrusion technique and equipment required are identical for these two propellants, the extrusion presses are only certified for use with a Class 2 propellant. The wrapping and finishing areas required are identical for both propellants and thus no conflict exists here.

(U) A summary of the sensitivity and stability test results for this propellant is in Table 2. Specific recommendations for fabrication processing precautions should be generated by an explosive hazards analysis of the high-energy propellant. This work should be undertaken as part of a full development program.

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13. ABSTRACT

A limited study was conducted ~~by~~ the Ammunition Engineering Directorate's Solid Rocket Propulsion Laboratory to determine the velocity improvement that could be obtained by substituting a high-energy, smokeless propellant for the N-5 Propellant in the 2.75-inch rocket motor which was developed nearly 20 years ago.

Developed by Picatinny Arsenal, this high-energy propellant incorporates HDX within the double-base matrix to achieve both a higher density and higher energy level than the standard double-base propellants while still retaining their desirable characteristics: smokeless and non-toxic exhaust, low sensitivity of burning rate to pressure and temperature variations, excellent stability characteristics and low cost. This program demonstrated by static testing that the predicted improvement can be achieved. The details and other preliminary findings resulting from this testing program are documented in this report.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
2.75-inch rocket weapon system						
Improved velocity study						
High-energy propellant						
Smokeless propellant						
RDX filled propellant						
HMX filled propellant						
N-5 propellant						
Static test program						
MK40 rocket motor						
M229 warhead						
M151 warhead						

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