DEVELOPMENT OF GUN LAUNCHED ROCKETS

F.M. GROUNDWATER

Thesis

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Abstract English

- In 1962 McGi11 University undertook a program of high altitude research using a 16" smooth bore Naval gun. The concept of investigating upper atmosphere physics using guns was proposed by Dr. G.V. Bull. The early history and technique is described in various references. Initially, the program concentrated on launching pure ballistic vehicles. It became apparent by the spring of 1963 that, with the available launching system, the pure ballistic vehicle had attained its maximum performance which was in the region of 120 kilometers. In order to achieve better performance, in terms of payload and apogee, it became necessary to investigate other concepts. [...]

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THE DEVELOPMENT OF

GUN LAUNCHED ROCKETS

F.M. GROUNDWATER

This thesis is submitted as the major requirement for the degree of Master of Engineering

Space Research Institute
892 Sherbrooke St.W.
Montreal, Quebec.

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SUMMARY

The need for high altitude probes for upper atmospheric studies is well known. The paper presents the basic concepts in the design of rocket boosted projectiles fired vertically from a large scale Naval gun.

Launch parameters of the gun are discussed. Response of various materials to an environment similar to the gun launch case is presented. A theoretical model of a rocket case is developed.

A series of component tests are made and the component evaluated in the light of the results of the tests.

The general philosophy of the mechanical design of components and assemblies is discussed.

The final design of a prototype vehicle is outlined. The results of test firings of these vehicles are presented.

On the experience acquired, modifications are made to the vehicles and a second set of test firing results are presented.

The details of a complete redesign to improve performance of the vehicles are presented along with a series of test firing results. Conclusions are drawn as to the overall suitability of the center cavity type of gun launched rocket probe.

A final series of tests is presented confirming these conclusions and the continuing development program is commented upon.

TABLE OF CONTENTS

TABLE OF FIGURES

NOMENCLATURE

A_b	=	Barrel Cross-Sectional Area
A_f	=	Frontal Area
A_1	=	Area at Cross-Section "1"
A_t	=	Throat Area
B	=	Ballistic Coefficient or Linear Burning Rate of Propellant
C_d	=	Drag Coefficient
C_M	=	Moment Coefficient
C_N	=	Normal Force Coefficient
c	=	Reference Length of Vehicle (usually diameter)
c_D	=	Discharge Coefficient
c_F	=	Thrust Coefficient
D	=	Drag Force
F	=	Thrust (sometimes denoted T)
g	=	Earth Acceleration
h	=	Altitude
I_p	=	Moment of Inertia in Pitch Plane
I_T	=	Total Impulse
I_{sp}	=	Specific Impulse
l	=	Column Length
m	=	Mass
$\dot{m}$	=	Mass Flow Rate
M	=	Moment

n	=	Exponential (measure of sensitivity of burning rate of propellant to pressure change)
N	=	Normal Force
P_A, P_C	=	Rocket Chamber Pressures at Section A or C
P_b	=	Breech Pressure
P_S	=	Pressure on base of Shot or Projectile
P_{st}	=	Stagnation Pressure
q	=	$v^2/2$
r	=	Range
s	=	Distance
T	=	Thrust
v	=	Velocity
V_{ave}	=	Average Velocity
v_θ	=	Velocity Vector resulting from Vehicle rotation
V	=	Specific Volume of Fluid
x	=	Distance
$\dot{x}$	=	Velocity
α	=	Angle of Attack
β	=	Linear Burning rate of double base propellant at a constant pressure of 1000 psi
Δ	=	Small Increment
ν	=	Poisson's Ratio
θ	=	Reference Angle with relation to ground level
θ_o	=	Initial Launch Angle
ρ	=	Density
Σ	=	Summation of Terms
σ	=	Stress
p	=	Pitch Frequency

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The author gratefully acknowledges his thanks to Dr. G.V. Bull for his patience and guidance in his capacity of Director of the entire High Altitude Research Project and more particularly as director of this portion of the research.

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The author acknowledges the cooperation of H.S. Dando, M. MacNaughton and R. Underwood of Canadian Arsenals Limited, Valleyfield, Quebec; John Watson and Mike Wilson of Heroux Machine Parts, Longueuil, Quebec and T. Holmes of Aviation Electric Limited, Montreal, Quebec, in the manufacturing phase of the program. These individuals contributed to the Project above and beyond normal industrial efforts.

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1.0 INTRODUCTION

In 1962 McGill University undertook a program of high altitude research using a 16" smooth bore Naval gun. The concept of investigating upper atmosphere physics using guns was proposed by Dr. G.V. Bull. The early history and technique is described in various references. * Initially, the program concentrated on launching pure ballistic vehicles. It became apparent by the spring of 1963 that, with the available launching system, the pure ballistic vehicle had attained its maximum performance which was in the region of 120 kilometers. In order to achieve better performance, in terms of payload and apogee, it became necessary to investigate other concepts.

Two broad avenues of approach were undertaken. The investigations into optimization of the launcher by addition of a muzzle extension, manufacture of more powerful propellants and refinement of vehicles was initially considered. The second approach was to consider the use of rocket-assisted vehicles.

At the out-set, relatively little information was available on the design of gun launched rockets for security reasons.

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* Reference 1, 2 and 3

Standard references on rockets offered little help in coping with problems associated with high acceleration launch environments. The limited budget of the program dictated the course of action undertaken. In general, commercially available materials were used in manufacture. This precluded the use of expensive refractory metals, ultra high impulse rocket fuels and sophisticated guidance systems.

2.0 INITIAL DESIGN CONSIDERATIONS

The Martlet III series of vehicles was designed to achieve better apogee and payload from a gun launched probe using rocket assist. The foremost consideration of design was the high acceleration level encountered in the launching tube. Accelerations of 5,000 to 20,000 "g's" are common (1 "g" is equivalent to the earth's gravitational acceleration). This consideration imposes severe restrictions on the design of mechanical members.

The complexity of liquid fuel and hybrid propulsion systems made them unattractive despite their excellent performance characteristics. In view of this, a decision was made to attempt to launch solid chemical propellant motors in these vehicles. Despite their relatively low performance, it was felt that the ability of the system to withstand high launch environments offered the best possibility for success.

Solid fuel rockets can be divided broadly into two categories; end-burning and radial burning. The end burning rocket motor is ignited from the base usually by means of a device incorporated in the discharge nozzle. The motor then burns in a fashion similar to a cigarette.

A major problem with this type of configuration is heating of the motor case. End-burning grains have relatively long burning times. The motor case is then exposed to high temperature gas wash for a sustained period which can cause structure weakening or damage. To overcome such a problem, protection must be incorporated on the inner walls of the case. Long burning times tend to make nozzle design more difficult due to erosion and heat transfer problems. The advantage of an end-burning grain is the fact that there are no voids or cavities and the loading density of the motor case is a maximum.

Radial burning grains have a central cavity. They can be ignited from the front or rear by projecting an ignition charge into the central cavity. The fuel then burns radially outwards until it is totally expended. The case is then always protected by a layer of fuel and does not experience any contact with the high temperature gas. In general, the radial burning grain rate of generation of gas products (at a given motor burning pressure) will be greater than an end-burning grain since, a much larger area of propellant is ignited. This fact makes the radial burning grain attractive from the point of view of nozzle design. The radial burner will generate the volume of gas in shorter time. This means a larger relative throat diameter in the nozzle to maintain constant internal pressure.

The larger throat diameter gives larger area for heat transfer which reduces thermal stresses on throat materials. Long discharge times with poor heat transfer characteristics increase probability of throat erosion. Since the performance of the rocket is dependent on thrust, which in turn is dependent on rocket burning pressure, the nozzle must not be allowed to erode to any degree or performance will be greatly reduced. For these reasons, it was decided to attempt to incorporate a radial burning grain in the vehicle.

The second consideration of preliminary design was the method of supporting and containing the motor. Two possibilities presented themselves. The first of allowing the motor to sit freely inside the rocket case was considered. However, this concept would lead to very high compressive stresses at the rear portion of the motor, since it would be only supported at the base. The disadvantage of this method was the fact that stresses of the order of 20,000 psi would be experienced at the base of the grain. A second possibility was to bond the motor to the motor case wall. In this way the acceleration loads on the motor would be transferred in shear through the bonding material to the case wall. The disadvantage of this system was the fact that relatively thick walled cases were necessary to transmit the acceleration forces from the motor case to the motor.

At an equivalent level of acceleration, the shear stress at the case wall would be less than 1,000 psi. It was felt on the basis of this disparity in stress that the bonding technique offered the better likelihood of success.

After some investigation, Canadian Arsenals Limited (C.A.L.), Valleyfield, Quebec, was chosen to produce radial burning motors for the program. C.A.L. had had considerable experience producing small scale, double base, rocket propellant grains. Within the limit of the arsenals preparation and extrusion machinery, the largest motor available was one, 6" diameter by approximately 40" long. It was decided to proceed on a design for the vehicle incorporating a motor of that size.

The design was a compromize of several factors including aerodynamics and stability, launcher performance, motor performance and materials limitations.

This paper presents the development of the mechanical design of the vehicles with the test results.

3.0 LAUNCH PARAMETERS

3.1 Ballistic Coefficient

In order to achieve altitudes of scientific interest the test vehicle must be fired at a velocity of 3,000 to 5,000 feet per second. The launched velocity of any vehicle will be dependent on several parameters; gun propellant design and weight, gun geometry and shot weight. The performance characteristic of the Project's 16" gun using standard service propellants and modified propellants has been documented in various references. * The muzzle velocity is reduced for increased shot weight indicating that projectile weights should be designed to the minimum.

The performance of a vehicle in terms of apogee attainable by gliding is a function of a ballistic coefficient. The ballistic coefficient B is defined by:

$$B = \frac{W_V}{C_d A_f} \qquad \text{.......... 1}$$

It then becomes important to design a vehicle for maximum weight to achieve maximum apogee. In pure glide vehicles this end is achieved by the use of a very thick wall of heavy material such as steel and by ballasting.

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* Reference 1

In the case of a rocket assisted vehicle, the ballistic coefficient may not be as important as in the case of the pure glide vehicle. The importance will depend on factors of the planned trajectory. * If the rocket is allowed to coast at muzzle exit before ignition, then a high ballistic coefficient is advantageous as it allows the vehicle to traverse the denser part of the atmosphere without losing a disproportionately high amount of its velocity. If the rocket is ignited in the barrel or close to the muzzle, achieving a high ballistic coefficient will be detrimental. It will mean a heavy vehicle with small rocket boost potential. To achieve significant rocket performance, the mass fraction must be as large as possible which means lightweight inert parts. As the vehicle has a glide path before ignition, the best way to maintain high ballistic coefficient is to use maximum density fuel.

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* Reference 19

3.2 Launch Acceleration

A gun launched rocket will be subjected to high acceleration loadings for a short period of time. The magnitude and the form of the loading are dependent on gun internal ballistic and propellant characteristics. In order to determine the exact shape and magnitude of the loading force curves, a simple relationship known as the Leduc Formula * was used. It is recognized that this method is not the most precise means of determining launch acceleration curve shape or magnitude, but its simplicity lends itself to field computations. When used consistently in all tests, it provides good approximations for comparison.

In the case of the HARP launcher, there was no way available to measure the accelerating pressure on the base of the projectile. In order to have an estimate of this pressure, it is necessary to relate it to a measurable pressure. Originally in the HARP launcher copper crusher gauges were used and latterly the breech has been instrumented with a piezo-electric gauge. The copper crusher characteristics have a disadvantage in that they give only peak pressure readings in the breech vicinity. They are unable to give a pressure/time history as does the piezo system.

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* Reference 7

As well, their response to rapid fluctuations of pressure is poor and in the case of eratic propellant burning, sharp peak pressures may not be recorded. The Leduc Formula takes into account the fact that the unburnt portion of the charge and the gas products must be accelerated with the projectile. It has been verified using the Leduc Formula that the following simple relationship is approximately correct near peak pressure which is the region of maximum acceleration.

$$\frac{P_b}{P_s} = 1 + \frac{W_c}{2W_s} \qquad \text{.........} \; 2$$

With this relationship the maximum accelerating pressure P_b on the base of the projectile can be determined and from this the maximum launch acceleration is found.

4.0 MATERIALS AT HIGH RATES OF STRAIN

Vehicles launched from guns are subjected to launch forces of large magnitude for very short periods of time. A typical length of time in the barrel is 30 milliseconds. The elastic or plastic deformation which occurs in the structure or motor can be reasonably said to take place at a high rate of strain.

It has been established * that a high rate of strain can be defined as a rate at which, molecular mechanisms responsible for deformations, change their character. This definition involves time and constants of the materials themselves rather than any arbitrary mechanical rate of strain.

Recent advances in metallurgy and solid state physics** have given deeper insight into the molecular behaviour of deformation at high rates of strain. In particular, dislocation theory has given a qualitative understanding of high strain rate/deformation phenomena. Metal deformation processes such as yielding and work hardening can be attributed to three categories of mechanisms, twinning, dislocations, and crack nucleation and propagation.

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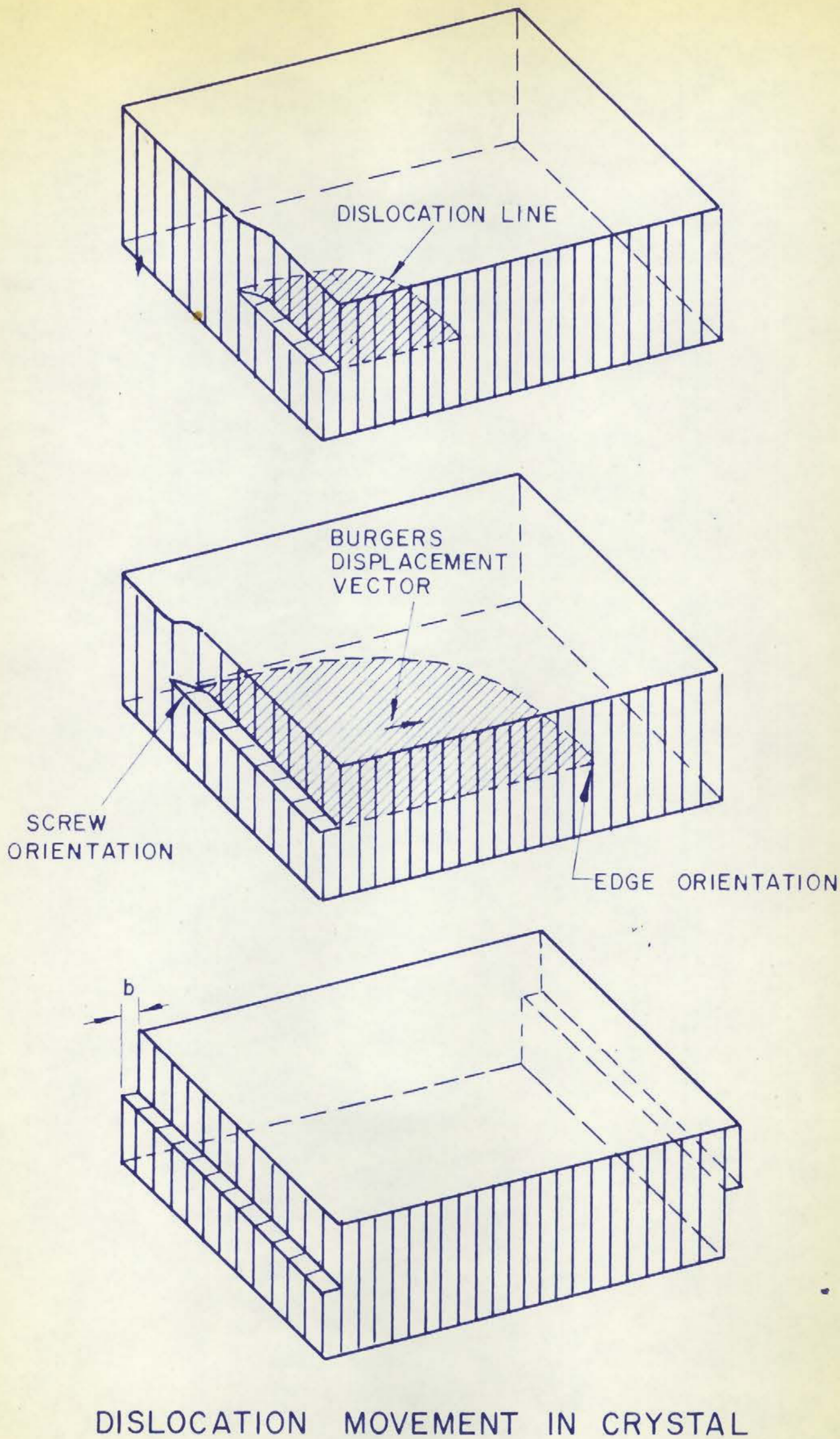
* Reference 8,
** Reference 22

Twinning is not felt to contribute materially to deformations of large extent. It takes place at a very high rate, orders of magnitude faster than the strain rate of the material under consideration in the gun launch case.

Dislocations are considered to be linear lattice defects in otherwise regular metallic crystal structure. They are believed to be responsible for ductile failure, in that yielding occurs as a result of the movement of a large number of dislocations in the crystal. It is now postulated that sources are established in the lattice by certain mechanisms (Frank-Read Sources) in order to produce the large numbers of dislocations necessary to account for deformations. The movement of the dislocation is shown in Fig. 1. It consists of a shear force moving one plane of atoms in relation to an adjacent layer. It can be seen that the movement of one dislocation through the lattice will displace one plane from the other only one interatomic distance. It is then obvious that very large numbers of these dislocations are necessary to produce macroscopic strain. Metallography and crystallography reveal that, in general, unstrained crystals do not contain a sufficient number of dislocations to produce observed strain, hence the postulation of the dislocation source mechanism.



DISLOCATION MOVEMENT IN CRYSTAL

FIGURE I

It is also felt that the rate of movement of dislocations and rate of generation are finite and stress dependent. If the rate of stressing is high, then fewer dislocations will be generated and fewer will have travelled far enough to contribute to the strain. This means that the specimen will tend not to yield ductilely.

In general, in a crystal which is stressed to deformation, there are two types of strain; elastic and plastic. The elastic strain is due to crystal distortion and will recover as the stress is released. The plastic strain is due to the movement of dislocations which are dependent on stress magnitude. Elastic strain takes place at a rate of propagation of sound in the crystal. Plastic strain takes place at a rate, orders of magnitude slower. Therefore, at high rates of stressing for the same total strain, a greater portion will be elastic in nature. This tends to appear as an increase in yield or effective strength of the crystal at high rates of stress/strain.

As well, the ultimate strength of a material can be expected to increase at high rates of strain because crack nucleation and propagation are strain rate dependent. Experimental evidence * has confirmed the theories advanced to the point that increases of 27% in ultimate strength of

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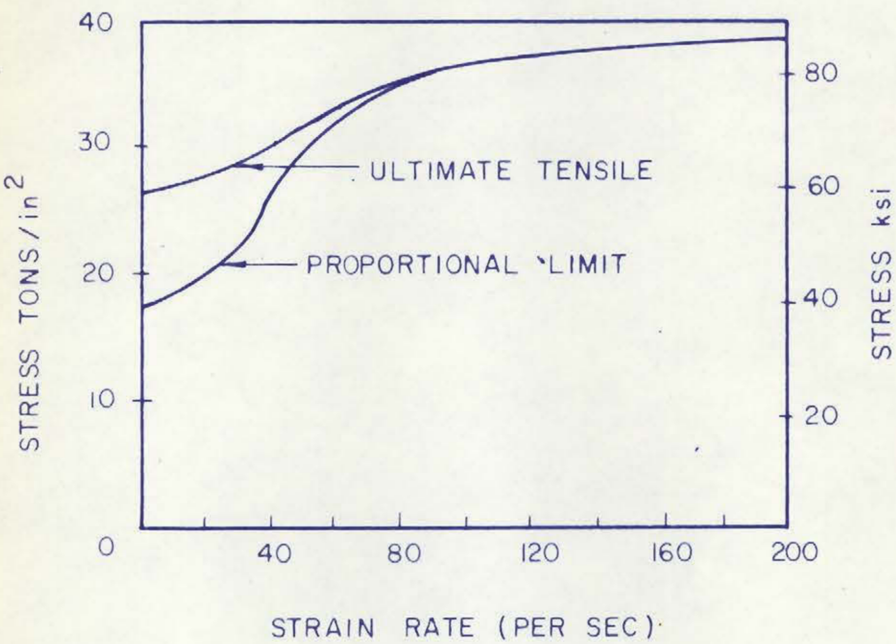
* Reference 8

chrome-nickel steel, 10-13% in SAE 4130, 10% in fully hardened 17-7 P H stainless, have been obtained. In general, higher increases of strength have been obtained in low alloy metals which have not been fully heat treated.

Although it is recognized that the probability of the crystallographic theories extending to the region of plastics and other non-crystalline structures was remote, nonetheless, a similar increase of mechanical properties is evidenced in these materials at high rates of strain. Some qualitative data is shown in Figs. 2, 3.* In designing the first generation of Martlet III vehicles, it was hoped that both of these phenomena could be utilized in order to achieve substantial increases in performance.

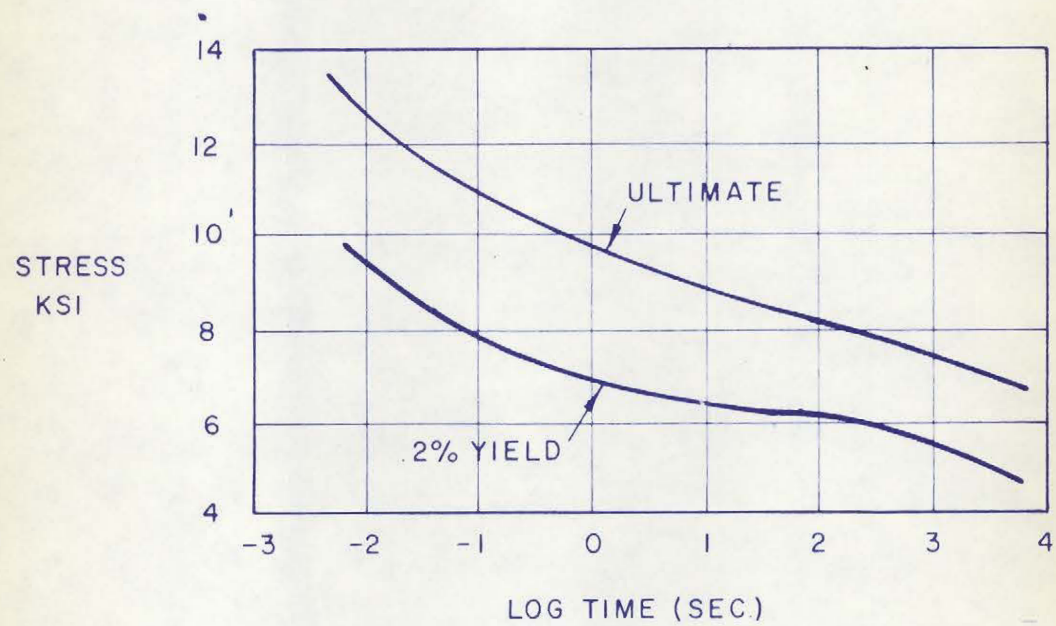
The mechanical strength of the rocket propellant used in the Martlet III was of the order of 1000 psi in compression. No quantitative data was available to ascertain shear strength values and a value of 60% of the compressive strength was assumed. On the basis of the increased tensile strength at high rates of strain, it was further assumed that shear strength characteristics would improve accordingly. In order to achieve significant performance, the motor would be stressed in the shear mode to the order of 1000 psi. It was felt that this was not overly optimistic

* Reference 8



STRAIN RATE vs ULTIMATE TENSILE STRESS AND PROPORTIONAL LIMIT OF MILD STEEL (.22%)

FIGURE 2



STRESS vs TIME TO STRESS OF METHYL-METHOCRYLATE PLASTIC SHEET. STRESS APPLIED AS RAMP FUNCTION

FIGURE 3

in view of the increase of strength depicted in Fig. 4. *

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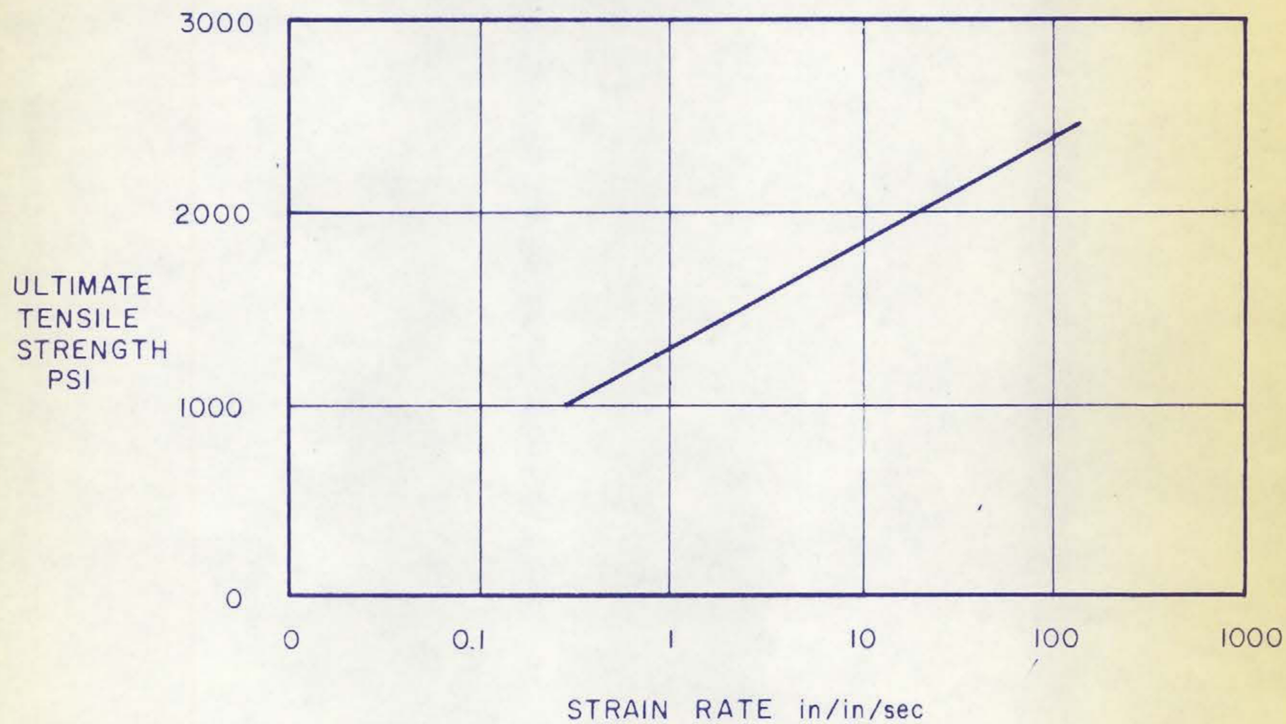
* Reference 9



TYPICAL ULTIMATE STRESS vs
STRAIN RATE FOR DOUBLE BASE
PROPELLANT

FIGURE 4

5.0 STRUCTURES

The structure of the vehicle will be subjected to the large acceleration forces generated by gun gases. The load supported by any member will be the weight of the components attached to the member plus its own weight multiplied by the "g" level generated at launch.

In order to obtain the best use of materials, it is necessary to achieve maximum permissible stress levels for all cross sections. In the case of the tubular rocket case the following analysis indicates the best shape.

Consider a tubular column which supports a fixed load W (e.g. nose cone, ignitor, etc.). The compressive stress in this tube will increase as cross sections are examined which are more distant from the top section of the case. This is obvious since the tube must support its own weight as well as the fixed weight W.

$$\text{Compressive Stress} = \frac{\text{Load}}{\text{Area}}$$

To utilize the material to best advantage, the stress must be constant at the maximum permissible compressive stress. Thus if the stress is a constant:

$$\text{Area} = \frac{1}{\sigma} \text{ function (load)}$$

$$\text{Original Load} = W \times g$$

$$\text{Tube Load} = \rho l A_1 g$$

$$\text{Total Load} = Wg + \rho l A_1 g$$

$$\text{Area to support load} = \frac{Wg + \rho l A_1 g}{\sigma}$$

It is evident that Wg/σ is a constant load which will not cause a change of wall thickness. Suppose the column length is increased a small amount dl, then a weight increase will result and the cross sectional area must increase in order to maintain constant stress level.

The increase of load will be $\rho dl (A_1 + dA_1)g$

The increase of area will be dA_1

To maintain constant stress then

$$dA_1 = \frac{\rho dl (A_1 + dA_1)g}{\sigma}$$

$$dA_1 = \frac{\rho dl A_1 g}{\sigma} + \frac{\rho dl dA_1 g}{\sigma}$$

Neglecting second order term, we obtain:

$$\frac{dA_1}{A_1} = \frac{\rho g}{\sigma} dl$$

Integrating we obtain:

$$\ln A_1 = \frac{\rho g l}{\sigma}$$

$$A_1 = e^{\frac{\rho g l}{\sigma}} \qquad \ldots\ldots\ldots 3$$

It is evident that if the structure is designed in accordance with an exponential function, as is derived here, the best utilization of material will be made. However, other factors,such as difficulty of manufacture must be taken into account. The relationship can be used as a check to stress actual cross-sections. If the cross-section of the design is greater than a theoretical A_1, the section should be adequate to support the load.

Where possible parts should be designed to take loads in compression. If some local failure occurs, the section will enlarge because of the yielding, and advantage can be taken of the increased stress area.

Members must be designed with adequate tension capacity as well. It has been observed that the vehicle on exit from the muzzle will be subjected to a sudden release of stress, and parts will be subjected to tensile forces. This phenomena can be likened to a compressed spring with a weight on the end. As the spring is released, the weight will be accelerated. The inertia of the moving weight will place the spring in tension as it passes the normal uncompressed position. As a guide, the so-called "rebound g" level was considered to be not greater than the acceleration of the vehicle just at the muzzle and the members were stressed accordingly.

In general, the working stresses have been limited to ultimate tensile or compressive. In designing at these stress levels, no account has been taken of dynamic increases of strength. Several agencies have successfully used values of 120 - 130% of yield. Rather than use these values to design with, it has been felt that the dynamic effect could be counted upon as a factor of safety.

6.0 PRELIMINARY COMPONENT TESTING

6.1 Ignition Device

The ignitor for the rocket motor must accomplish two tasks; it must raise the temperature of the grain to ignition temperature, and it must raise the pressure in the chamber to a level so that once ignited the burning is self-sustaining. The area of propellant ignited must be large enough to produce a substantial mass flow. If a small area is ignited, the mass flow will not be sufficient to "choke" the nozzle, and allow the internal pressure to rise. This means the motor will probably not ignite. If the pressure produced is marginal, the motor may experience a phenomena known as "chuffing". The motor will ignite, but the pressure will be too low and it will extinguish. However, enough grain remains ignited to allow the pressure to build again and it re-ignites. This cycle may occur several times. It is undesirable for several reasons. The rapid pressure fluctuations can cause physical break-up of the grain and resultant explosion. It also means erratic thrust with much propellant consumed at low pressure with resultant poor thrust characteristics.

In approaching the ignition problem, it was decided to use a standard ignitor as used by C.A.L. to ignite their 2.75" rockets.

This ignitor consisted of a small metal cannister with a volume of about 9 cc. Inside the cannister was a mixture of 95% black powder and 5% magnesium powder. Initiation was by means of an electrical discharge across a squib into the powder. The base of the cannister had a circular diaphragm which blew out on ignition allowing the hot gases and burning magnesium particles to spray along the length of the internal star perforation of the motor. In order to maintain a sustaining burning pressure, an obturating plug was fitted into the discharge nozzle which was designed to release when the internal pressure reached a proper level, approximately 300 psi.

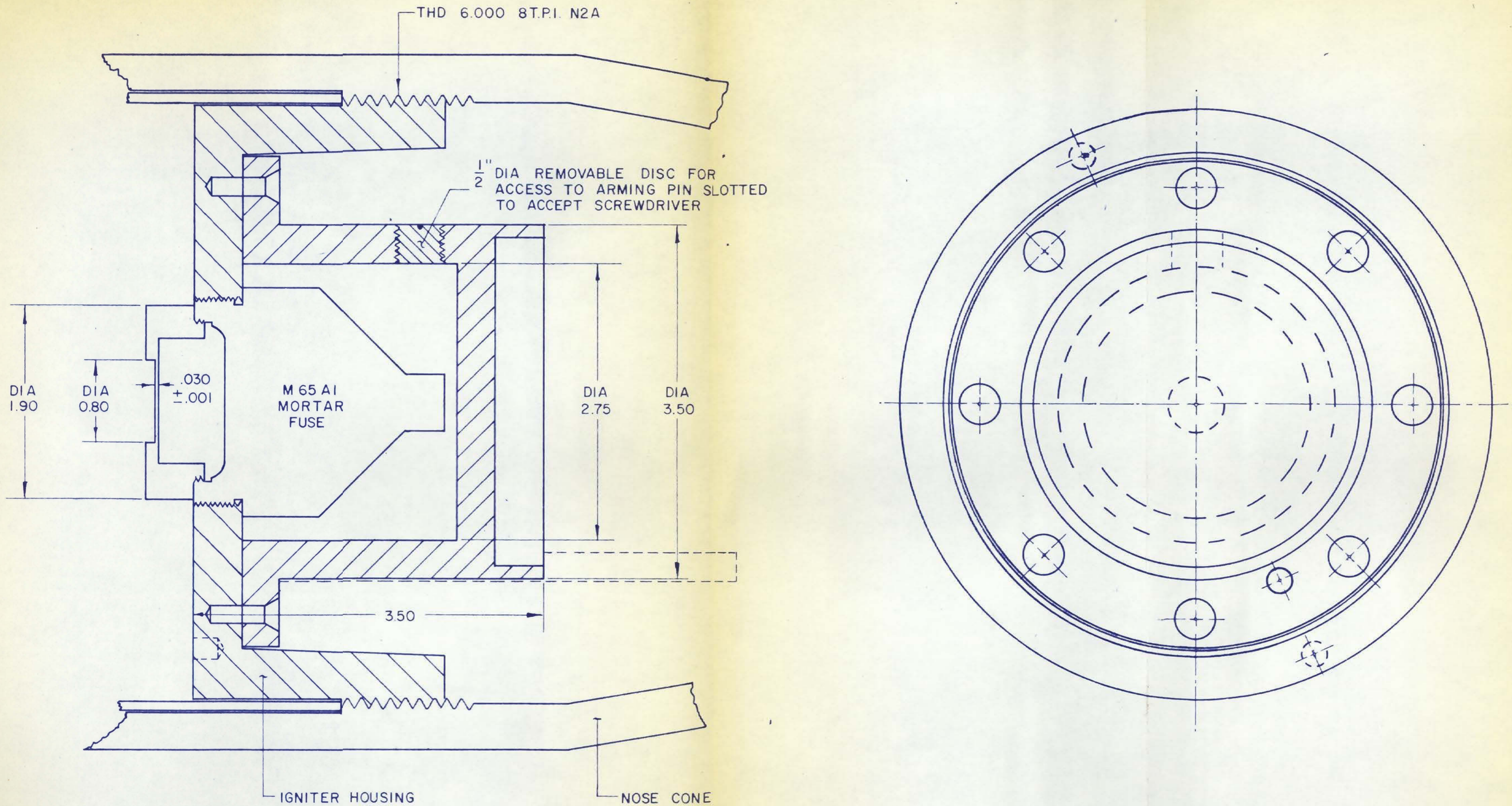
A series of static tests using the static test facilities of C.A.L. were undertaken. The results of these tests are listed in Appendix I.

It was then necessary to design an ignition device for the flight vehicles. After some consideration it was decided to incorporate a delay feature into the ignition device for safety purposes. In the event of a malfunction on ignition, this would allow the rockets to be some distance away from the launch site.

At that time the Project had not yet developed reliable electronic payloads and it was felt that the best means of ignition would be a mechanical time fuse. A standard mortar fuse (U.S. Army - M65A1) was chosen. This fuse was a "set-back" operated device incorporating a plunger which struck a fulminate cap while experiencing the set-back forces of launch. The fulminate cap ignited a pyrotechnic train which burned for 14 seconds. At the end of the pyrotechnic train was a small booster charge which flashed into the ignition mixture of black powder and magnesium.

The fuse was modified to accept a retainer cap which held the ignition charge (See Fig. 5). The geometry of the retainer cap, with respect to the standard 2.75" ignitor, was maintained as closely as possible in order to duplicate the successful static test ignitions.

In order to prove the system dynamically, the ignitor/fuses were assembled into a 105 millimeter mortar case and fired. The cases were drilled in four places in order to allow observation of the ignition. In all tests the ignitors functioned and a bright flash was evident from the burning powder exiting from the holes in the cases at 14 seconds after firing. The fuses were tested to the maximum acceleration limit of the 105 millimeter mortar and experienced successfully as high as 7,500 "g's".



MARTLET 3A
IGNITER ASSEMBLY

FIGURE 5

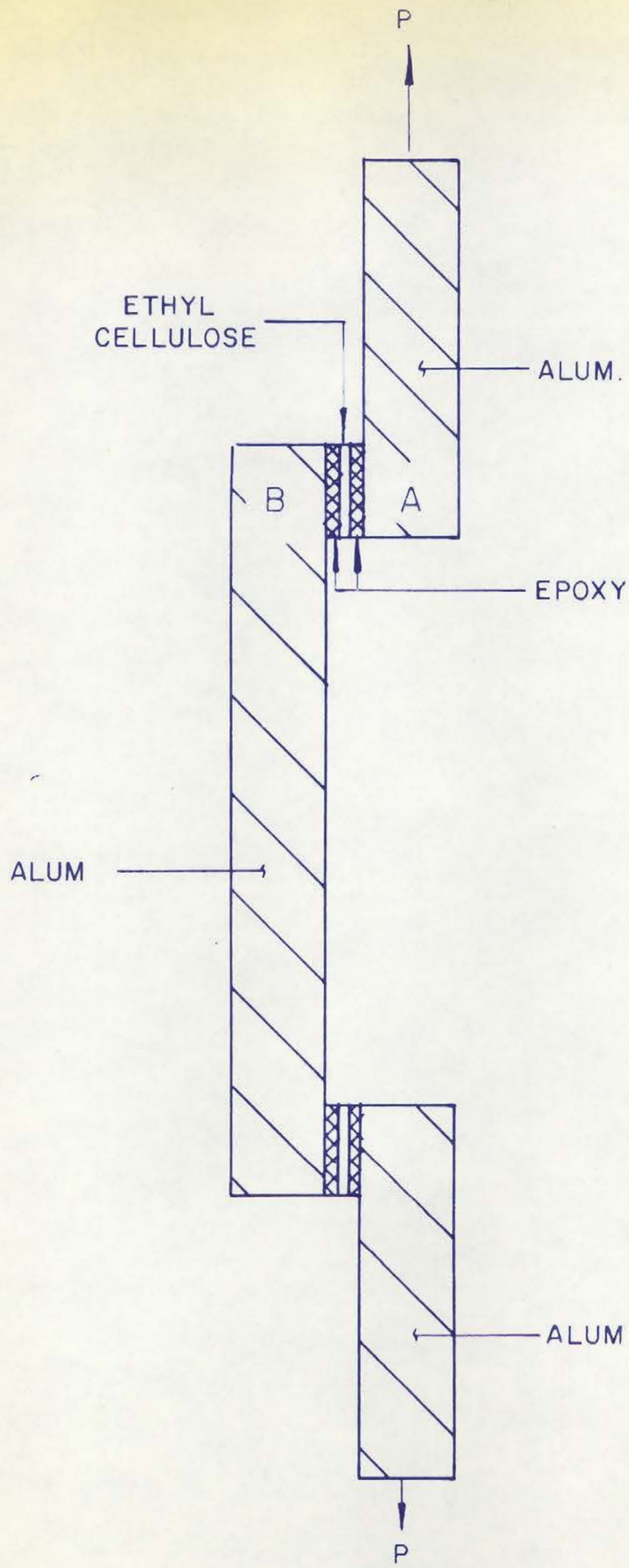
Having conducted these tests it was felt that within the time and funds available the best possible ignition device was the modified fuse.

6.2 Bonding Tests

In order to obtain a bond material for bonding the rocket motor to the case wall, it was necessary to investigate several trade brands. The rocket motors were wrapped with an inhibiting material, in order that when ready for ignition the only exposed propellant was the internal star. The inhibitor used was ethyl cellulose and it was wrapped on the outside of the cylinder of propellant. The ends of the propellant were also capped with the same material. In wrapping the propellant the ethyl cellulose was brushed with solvent so that it would adhere to the propellant and subsequent layers of tape would adhere to each other. The motor, when finished, was machined to the required size. The tape wrapped, ethyl cellulose, upon evaporation of the solvent, was an integral part of the propellant.

The bonding agent therefore, had to give good strength between ethyl cellulose and the case wall (in the initial case, aluminum, and later steel).

As well, it was evident that the bond would be subjected to shear forces rather than tensile. A testing mechanism shown schematically in Fig. 6 was used to test various compounds.



BOND TESTER

FIGURE 6

A sheet of ethyl cellulose was coated on both sides with the speciman under test and then clamped between bars A and B.

After curing the assembly was placed in a tensile pull machine and the bonds tested to destruction.

The results are tabulated in Table I.

Having chosen the Epoxy Products brand of compound it was felt necessary to test the bond dynamically.

To accomplish this, a sample of inhibited propellant was bonded into a mortar shell casing. The sample was bonded in with a nominal .007" interference fit of propellant to tube. In order to simulate conditions which would be generated in the gun, a ballast slug of steel was placed on top of the propellant. This slug enabled the propellant to experience shear stresses at the wall of a magnitude to those predicted in the gun.

The initial test developed conditions at the wall, equivalent to 4150 "g" on a six inch vehicle. The second test achieved an equivalent limit of 8,300 "g's". The propellant was X-rayed after test but no damage internally was apparent.

6.3 Static Testing

During the same period (May - June 1963) the preliminary static testing of the rocket motors was undertaken.

Canadian Arsenals Limited modified their existing static test facilities in order to handle the increased thrust of a 6" diameter, 40" long motor. The static test bed was equipped to ignite the motor electrically and measure thrust/time and internal pressure/time histories.

Based on preliminary designs from HARP personnel, C.A.L. produced by extrusion a series of rocket motors in N5 propellant. The motors were wrapped with inhibitor and made available for test firing.

Preliminary testing was initiated in order to check the static test bed and instrumentation as well as ignition, obturation and nozzle size. Initially, the nozzles were fabricated from a steel billet with a throat size determined from the mass flow-pressure curves. The inlet of the nozzle was radiused using the throat diameter as radius. An expansion cone was not included since the first firings were intended to indicate feasibility only. The results and observations of the static tests are presented in tests Nos. 1 to 6 in Appendix I.

Based on the static tests it was decided that the ignition charge, obturation device and nozzle characteristics were sufficiently well known and reliable to warrant the construction of four flight test vehicles.

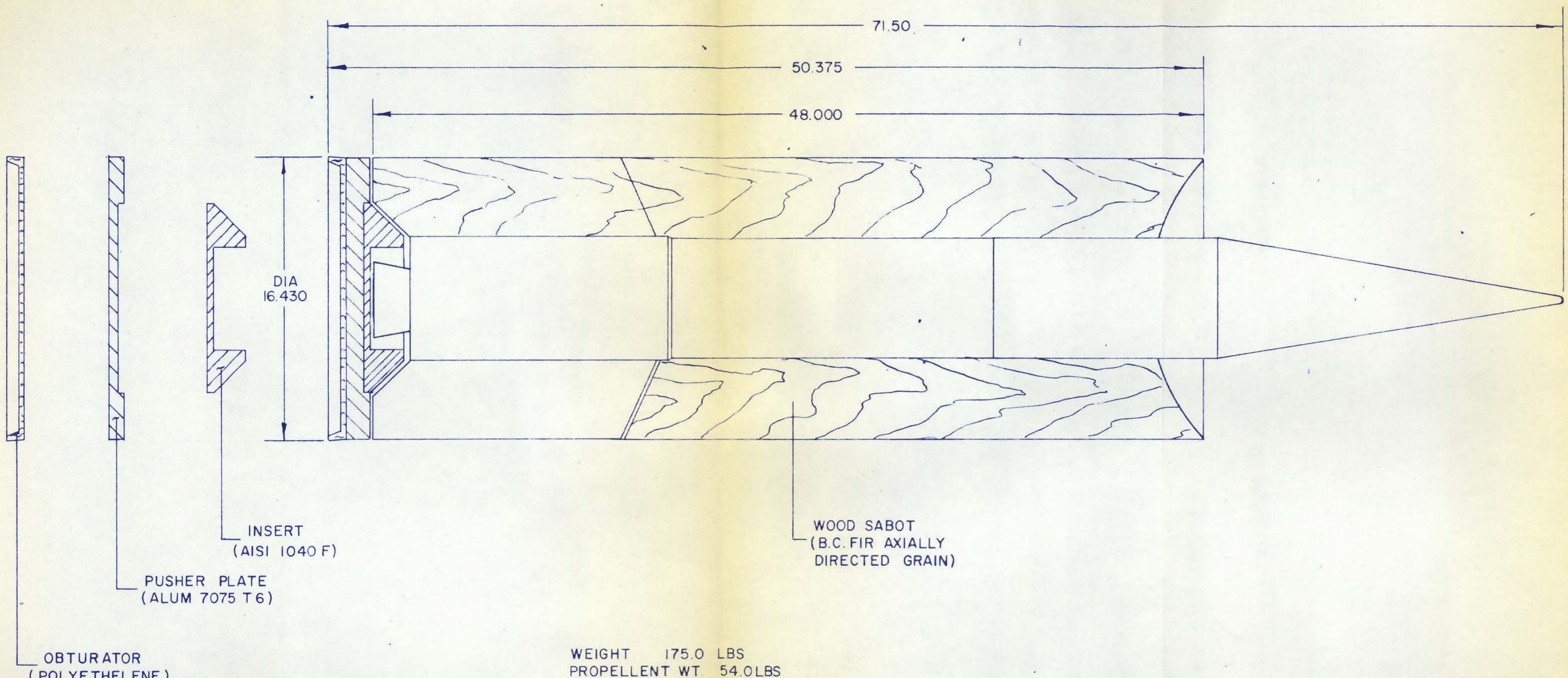
7.0 MECHANICAL DESIGN - GENERAL

The initial mechanical design of the vehicle was considered, incorporating a rocket motor of the following dimensions:- 6" outside diameter by 40" length. Four vehicles (as shown in Fig. 7) were fabricated from high strength aluminum alloy.

Basically, the vehicle can be broken into components as follows; nose cone, ignitor, case, fins, nozzle and ballast or payload. The round includes the side sabots as well as a pusher sabot.

The case was fabricated from high strength heat treated aluminum tubing (7075T6). The inside diameter of the tubing was 6" and was not machined since tube manufacturing tolerances were adequate. The outside of the case was fully machined to a diameter of 7". At the base of the vehicle the diameter of the body was increased to 7.25". This increase was made for two reasons. The additional cross-sectional area was needed to accommodate increased loads near the base. It also allowed enough thickness to mill "T" shaped slots to accommodate the stabilizing fins.

The nose cones were heat treated castings of Alcan 350 Aluminum. They were machined fully on the outside to give a 3:1 fineness ratio.



WEIGHT 175.0 LBS
PROPELLENT WT. 54.0 LBS
MASS FRACTION 0.308
ALL UP WEIGHT 380 LBS

MARTLET 3A

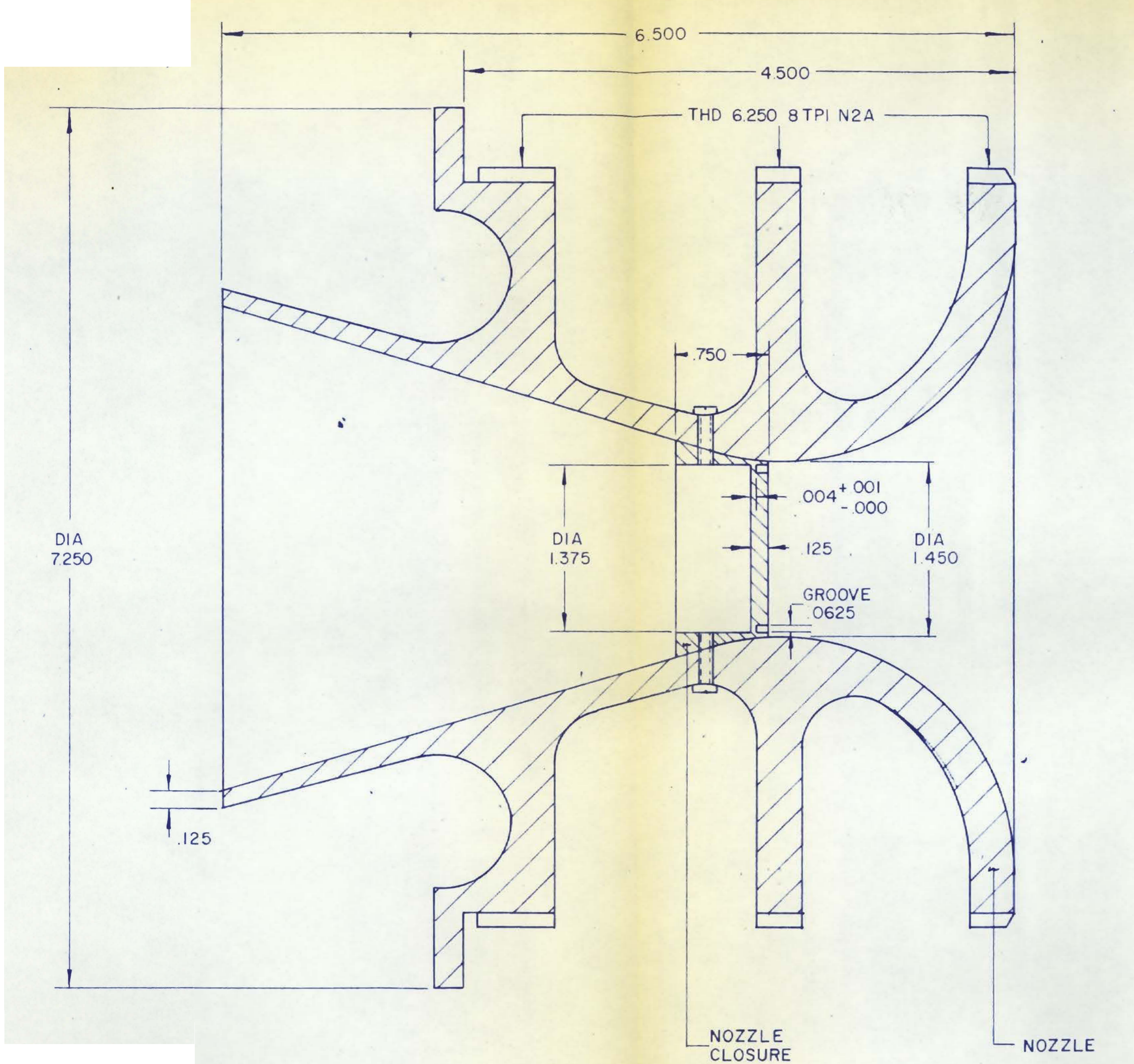
FIGURE 7

Inside the cones were threaded to mate the case, but left unfinished elsewhere.

The fins were fully machined from flat bar stock 7075T6 aluminum. The base of the fin was "T" shaped to slide into a mating slot in the body. The slot was oriented to produce an offset of ½ degree in order to cause the vehicle to spin in flight.

The nozzle (Fig. 8) was machined from a mild steel casting (AISI 1020). The converging section was machined to a circular radius equal to 1.5 times the throat diameter. The expansion section was a straight cone machined with a 30° included angle. The expansion ratio was 8.6 : 1 with a throat diameter of 1.450" for vehicles incorporating X8 propellant, and 1.260" for the vehicle incorporating N5 propellant. The outside of the flanges of the nozzle were threaded in order to screw into the base of the vehicle. The rear flange of the nozzle was utilized as a retainer to keep the fins from sliding out of their slots. The choice of mild steel for material was based on best results of the static testing.

The pusher sabot was an assembly of steel, aluminum and polyethylene. The main pusher plate was fabricated from heat treated alloy aluminum (7075T6).



MARTLET 3A
NOZZLE

FIGURE 8

An insert of medium carbon steel, heat treated, was recessed into the main pusher plate to provide better bearing strength in the pusher assembly against the steel nozzle. The aluminum/steel pusher assembly was backed by an obturating disc of polyethylene. The disc was machined so that a concave face presented istelf to the gun gases. This allowed the polyethylene to squeeze out against the bore thus sealing the gases from leaking by the aluminum/steel assembly.

The side sabots were fabricated from solid pieces of British Columbia fir. The side sabots were split into six equal segments and slots were milled in the base of each in order to accommodate the fins.

The body materials were chosen from those commercially available to the project for high strength to weight characteristics. The nozzle material was chosen because it had performed best in static tests. The pusher assembly was similar in concept to the type already successfully flown. In an attempt to reduce manufacturing costs the side sabot material was changed from layers of plywood bonded together to a solid section of British Columbia fir.

In carrying out a preliminary design the weights of the various parts were calculated to be as follows:-

Nose Cone	18.25 lbs.
Ignitor Assembly	5.00 lbs.
Case	42.50 lbs.
Nozzle	14.00 lbs.
Propellant	57.00 lbs.
Fins	11.00 lbs.
TOTAL	147.75 lbs.

Having established an exterior geometry, aerodynamic models were manufactured in order to assess the performance of the vehicle. These vehicles were then fired in an instrumented range at Aberdeen Proving Ground. *

The results yielded aerodynamic drag and stability data. It became apparent that in order to achieve good stability the center of gravity of the proposed configuration would have to be shifted forward a significant amount. This meant that the nose cone would require ballasting.

The components when assembled realized a center of gravity of 24.25" from the base of the vehicle (nozzle flange). The aerodynamic model tests indicated a center of pressure at 24.60" from the base of the vehicle.

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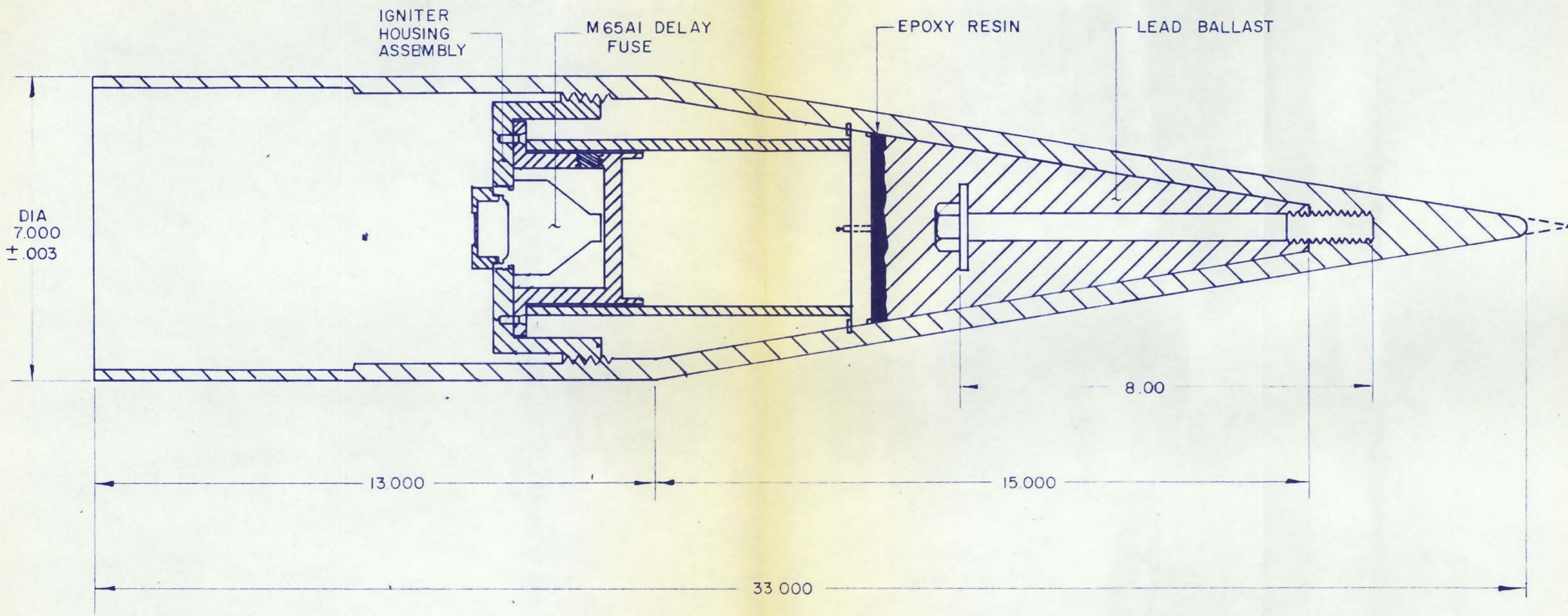
* Reference 2

In order to shift the center of gravity it became necessary to add approximately 25 pounds of lead ballast in the nose cone. The ballast was supported in three ways (See Fig. 9). A steel bolt with a flat plate was installed in the nose tip. The lead ballast was then cast into the cone, surrounding the bolt/plate sub-assembly and machined flat. A steel plate with an "O" ring seal was seated against the lead. Into a machined groove in the wall of the cone, a flat steel retainer clip was inserted thus supporting the steel plate. The volume between the lead and steel plate was pumped full of epoxy in order to assure uniform loading of the plate. As a final means of support, a short cylindrical sleeve was incorporated. The sleeve fitted over the top of the ignitor housing and butted firmly (when the igniter assembly was turned home) against the steel retainer plate.



MARTLET 3A
BALLAST NOSE CONE

FIGURE 9

7.1 Miscellaneous Design Details

In order for the ignitor to function correctly, it was necessary to vent tht nose cone to atmosphere. If the combustion products of the pyrotechnic train were confined and pressure allowed to build-up, the burning would have accelerated. This would have meant unreliable and unrepeatable ignition.

The vehicles were assembled in Canada and flown to the launching site in Barbados. No special effort was made to protect the rockets from the effects of temperature cycling or vibration and shock-loading.

The rounds were assembled in two stages. The initial assembly of the case, fins and nozzle was straight forward. The fins were swaged at the "T" section in order to overcome slackness of fit due to manufacturing tolerances. They were then driven into the motor case slots.

The rocket motor was precooled to approximately $-10^{o}F$ in order to allow a shrink fit with the motor case. The inside of the motor case was degreased with trichloroethylene and then epoxy was spread on the circumference using an adapted rubber squeegee.

The motor was removed from the cold cabinet and wiped clean and dry (from condensate) before it was inserted in the case. The motor was pushed past its seating position and the nozzle inserted and turned home thus, driving the motor back to its seating position. This guaranteed that the motor would seat firmly against the nozzle. The assemblies were then stood on end, and allowed to return to room temperature. At this temperature, an interference of some .030" was anticipated. This allowed for a very close contact between the case and motor, assuring a shear type of loading for the epoxy. The epoxy was allowed to set for 48 hours and the excess which had been squeezed out due to the expansion of the motor was removed. The rounds were then capped with the nose cone assembly less ignitors and crated in ordinary plywood boxes for shipment. The sabots and pusher plate assembly were crated and shipped separately.

8.0 TEST FIRINGS

The initial firings were scheduled for late August and early September in 1963. The range was set up to cover the flights with various instrumentation.

The gun was instrumented with copper crusher gauges to record breech pressures.

To cover vehicle integrity, four Smear cameras were set up close to the gun with a field of view of some 100 feet from the gun muzzle. To measure velocity a series of four Fastax framing cameras were set up in the same area as the Smear cameras. These cameras were connected into the firing circuit and functioned automatically.

To cover ignition and rocket burn trajectory, three stations were set up some distances from the gun. These stations had cine-theodolites which were manually operated. The stations were tied into the count-down via shortwave radio.

For general surveillance the Project's M33 radar was used. An effort was made to try to track the vehicles although, the radar set was not designed as a tracking instrument.

The Atlantic Missile Range tracking ship "Twin Falls" was standing off shore with tracking radar aboard. Unfortunately, other committments made it necessary for the ship to leave after the first two test firings.

Prior to each shot, conditions of launch were determined in order to obtain best data and results from each shot. In many cases, they consisted of modifications to vehicles, gun charges, launch angles and so on. These changes will be indicated in the description of the shots.

8.1.1 TEST PROGRAM FIRING RECORD

SHOT #1 MARTLET IIIA August 28, 1963

a) Basic Data

Vehicle Weight	178.5 lbs.
Projectile Weight	380.0 lbs.
Motor Weight	54.0 lbs. X8
Gun Propellant Weight	321 lbs. (WMC .245)

b) Predicted Interior Ballistics

Muzzle Velocity	3,500 fps
Maximum Breech Pressure	15,000 psi
Maximum Acceleration	5,850 "g"
Muzzle Elevation	70^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,500
Ignition	14	27,113	10,200	1,260
Burn Out	16.8	33,160	12,790	3,643
Apogee	95.0	135,800	105,190	1,110
Impact	204.0	0	200,400	1,080

d) Results

Muzzle Velocity	3,498 (apparent)
Maximum Breech Pressure	16,700 psi
Maximum Acceleration	6,500 "g"

Vehicle totally disintegrated

e) Discussion

Many fragments of the vehicle and sabots were recovered and along with the Fastax films the failure was reconstructed. The gun barrel was not damaged by any of the fragments.

f) Conclusion

It was felt that the aluminum pusher plate had "cocked" in the barrel on loading. This was due to the fact that the ramming device was not perpendicular to the barrel axis and the pusher plate was too thin in relationship to its diameter to align well with the bore to overcome cocking. The polyethylene obturature was also damaged. The rear flange which was designed to press against the gun barrel to seal the gases tore away from the body of the disc. It was felt that the pressure forces pressing the flange against the wall generated sufficient friction to tear the flange off.

Fragments of the sabot leaves indicated severe axial crushing.

g) Action

The rear pusher plate was modified in order to give it better stability in the bore as shown in Fig. 10. An extra plate of 2024T4 Aluminum was slotted to accommodate the fins and pinned ahead of the regular pusher plate. A second pusher plate of 3" thickness was placed behind the regular pusher plate. Attached to this plate was a 2" thick disc of polyethene which was not flanged.

The wooden side sabots were also modified. To carry the loads better, they were cut into two sections. A plate of sheet aluminum ¼" thick was inserted between sections. The bottom half of the wood was drilled longitudinally and two pieces of steel pipe inserted into the holes. Within the pipe, smaller diameter pipe was inserted. The pipe then rested against the front of the pusher plate and against the rear of the aluminum insert plate.

8.1.2 TEST PROGRAM FIRING RECORD

SHOT #2 MARTLET IIIA August 29, 1963

a) Basic Data

Vehicle Weight	178.25 lbs.
Projectile Weight	447.0 lbs.
Motor Weight	54.0 lbs. X8
Gun Propellant Weight	279 lbs. (WMC .245)

b) Predicted Interior Ballistics

Muzzle Velocity	3,200 fps
Maximum Breech Pressure	13,000 psi
Maximum Acceleration	4,700 "g"
Muzzle Elevation	70^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,200
Ignition	14	24,640	9,860	1,140
Burn Out	16.8	30,000	11,870	3,500
Apogee	68.0	116,600	80,150	1,000
Impact	153.0	0	166,800	1,080

d) <u>Results</u>

Muzzle Velocity	2,705 fps (apparent)
Maximum Breech Pressure	12,090 psi
Maximum Acceleration	4,350 "g"

Vehicle totally disintegrated

e) <u>Discussion</u>

The second round appeared to have failed in the same fashion as the previous round despite a 50% reduction in launch acceleration. As in the previous case, the Fastax films indicated a failure deep in the barrel. The recovered fragments did not leave any positive identity as to the failure mode. The gun barrel inside bore was scored (shallow mark a few thousandths deep) with twelve fairly evenly spaced longitudinal marks commencing close to the seating position of the round.

f) <u>Conclusion</u>

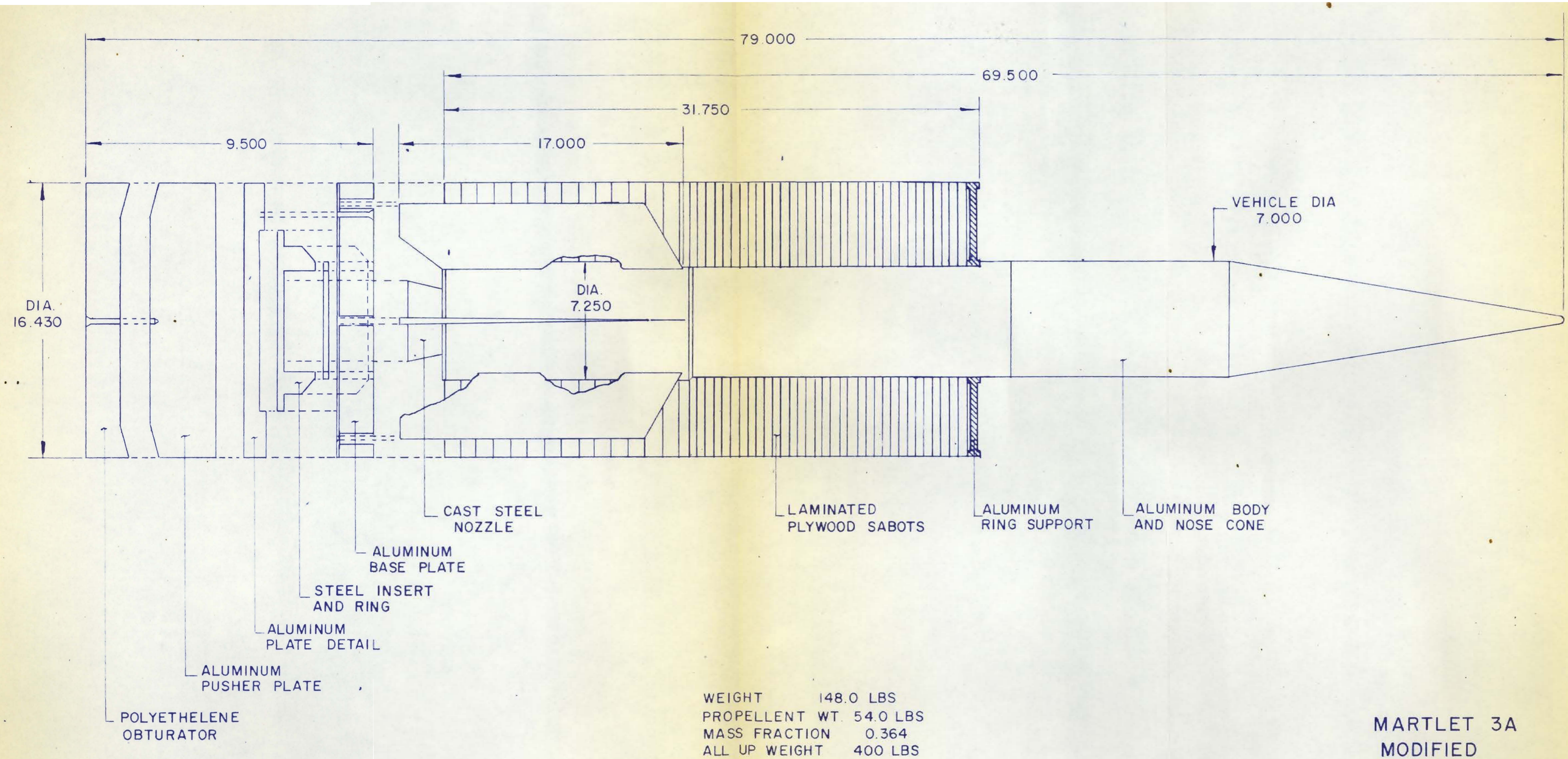
It was concluded that the solid grained side sabots were failing possibly by splitting. The twelve sections of pipe which had been incorporated into the sabot in order to strengthen it had been forced out of the wood against the gun barrel wall thus, scoring it.

It was felt that the lead ballast was not sufficiently well supported and that the possibility of a nose cone failure due to over-stressing was highly likely. It was realized that the stability of the vehicle would be reduced but considering the objective being to launch intact, a rocket, stability was of less concern.

g) Action

The solid wood sabots were discarded. A new set of sabots were manufactured from plywood on site. (Refer to Fig. 10) In order to better support the vehicle in the gun, the tops of the sabots were modified to accommodate an aluminum ring of I cross-section. This ring was split into six segments. The aluminum ring bore on the gun barrel at its outer diameter and on the vehicle wall at its inner diameter.

The ballast lead along with all supporting devices was removed. This caused a rearward shift of the center of gravity from 27 3/16" from the base to 24¼" from the base. The removal of the ballast and supports decreased the stress levels throughout the vehicle by approximately 15% over former levels.



MARTLET 3A
MODIFIED

FIGURE 10

It was also felt that the aluminum plate which had been slotted to accommodate the fins and give the pusher assembly more stability in the barrel was unnecessary. It was decided to omit it from the next shot.

8.1.3 TEST PROGRAM FIRING RECORD

SHOT #3 MARTLET IIIA September 2, 1963

a) Basic Data

Vehicle Weight	152.5 lbs.
Projectile Weight	369.5 lbs.
Motor Weight	54.0 lbs. X8
Gun Propellant Weight	279 lbs. (WMC .245)

b) Predicted Interior Ballistics

Muzzle Velocity	3,200 fps
Maximum Breech Pressure	13,000 psi
Maximum Acceleration	5,400 "g"
Muzzle Elevation	70°

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,200
Ignition	14	24,640	9,860	1,140
Burn Out	16.8	30,000	11,870	3,500
Apogee	68.0	116,600	80,150	1,000
Impact	153.0	0	166,800	1,080

d) Results

Muzzle Velocity	3,380 fps (measured from films)
Maximum Breech Pressure	13,000 psi
Maximum Acceleration	5,400 "g"

Vehicle launched intact

e) Discussion

From the Fastax and Smear cameras filmed records, the vehicle appeared to launch intact. No evidence from the photographs indicated any failure and no fragments other than disintegrated wood from the sabots were found.

The motor ignited at 14 seconds and was observed from the ground both visually and audibly. The sound of burning was timed and indicated perfect functioning of the rocket motor. An exhaust product trail was visible and observed by the ground stations.

The M33 radar did not acquire or track the vehicle. No out-stations acquired or photographed the vehicle in flight.

f) Conclusion

The vehicle was launched successfully and the rocket motor functioned as expected. Due to an error in camera settings, no camera recorded the burning of the rocket motor.

The possibility of failure of the nose cone due to over-stressing was eliminated by removal of the ballast. It could not definitely be stated that the ballast had been the cause of previous failures. However, the removal was considered the safer course.

g) Action

Repeat the shot at the same conditions of launch and modifications as Shot #3.

FASTAX PHOTO OF VEHICLE NO. 3

FIGURE 10A

8.1.4 TEST PROGRAM FIRING RECORD

SHOT #4 MARTLET IIIA September 5, 1963

a) Basic Data

Note: This vehicle being essentially the same as the previous vehicles had certain major differences. The first of these was the fact that the motor case was manufactured from 6065T6 aluminum. The strength of this material is only 50% of the 7075T6 material used on the other cases. The body was 1½" shorter than the other vehicles. This gave a rocket motor length of 38½" as opposed to 40" in the previous vehicles.

The rocket motor was N5 propellant which was similar to X8 although, slightly less powerful.

Vehicle Weight	145.5 lbs.	
Projectile Weight	404 lbs.	
Motor Weight	52.5 lbs.	N5
Gun Propellant Weight	252 lbs.	(WMC .245)

SMEAR PHOTO OF SHOT NO. 4

FIGURE 10B

ASSEMBLY OF PROJECTILE PRIOR TO LAUNCH

FIGURE 10C

b) Predicted Interior Ballistics

Muzzle Velocity	3,000 fps
Maximum Breech Pressure	10,000 psi
Maximum Acceleration	4,000 "g"
Muzzle Elevation	70^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,000
Ignition	14	24,755	9,925	1,100
Burn Out	18.9	36,356	15,740	3,600
Apogee	105.4	162,390	139,890	1,000
Impact	224.0	0	276,750	1,080

d) Results

Muzzle Velocity	3180 fps
Maximum Breech Pressure	8940 psi
Maximum Acceleration	3540 "g"

Vehicle launched intact

e) Discussion

From the high speed camera records the vehicle appeared to have launched intact. No evidence of failure was found. No fragments other than those of sabots were found.

The motor ignited at 14 seconds and was observed both visually and audibly from all stations. Thr burning time was recorded from the sound and the motor appeared to perform as predicted. The exhaust products formed a trail which was observed.

The M33 Radar acquired the vehicle optically from ignition and tracked manually throughout the burn period. It did not lock on to the vehicle and tracking was lost at burn out.

The data from the cine-theodolites was reduced and is presented in Figs. 11 - 14.*

f) Conclusion

The vehicle launched successfully and the motor performed somewhat eratically, from the data reduction. However, motor performance appeared to be better than predicted. The trajectory followed was very close to the predicted one. The vehicle was tracked from two independent stations indicating complete success.

h) Action

This concluded the preliminary series of feasibility studies.

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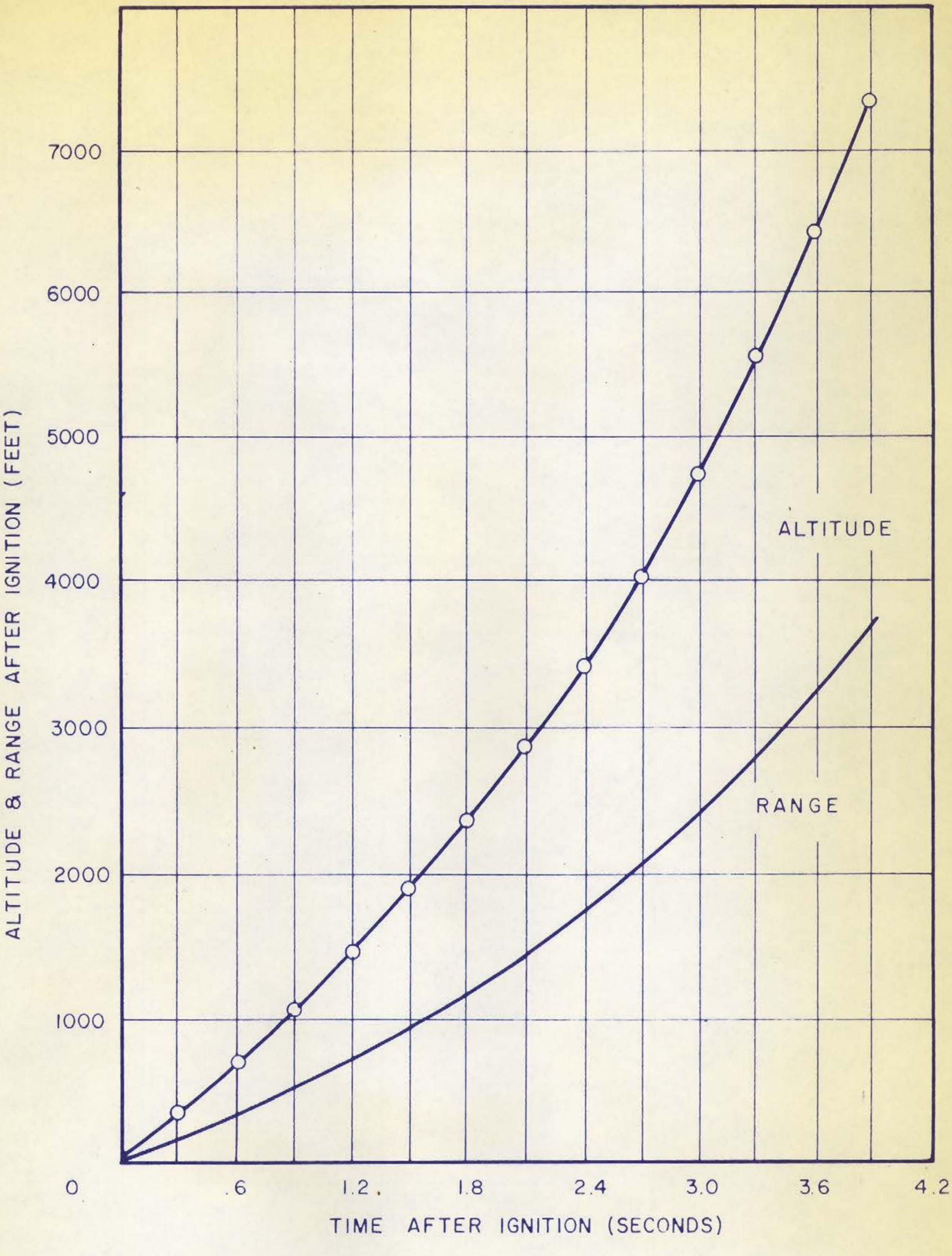
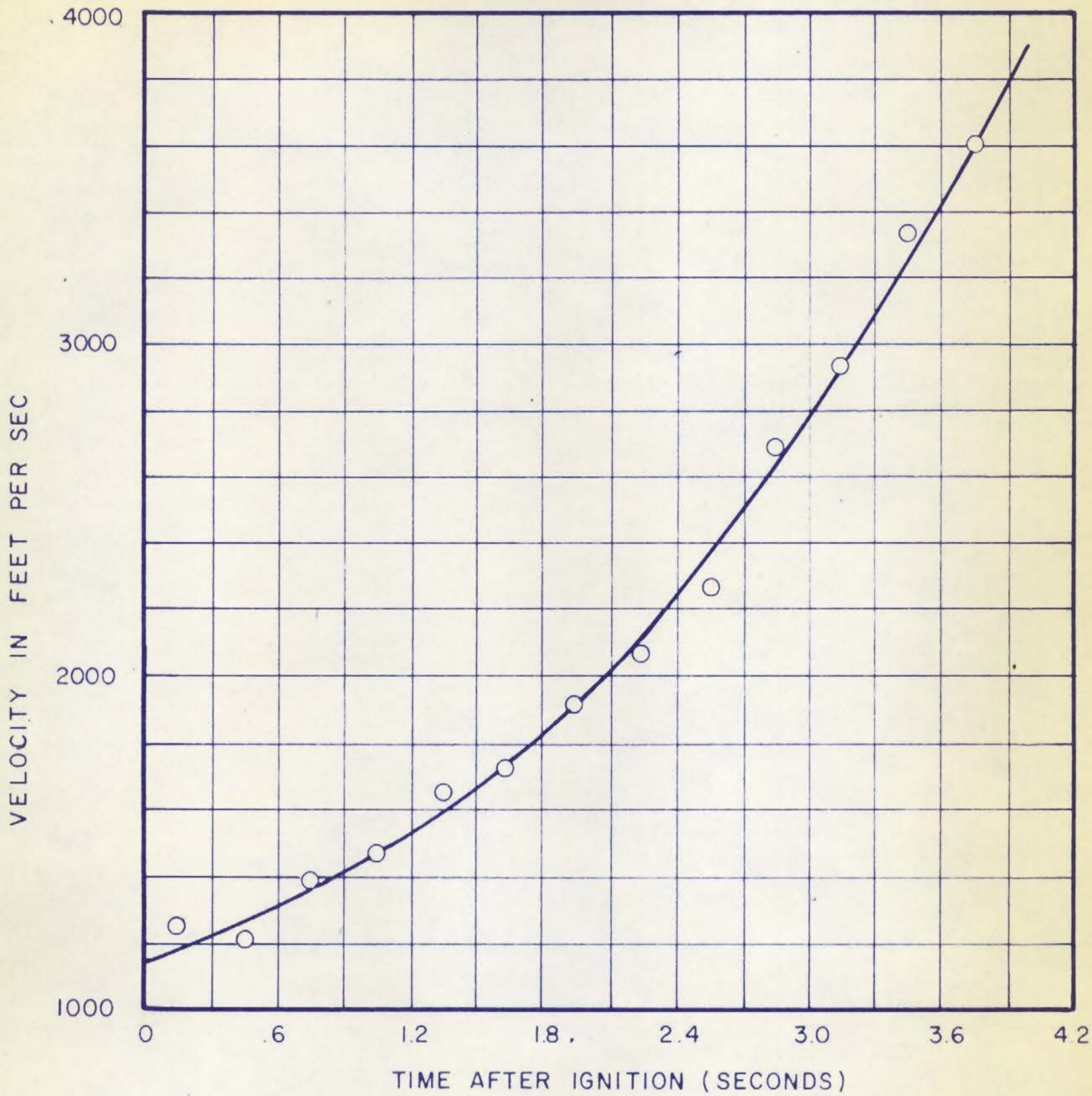
* Reference 24



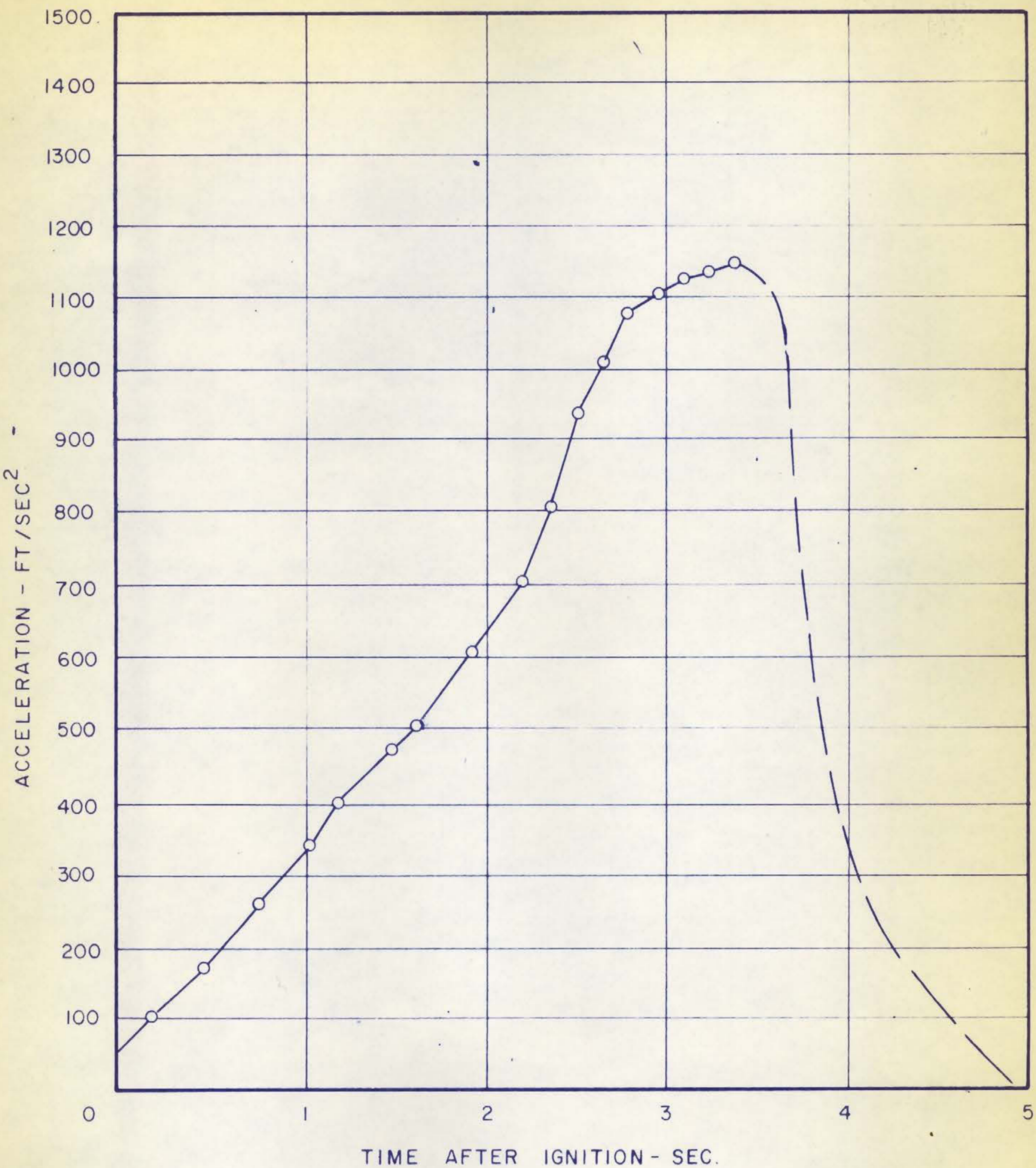
MARTLET 3A SEPT 5, 1963 FLIGHT TRAJECTORY
COORDINATES FROM CINE THEODOLITES
IGNITION CONDITIONS - TIME AFTER LAUNCH 14.3 SEC
- RANGE FROM LAUNCH 9140 FT.
- ALTITUDE FROM LAUNCH 23190 FT.

FIGURE 11



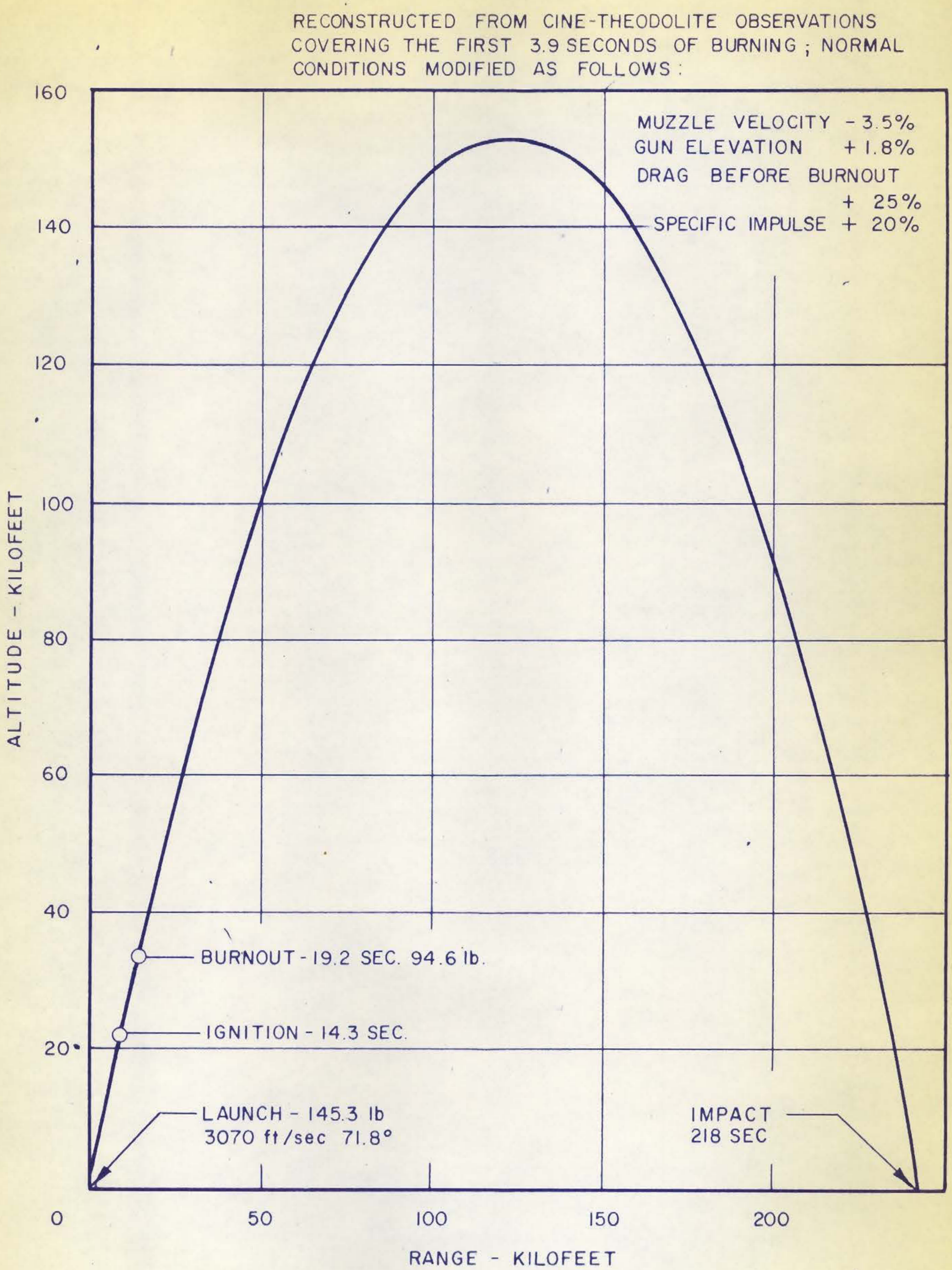
MARTLET 3A SEPT. 5, 1963 FLIGHT
VELOCITY DURING BURNING
FROM CINE-THEODOLITE DATA

FIGURE 12



MARTLET 3A SEPT. 5, 1963
ACCELERATION DURING BURNING

FIGURE 13



MARTLET 3A TRAJECTORY

FIGURE 14

8.2 Conclusions

It was considered on the basis of the final two shots of the series that launching of rockets from guns was feasible.

It was not demonstrated that the vehicles could perform to their maximum stress/load capability.

The probability was established that pusher plate assemblies should have a minimum length to diameter ratio of 0.3 in order to prevent "cocking" action on loading and/or instability during shot travel. This consideration was mandatory not withstanding low stress levels in such thick plates.

It was conclusively demonstrated that solid wood sections for sabot leaves were totally unreliable and that laminated sabots performed well.

9.0 MARTLET IIIA - MOD. I

9.1 Introduction

On the basis of the first series of shots with two highly successful launches it was decided to continue development of the vehicles.

The main objectives of the next series of vehicles was to better the performance of the initial vehicles in terms of apogee and payload. In order to achieve this, it was planned to increase the launch velocity until the "g" level limit was reached. For this reason the nose cone assembly was extensively redesigned as well as the front end of the motor case to accommodate much higher acceleration levels.

Since the same basic external geometry was used little could be done to increase the mass fraction in order to boost the burn out velocity. However, a major effort was made to increase the performance of the rocket motor. Aluminum powder was added to the chemical mixture which increased the specific impulse of the fuel. At the same time a major effort was made to reduce the throat erosion in the nozzle.

Enough confidence was held in the vehicles to use them as a test bed for initial telemetry flights. To this end the nose cone was redesigned to house a telemetry package and carry external quadraloop antennae.

As before, a test program was initiated at the Inspection Services facility at Nicolet using a 81 millimeter mortar. A sleeve was fitted into the mortar shell case which housed the graphite. A ballast slug of steel was mounted resting on the graphite in order to simulate the compressive loads expected in the full scale gun launch test.

In three tests the graphite was shock loaded to the equivalent of 10,000 "g's", in a full scale test vehicle, with no damage evident. Unfortunately, this phase of the program was completed only one week before the scheduled test series and it was impossible to have new nozzles and rocket motors manufactured and assembled in that time.

9.2 Testing Program

In order to improve the propellant performance an attempt was made to add powdered aluminum to the basic N5 fuel. No problem was encountered in mixing and extrusion with additions of up to 10% (by weight) of aluminum powder to the N5 fuel. A slight reduction in tensile strength was evidenced.

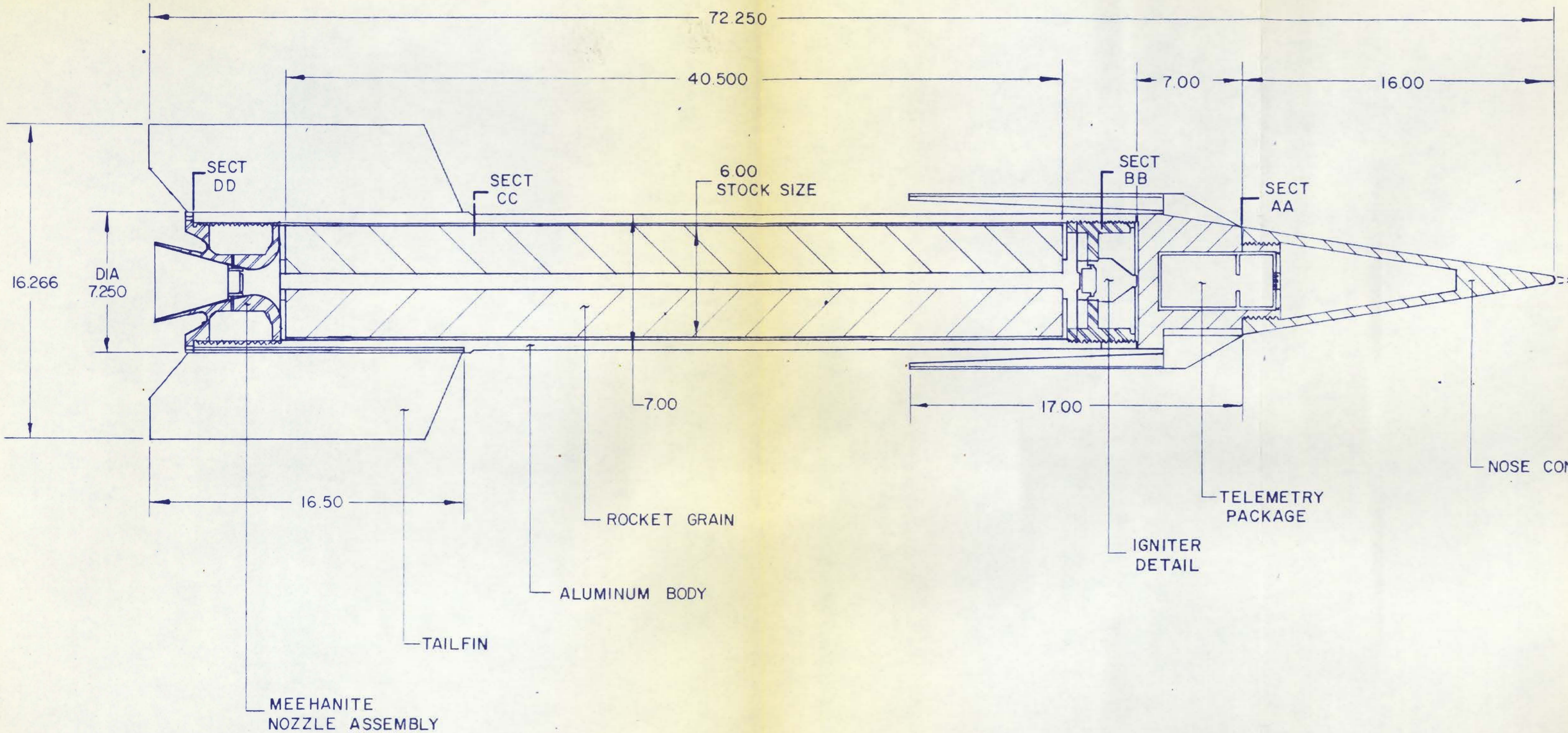
In late November 1963 a series of static tests was performed in order to test the new propellant. The optimum mixture appeared to be N5 plus 10% aluminum as determined from calorimeter tests. The results of the static tests are presented in tests 7 to 15 in Appendix I.

The tests immediately demonstrated that the nozzle materials in use to that point were totally inadequate for aluminized propellant. Several types of nozzles were tried in static test. Because of time limitations, it was decided to proceed with the manufacture of vehicles for the test series using the more proven N5 non-aluminized type of propellant, although every effort was made to obtain an adequate nozzle material for the aluminized propellant.

Unfortunately, a suitable combination of materials was not obtained in time to incorporate the design into the test series of vehicles.

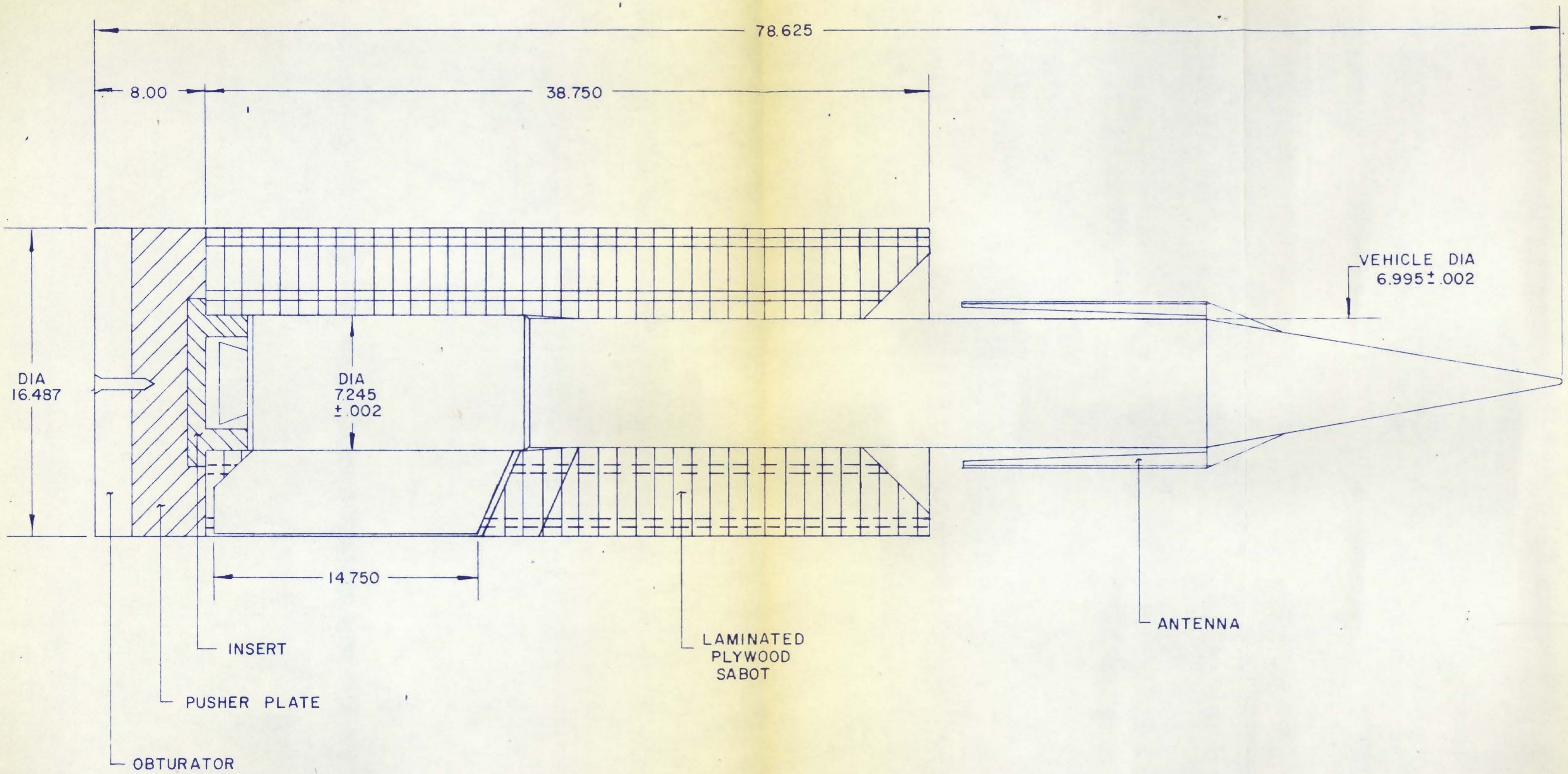
In latter static tests a graphite throat section was incorporated into the nozzle design, which performed excellently. No measurable erosion occurred with the aluminized propellant. Some doubt was expressed that the graphite could successfully survive the launch shock loads experienced in the gun. The rear pusher plate assembly was modified utilizing experienced obtained in the initial successes. (Refer to Fig. 16) That is to say, the main consideration was stability in the bore during shot travel. The main pusher plate was fabricated using two aluminum discs bolted together to give an over length of five inches. The rear obturator was redesigned using a 2" thick disc of polyethylene which was dished to provide a good seal.

The steel insert was redesigned by removing the chamfered pedestal section and substituting a straight column support. This reduced the assembly weight which had been increased by the additional thickness of aluminum plate. The removal of the sloping portion of the pedestal also allowed better area for the wooden side sabots.



MARTLET 3A MOD. I

FIGURE 15



VEHICLE WEIGHT 170.0 lbs
MOTOR WEIGHT 57.0 lbs
MASS FRACTION 0.335
PROJECTILE WEIGHT 435 lbs

MARTLET 3A MOD. I

FIGURE 16

The sabots were redesigned using glued plywood with alternate layers rotated in order to provide as much homogeneity to the material as possible.

9.3 <u>Design - Modifications</u> (Refer to Fig. 15)

The joint between the nose cone and motor case was redesigned to give better strength and easier assembly procedure. The joint was effected by using an internal coupling which also acted as an ignitor housing. The nose cone tip was allowed to remain essentially the same. Between the nose cone tip and ignitor housing (coupling) a payload section was designed to house both telemetry package and carry antennae. In all changes 7075T6 aluminum bar stock was used for material. The motor case was left unchanged except for the modification to accept the ignitor housing.

The nozzle was modified slightly with the removal of one flange and the thickening of certain wall sections particularly near the throat. The nozzle material was changed to a cast modular iron type of material (Meehanite). The modifications to the nozzle reduced its weight slightly.

9.4 Test Firings

The second series of test firings was scheduled for the first week of January 1964.

As before conditions of launch were determined just prior to each shot in order to obtain best results and data from each test. Changes from the previewed program will be presented with each shot. The test series had two specific aims: (1) To test the structural integrity and reliability of the vehicle to ita maximum limit of performance and (2) To test newly developed "high-g" telemetry in a relatively moderate launch environment.

The range instrumentation for this series of shots is listed below:

Muzzle Data	-	4 High speed Framing Cameras (Fastax)
	-	2 High Speed Smear Cameras
Tracking	-	2 Cine-theodolites
	-	M33 Radar
	-	Twin Falls Radar Ship
Telemetry	-	B.R.L. Telemetry Receiving Van
	-	Twin Falls Telemetry Receivers

9.4.1 TEST PROGRAM FIRING RECORD

SHOT #1 MARTLET IIIA Mod.I (6414) January 4, 1964.

a) Basic Data

Vehicle Weight	169.5 lbs.
Projectile Weight	431.5 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	317.0 lbs. (WM .245)
Payload	250 MC Telemetry (CDC)

b) Predicted Interior Ballistics

Muzzle Velocity	3,500 fps
Maximum Breech Pressure	15,000 psi
Maximum Acceleration	5,350 "g"
Muzzle Elevation	80^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,500
Ignition	14	36,000	6,200	1,650
Burn Out	18.9	49,000	9,500	3,800
Apogee	128.0	224,000	92,500	750
Impact	255.0	0	177,000	1,625

d) Results

Muzzle Velocity	3,760 fps (from Fastax)
Maximum Breech Pressure	17,900
Maximum Acceleration	6,500 "g"

Vehicle launched intact

e) Discussion

This shot had been planned as an attempt to duplicate the best launch velocity achieved in the first series of tests.

From the Fastax films the vehicle appeared to launch correctly. One fin was detached most probably having been struck by a fragment of sabot peeling away from the vehicle. Recovery of the damaged fin indicated a strike of wood material on the leading edge. No other damage was evidenced from the films and no other fragments found excepting sabotry.

Motor ignition and burning were recorded by ground observers at gunsite and at launch control. From audio and visual observations the motor appeared to have functioned normally. Neither radar or cine-theodolite stations acquired or tracked the vehicle.

The telemetry functioned and was recorded with a strong signal for 98 seconds.

f) Conclusion

The flight appeared normal except for the clipping of a fin. It was felt that loss of the fin plus slightly higher velocity than predicted could have changed the actual trajectory sufficiently from the predicted trajectory to account for lack of acquisition by tracking instrumentation.

This flight was the highest launch velocity yet achieved by a rocket vehicle. The launch acceleration sustained was 20% higher than any previous successful shot. As well, the launch environment exceeded the design limit by 13%.

The fact that the telemetry transmitted for only 98 seconds in inconclusive since some difficulty had been experienced with the telemetry transmitter at final check out.

h) Action

Based on this success it was decided to raise the gun charge in order to achieve a higher launch velocity.

9.4.2 TEST PROGRAM FIRING RECORD

SHOT #2 MARTLET IIIA Mod.I (6416) January 6, 1964

a) Basic Data

Vehicle Weight	168.5 lbs.
Projectile Weight	435.0 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	379.0 lbs. (WM .245)
Payload	250 MC Telemetry (HDL)

b) Predicted Interior Ballistics

Muzzle Velocity	4,000 fps
Maximum Breech Pressure	25,000 psi
Maximum Acceleration	8,550 "g"
Muzzle Elevation	80^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	4,000
Ignition	14	39,000	8,000	1,925
Burn Out	18.9	55,000	10,500	4,125
Apogee	140	277,000	110,000	800
Impact	276	0	215,000	1,625

d) Results

Muzzle Velocity	4,100 fps (apparent from Smear camera)
Maximum Breech Pressure	26,000 psi
Maximum Acceleration	8,950 "g"

Vehicle disintegrated completely

e) Discussion

This test was performed with a view to obtaining higher muzzle velocities and improved overall performance. To achieve this the gun charge was increased resulting in much increased launch acceleration.

The Smear cameras showed fragments emerging from the muzzle indicating a catastrophic failure deep in the barrel.

Examination of the vehicle fragments indicated possible failure of both vehicle and sabot.

It can be noted that the launch acceleration was 35% higher than any other successful launch and 55% higher than vehicle design limit.

f) Conclusion

The vehicle and sabot were both presumed to have failed, but, it was indeterminate which had failed first precipitating failure of the other.

The suspected causes in order of degree were: (1) Sabot failure; (2) Aluminum case failure due to over load; (3) Propellant failure.

g) Action

The decision was made to lower the charge to coincide with the first shot of the series and to use modified sabots. Composite sabots were then made up. These consisted of the lower half machined from ethylux bar stock to the same geometry as the lower half of the plywood sabots. The top section of the regular plywood leaf was cut off and dowelled to the plastic lower section.

9.4.3 TEST PROGRAM FIRING RECORD

SHOT #3 MARTLET IIIA Mod.I (6418) January 9, 1964

a) Basic Data

Vehicle Weight	167.5 lbs.
Projectile Weight	489.0 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	325.0 lbs. (WM .245)
Payload	250 MC Telemetry (HDL)

b) Predicted Interior Ballistics

Muzzle Velocity	2,650 fps
Maximum Breech Pressure	19,000 psi
Maximum Acceleration	6,300 "g"
Muzzle Elevation	80^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	2,500
Ignition	14.0	29,000	5,400	1,075
Burn Out	18.9	38,000	8,500	3,150
Apogee	106.0	114,000	57,000	600
Impact	206.0	0	87,000	1,625

d) Results

Muzzle Velocity	3,700 fps (apparent from Fastax camera)
Maximum Breech Pressure	19,300 psi
Maximum Acceleration	6,300 "g"

Vehicle completely disintegrated

e) Discussion

The failure of this shot removed the suspicion of sabot failure and indicated vehicle over load as the more probable cause. From recovered fragments, break-up appeared to be typical of brittle fracture under impact loading conditions.

It is interestint to note that the first shot of this series launched at a "g" level some 6% higher than the level at which this vehicle failed.

f) Conclusion

The vehicle was concluded to have failed by brittle fracture.

g) Action

The decision was made to reduce the gun charge further in order to allow the launch acceleration to reach a level below that of the design limit. It was also decided to return to the regular sabot configuration.

FASTAX PHOTO OF SHOT NO. 3

FIGURE 16A

9.4.4 TEST PROGRAM FIRING RECORD

SHOT #4 MARTLET IIIA Mod.I (6415) January 10, 1964

a) Basic Data

Vehicle Weight	166.0 lbs.
Projectile Weight	433.0 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	271.0 lbs. (WM .245)
Payload	None

b) Predicted Interior Ballistics

Muzzle Velocity	3,500 fps
Maximum Breech Pressure	13,000 psi
Maximum Acceleration	4,950 "g"
Muzzle Elevation	80^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,500
Ignition	14	36,000	6,200	1,650
Burn Out	18.9	49,000	9,500	3,800
Apogee	128.0	224,000	92,500	750
Impact	255.0	0	177,000	1,625

d) Results

Muzzle Velocity	3,370 fps (Smear camera)
Maximum Breech Pressure	12,500 psi
Maximum Acceleration	4,750 "g"

Vehicle launched intact - fins damaged

e) Discussion

The Smear camera photographs indicated good launching with damage to two and possibly three fins. The photographs indicated the leading edge of the fin was struck by part of the wood sabot leaf as it petalled away. Recovery of fin fragments confirmed this indication.

Tracking instrumentation failed to acquire the vehicle.

The motor did not appear to burn correctly. A single sharp explosion was heard which was not followed by the usual rocket burn sound. A very short smoke trail was observed somewhat below predicted ignition elevation.

The acceleration level was approximately 20% below that of the design limit.

f) Conclusion

The vehicle launched with fin damage. The fin damage was caused by the wood sabot leaves petalling away from the vehicles. The loss of the fins caused enough dispersion for the vehicle to fly out of the tracking instrumentation acquisition beam width. The motor burning irregularity was attributed to possible motor case damage due to break-up of the fins.

g) Action

The close fitting slots in the sabot leaves in which the fins fitted were widened and lengthened to give maximum clearance. The slots were widened to 1½" the entire length of the sabot excepting a 4" ring at the top to ensure correct locating in the barrel.

9.4.5 TEST PROGRAM FIRING RECORD

SHOT #5 MARTLET IIIA Mod.I January 10, 1964

a) Basic Data

Vehicle Weight	183.0 lbs.
Projectile Weight	422.5 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	300.0 lbs.
Payload	Robin Balloon (BRL)

b) Predicted Interior Ballistics

Muzzle Velocity	3,500 fps
Maximum Breech Pressure	17,000 psi
Maximum Acceleration	6,150 "g"
Muzzle Elevation	80°

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,500
Ignition	14.0	36,000	6,200	1,650
Burn Out	18.9	49,000	9,500	3,800
Apogee	128.0	224,000	92,500	750
Impact	255.0	0	177,000	1,625

d) Results

Muzzle Velocity	3,500 fps (apparent from Smear camera)
Maximum Breech Pressure	17,000 psi
Maximum Acceleration	6,150 "g"

Vehicle totally disintegrated

e) Discussion

From the Smear photographs the fragments emerging from the muzzle indicated total failure deep in the barrel.

The payload of this vehicle was manufactured by the Ballistic Research Laboratories of Aberdeen, Maryland. Owing to difficulties of packaging the tracking balloon, it was necessary to have a nose cone which weighed some 15 lbs. more than the regular nose cone. At the "g" level experienced by this vehicle, the additional weight raised the stress level at the base of the vehicle to a level approximately 35% over ultimate tensile (design limit).

f) Conclusion

The vehicle failed in the barrel with brittle fracture indicated as the mode of failure. Failure attributed to high over-stress condition.

g) Action

The gun charge was lowered for the next shot to bring the launch acceleration level below the design limit. The wide slots in the sabots were retained.

9.4.6 TEST PROGRAM FIRING RECORD

SHOT #6 MARTLET IIIA Mod.I (6411) January 13, 1964

a) Basic Data

Vehicle Weight	169.5 lbs.
Projectile Weight	429.0 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	250.0 lbs.
Payload	250 MC Telemetry (CDC)

b) Predicted Interior Ballistics

Muzzle Velocity	3,000 fps
Maximum Breech Pressure	10,000 psi
Maximum Acceleration	3,900 "g"
Muzzle Elevation	80^o

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,000
Ignition	14.0	32,500	5,800	1,360
Burn Out	18.9	43,500	9,000	3,475
Apogee	117.0	169,000	74,250	675
Impact	231.0	0	132,000	1,625

d) Results

Muzzle Velocity	3,050 fps (Fastax camera)
Maximum Breech Pressure	10,000 psi
Maximum Acceleration	3,900 "g"

Vehicle launched intact

e) Discussion

From the Smear camera photographs, the launch appeared to be excellent with the exception that one fin was damaged on the leading edge. Again, none of the tracking instrumentation acquired or tracked the vehicle.

The motor burning was irregular. Ignition occurred at the correct time and the motor burned for approximately three seconds and appeared to explode. The M33 Radar commenced to track debris. The vehicle motor case was recovered. It had been split longitudinally as would be expected from a pressure vessel type of failure. At the line of fracture, two marks could be seen which appeared to be the result of contact with the antennae.

The nose cone was ejected by the motor explosion and flew a trajectory. The telemetry was switched on by the motor explosion and continued to generate weak signals for two minutes and forty seconds, indicating normal flight to impact. It was noted that the launch acceleration was only 60% of design limits.

f) Conclusion

The vehicle launched intact and on trajectory. Ignition occurred at prescribed time and the motor ignited properly. During the early burning period the motor malfunctioned possibly due to a sudden fluctuation of pressure or nozzle blockage and the vehicle exploded. The damage caused by the clipping of the fin may have damaged the case in turn causing malfunction. However, a major suspicion was grain cracking. It was not clear if the possible cracking had occurred prior to, at launch, or during motor burn.

g) Action

It was decided to repeat the flight at the same launch conditions with the sabot completely slotted ahead of the fin to prevent clipping. Only small sections 1" by 2" were left to locate the round concentrically in the bore.

FASTAX PHOTO OF SHOT NO. 6

FIGURE 16B

9.4.7 TEST PROGRAM FIRING RECORD

SHOT #7 MARTLET IIIA Mod.I January 14, 1964

a) Basic Data

Vehicle Weight	168.5 lbs.
Projectile Weight	428.0 lbs.
Motor Weight	57.0 lbs.
Gun Propellant	250.0 lbs. (WM .245)
Payload	250 MC Telemetry (HDL)

b) Predicted Interior Ballistics

Muzzle Velocity	3,050 fps
Maximum Breech Pressure	10,000 psi
Maximum Acceleration	3,900 "g"
Muzzle Elevation	70^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,000
Ignition	14.0	32,500	5,800	1,360
Burn Out	18.9	43,500	9,000	3,475
Apogee	117.0	169,000	74,250	675
Impact	231.0	0	132,000	1,625

d) Results

Muzzle Velocity	2,800 fps (Fastax camera)
Maximum Breech Pressure	10,000 psi
Maximum Acceleration	3,900 "g"

Vehicle launched intact

e) Discussion

The muzzle camera coverage indicated a perfect launch with no fin damage. The vehicle flew on predicted trajectory and ignition appeared in all cine-theodolites. The vehicle exploded on ignition. The M33 Radar tracked debris from three seconds after the explosion. The telemetry did not transmit at any time.

f) Conclusion

The vehicle exploded after a motor malfunction confirming evidence from previous rounds. However, it was proved that fin damage was not the immediate cause of motor malfunction. From previous explosions it appeared that most, if not all of the motors, were defective.

g) Action

The remaining shot with a heavy tracking balloon nose cone was cancelled.

9.5 Conclusions

The series demonstrated a basic weakness in the rocket motors as evidenced by the explosions in the Shots 4, 6 and 7. The weakness could be the product of the following factors; poor bonding strength and subsequent failure; poor propellant strength and subsequent failure; propellant cracking due to cycling and rough handling.

It is interesting to note the shear stress level at the wall of the motor case in the bond in each of the shots:-

Shot #1	480 psi *
Shot #2	640 psi ***
Shot #3	460 psi ***
Shot #4	340 psi **
Shot #5	445 psi ***
Shot #6	280 psi **
Shot #7	280 psi **

The single "starred" shot was completely successful within the limitation of the recorded data.

The double "starred" shots launched properly (with fin damage in certain cases) and exploded after ignition.

The triple "starred" shots failed catastrophically in the barrel.

The shear stress level in all of these rounds is well below failing stress as exhibited by the bonding materials in static tests. This fact adds strength to the thesis that the rocket fuel had a basic weakness. The actual mode of failure was unknown since it was inobservable and possible modes of failure are pure speculation. In order to generate pressures sufficient to burst the case, over pressures of three times the regular burning pressure must be generated. This could happen in two ways. At launch, the propellant could have been cracked or shattered, exposing large areas of propellant to the ignition flash. The pressure of burning is a function of the burning area among other parameters. If sufficient area were exposed, and ignited, bursting pressures could be generated. The second possibility arises if the propellant were partially damaged and burning of a portion of the motor resulted in the collapse of certain segments of the propellant thus, causing nozzle blockage. Again, the case would burst. The failure phenomena could be a combination of these two possible causes.

In comparing the series to the previous one to try to determine the cause for the vehicle malfunction the following points became evident. In the first series the vehicles were fabricated and assembled during the summer months. They were then transported immediately to Barbados and launched. In the second series of vehicles, they were assembled during the winter months. During transport the vehicles were subjected to temperature cycling at least three times in the range of $+10^{o}F$ to $+100^{o}F$.

As well, no particular care had been taken in packaging or handling to avoid vibration. It was then postulated that the cycling and handling technique might have caused cracking in the fuel with resultant failures.

It was demonstrated that fin damage apparently had little to do with the direct failure of the motors. It was also demonstrated that the long slots in the sabots were not effective in all cases for preventing fin damage. From the recovered fin parts, it was concluded that the fin section was too weak to withstand anything except the slightest of blows from foreign objects at launch. The method of attachment using "T" slots was not rugged enough as well.

Despite the successful launch of a vehicle (Shot #1) at an acceleration level of 13% above the design limit, it was apparent that no stress calculations should be made using stresses greater than static ultimate levels for any materials with high alloy content or maximum heat treatment. Any over-stress capability due to high rates of loading should be considered a factor of safety.

It was evident from the successful launchs that plywood sabots perform adequately.

It was obvious that with the gun propellant available and no change in gun geometry the maximum velocity likely to be attained without exceeding the designed acceleration load potential was not more than 3,300 - 3,400 feet per second. Since at 80^{o} muzzle elevation the apogee of the vehicle would not exceed 225,000 feet, it was felt that little was to be gained in scientific experiments by redesign and refinement of the existing configuration. Pure glide ballistic vehicles had already attained an altitude of 300,000 feet reliably.

The overall conclusion gained from this series was that a new generation of vehicles must be designed incorporating increased strength air-frames.

10.0 MARTLET IIIB

10.1 Introduction

Following the two series of shots using aluminum structures, it was decided to redesign the rocket vehicle using a steel motor case of enlarged dimensions in an effort to launch an airframe of much greater strength.

As well, the design limits were held to maximum tensile stress. Provision was incorporated for supporting the grain at the base so that the bond at the wall would not be as highly stressed.

The increase of size of the vehicle presented certain problems since the maximum manufacturing capacity of Canadian Arsenals had already been reached. For this reason, a new method of rocket motor fabrication was inaugurated and perfected.

In order to achieve the aims of the program, a series of twelve vehicles was planned for July 1964. A determined effort was made to assure better handling of the vehicles as well as limiting temperature cycling to the minimum possible.

The Martlet IIIB was designed around an 8" diameter, 40 inch length motor. The vehicle was designed to survive a launch acceleration of 10,000 "g's" and at the same time, a considerable effort was made to improve the altitude capabilities. In order to achieve this aim, ultimate tensile stresses were used as working stresses and all sections were kept as lightweight as possible.

Due to the increase of diameter of the motor case and limitations of the barrel diameter, it was necessary to use stabilizing fins with long overhang. This presented certain saboting problems. As well, the long overhang was not too desirable from the point of view of center of gravity of the overall vehicle. For these reasons the overhang was kept to an absolute minimum, and stability was expected to be just over marginal.

The case and fin material were changed to alloy steel (SAE 4130) which was heat treated. The fins were attached to the motor case by welding, using preheat techniques and inert gas shielded arc processes. The welds were X-rayed for cracks and overall density and integrity.

The nose cone was manufactured from aluminum for minimum weight. Again it was planned to fly experiments using previously proven telemetry and antennae as well as chemical release, experiments similar to ballistic round experiments.

Aside from a longer pusher pedestal, the sabot design remained essentially the same as on previous rocket vehicles.

From the successful static tests the nozzle design was changed to incorporate graphite linings. This allowed the use of the more powerful aluminized propellants.

In order to produce rocket motors for the series, it was necessary to change manufacturing techniques. The following process offered considerable promise. Several motors were manufactured for static test. The rocket propellant was rolled into thin sheets (¼" thick). The sheet was then die cut to the required outside diameter. The punched out disc was then perforated in the same manner in the center with a seven point star internal cavity shape. Enough discs to comprise one motor were then mounted on an eight point star shaped mandrel, spaced loosely along the mandrel. The mandrel was lowered into a solvent bath. On withdrawal from the solvent, the discs were compressed together with a pneumatic press and the solvent allowed to evaporate. This process took considerably longer than the regular extrusion technique, but produced motors of equal integrity. On X-ray, no cracks were evident longitudinally or between layers of propellant. This fact was confirmed when several motors were cut open for inspection.

While the process was markedly slower (due in part to lack of tooling for the specific process), it had no limitations as to diameter or length of motor possible to produce. Quality of the motor was at least as good as the extruded motors and any possible residual stresses due to extrusion were eliminated.

To broaden the scope of the program, it was decided to incorporate four motors manufactured by Picatinny Arsenals, Dover, New Jersey, in four of the twelve vehicles. Relatively, little information was obtainable concerning the manufacture of these motors because of security regulations.

They were of the double base (nitrocellulose nitroglycerine) propellant type similar to the type manufactured by Canadian Arsenals.

These motors were mechanically stronger with a tensile strength of approximately 1200 psi but with a specific impulse range identical to the C.A.L. propellant. In lieu of a central star perforation, a perforation of circular cross-section which increased in diameter as it progressed to the base of the motor was incorporated.

H.A.R.P. supplied complete vehicles excepting motors and nozzles to Picatinny Arsenals. Picatinny Arsenals manufcatured and installed motors and nozzles. The motors were bonded to the vehicle wall but not shrunk fit as C.A.L. rounds were. The nozzles as used by Picatinny Arsenals were similar to regular assemblies incorporating graphite linings but having much larger exit diameter thus affording a better expansion ratio. The bonding technique and graphite used in these rounds are not described for security reasons. Due to the larger nozzle exit diameter, the pusher pedestal of the rear sabot assembly had to be slightly modified.

10.2 Testing Program

Static testing was continued using the new 8" diameter laminated motors in order to test the new manufacturing technique. The test equipment was suitably modified to accommodate the larger motors which had increased thrust and burning times. Static tests yielded data on ignitor performance and nozzle performance which are presented in tests 16 - 21 in Appendix I. During these tests, it became evident that the ignition device would have to be modified. The original idea of a diaphragm which would punch out at ignition was tried initially, but poor ignition was obtained in several cases, as is evidenced in the static test results. It appeared that with the increased charge for the larger motor, the diaphragm was releasing before the total charge had been ignited. Thus most of the charge was propelled down the center perforation unignited. The charge cannister was modified (see Fig. 20) by eliminating the diaphragm at the base and replacing it with side vents drilled at a angle in the walls of the cannister. The cannister was then lined with Mylar to retain the ignition charge. This modification eliminated ignition problems.

From experience gained from the 6" rocket motor tests, graphite throated nozzles were tested with the larger motor. The throat sections performed very well with no erosion experience with the aluminized propellant. The divergent section was badly eroded due to the longer burning times. To prevent failure of the divergent section a graphite liner was incorporated protecting the expansion cone walls in the area of most damage.

With these modifications, the static test motors performed excellently.

At the same time, a program was started using quarter scale models of the flight vehicles in order to determine stability and drag characteristics. Several models were manufactured and fired in the test range of Inspection Services at Nicolet.

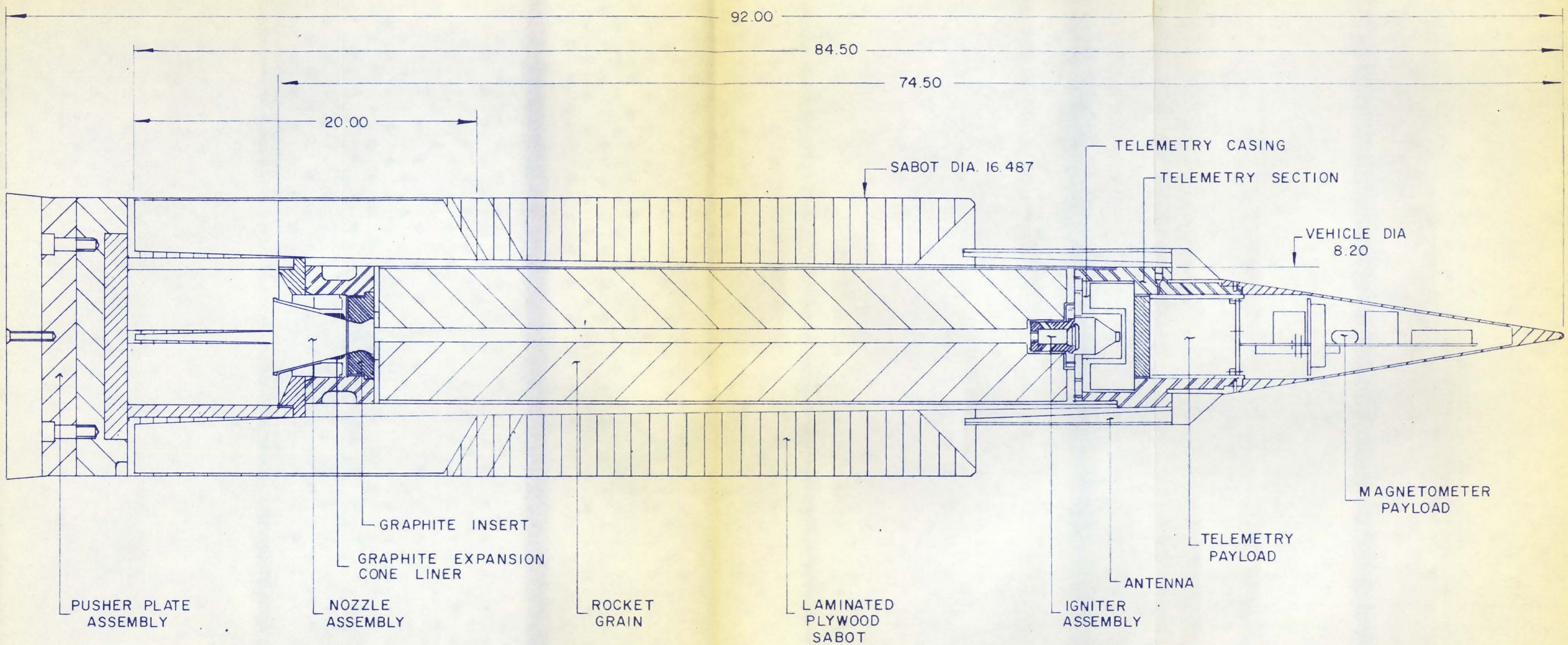
As well in launching these models, it was found that the long pusher pedestal which fitted between the overhanging fins separately cleanly with no fin damage. The fact was most important since considerable doubt was held that they would separate cleanly.

10.3 Mechanical Design

From the results of the static tests, the vehicle was designed around an 8" diameter, 40" length rocket motor. (See Figs. 17, 18, 19) The model test program indicated the external geometry and the mechanical design was based on this external geometry.

The motor case was changed to a long taper cross-section of high alloy heat treated steel (SAE 4130). The stabilizing fins were reduced in number from six to four and their length increased so that the overhang over the base of the motor case was approximately 10 inches. The fins were attached by welding using an inert gas shielded arc process with high strength welding rods. In order to prevent warpage and cracking, welding fixtures were used along with a preheat (to 600°F) of fin and case. To assure good welds on the completed motor cases, all welds were X-rayed. In certain cases, a small amount of porosity in the isolated sections was defected. It was felt that these areas were not too serious since the general stress level on the welds was low.

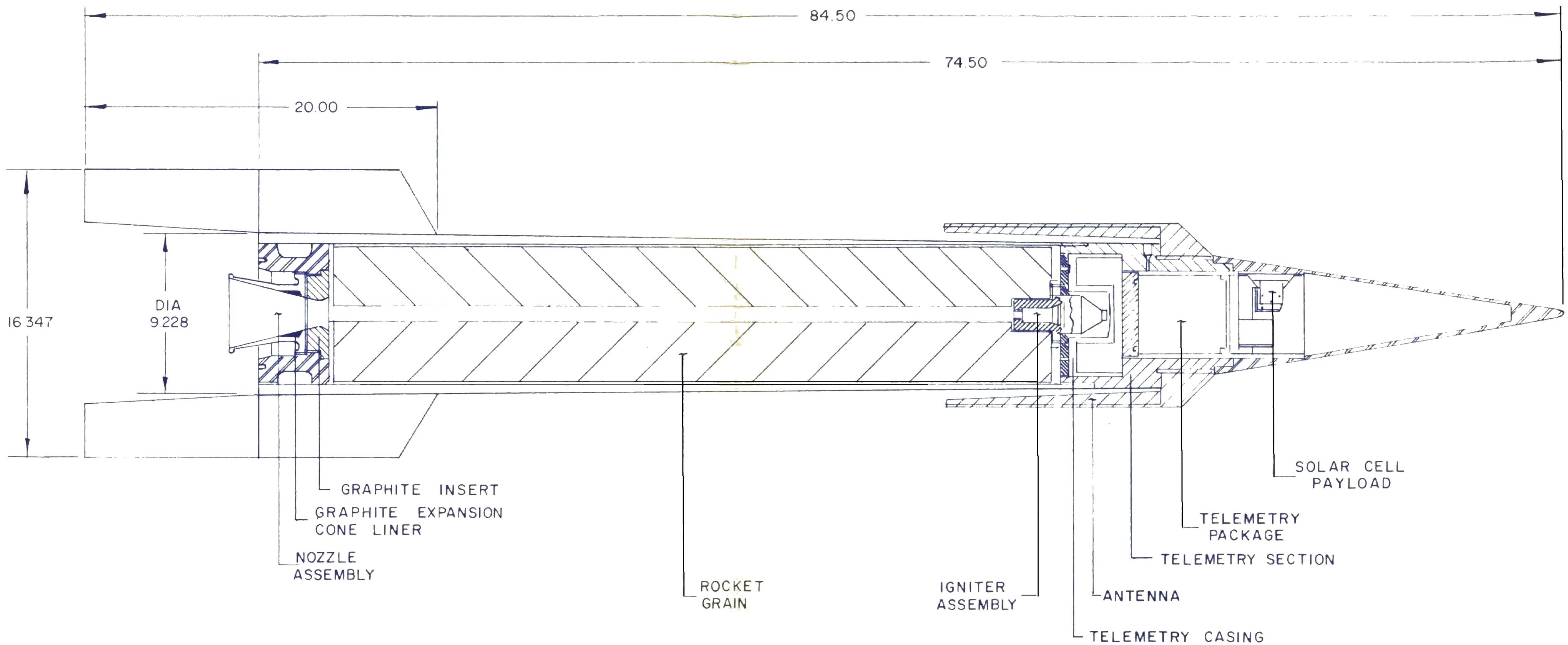
After fin welding, the motor case assembly was heat treated drawing back to a hardness of Rockwell C 40-42 thus giving an ultimate tensile strength of 205,000 psi. The welds were not heat treatable but



VEHICLES -	ARVIDA	ESCUMINAC
WEIGHT lbs -	314	313.5
MOTOR WEIGHT -	103.0	103.0
MASS FRACTION -	0.328	0.327
ALL UP WEIGHT -	6.666	746

MARTLET 3B
ASSEMBLY

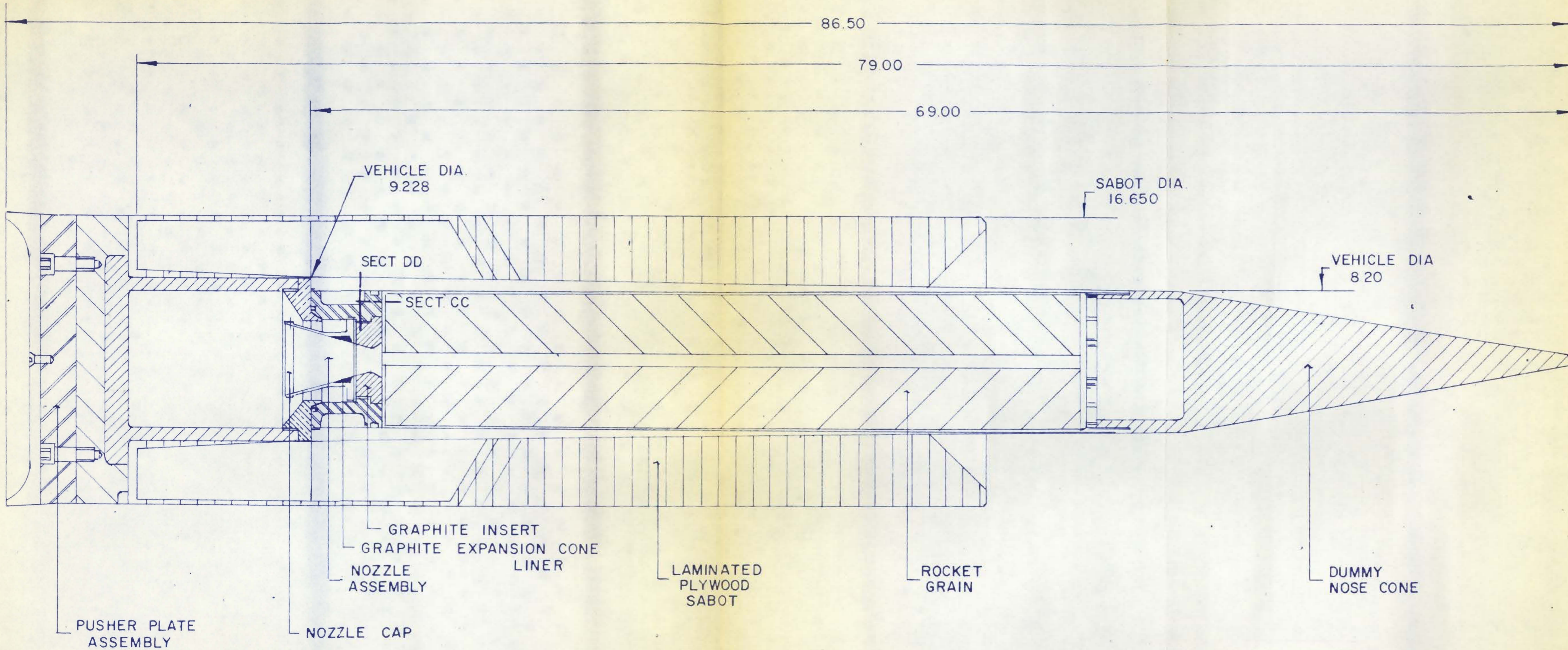
FIGURE 17



VEHICLES -	CHICOUTIMI	FONTAINEBLEAU
WEIGHT lbs -	313.0	315.0
MOTOR WEIGHT lbs -	103.0	112
MASS FRACTION -	0.329	0.356
ALL UP WEIGHT lbs -	680.0	679.0

MARTLET 3B
ASSEMBLY

FIGURE 18



VEHICLES	MTV1	MTV2	MTV3	MTV4	MTV5	BROME
WEIGHT lbs	309.5	318.25	319	308	329	306
MOTOR WEIGHT	103	112	103	103	103	112
MASS FRACTION	0.333	0.351	0.323	0.334	0.313	0.367
ALL UP WEIGHT	688.5	683.75	689	676	700.5	666.5

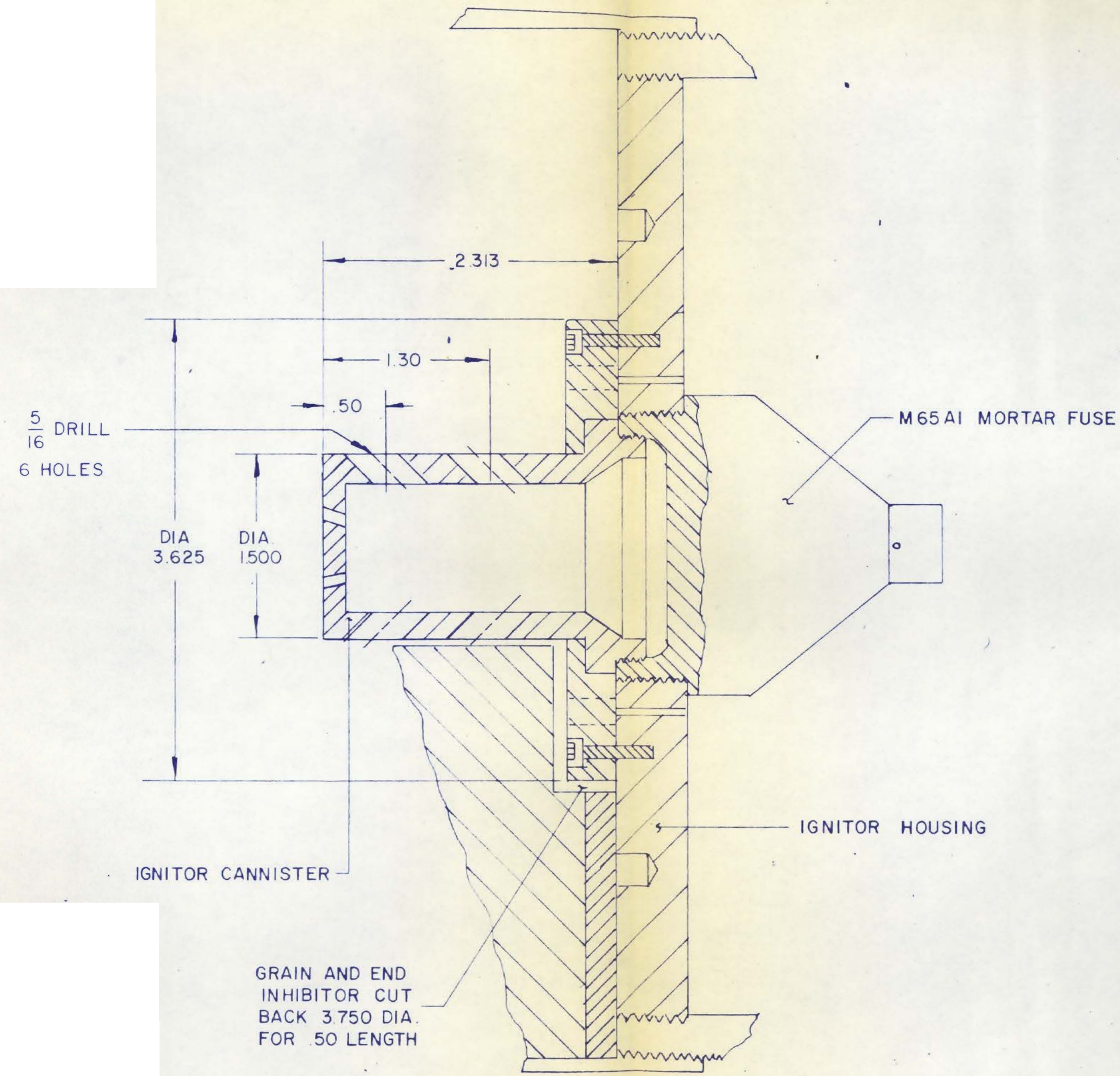
MARTLET 3B
ASSEMBLY

FIGURE 19

the best rod available was used (P & G Low Hydrogen MIL 110 18 Class 1) giving a weld strength of 110,000 psi in tension. The drawing temperature was chosen to give the best tensile strength while retaining good impact and shock loading qualities (High Izod-rating).

The nose cone was designed to carry telemetry and sensing elements. Two nose cones incorporated magnetometers mounted on Catesian axes for the measurement of the earth's magnetic field. Two nose cones were instrumented with telemetry and photoelectric sensitive devices (sun seekers). The nose cones were manufactured from aluminum barstock. The telemetry elements and instrumentation were mounted on sheetmetal frames and then encapsulated in potting compound in the cone. Antennae (external quadraloop) which had been proven in previous firings were incorporated for transmission of the telemetered instrument signals.

The nose cone threaded into the top of the motor case. The acceleration loads were taken in shear through cone/case mating threads. The ignitor was threaded into a steel plate which threaded into the base of the nose cone. The ignitor cannister protruded into the rocket motor cavity (Fig. 20). A retaining plate was added to retain the cannister due to its increased loads.



MARTLET 3B
IGNITER ASSEMBLY

FIGURE 20

The nozzle configuration was a duplicate of the one used in successful static tests with respect to internal shape and material. The nozzle was housed in an aluminum housing which threaded into the base of the motor case. The housing was a modified "I" section which butted against the motor and rested on the top flange of the pusher pedestal.

The housing was designed to withstand a total crushing load equivalent to the motor weight at 10,000 "g's" so that in the event of total failure of the wall bond material some second mode support was available.

Since the housing was supported by the pusher pedestal, it was felt unnecessary to make the joint between the housing and motor case strong enough to carry the potential motor set back load. Because of this the threaded portion of the housing was designed to retain the nozzle assembly only under the pressure loads due to motor burning. The nozzle closure (obturator) device was changed. Instead of retaining the obturator with two pins, the obturator was fabricated from a thin disc (with an under cut for diaphragm blow out) which was sandwiched between the graphite convergent section and the divergent expansion cone. This method had proven successful in static tests. The sabots were in general similar to those used in the previous series of tests. Plywood was used for the side sabots. The pusher sabot consisted of two plates of aluminum bolted together with a steel insert similar to previous projectiles. The major difference was the steel insert. Of necessity due to the long overhang of fins, it was long. The steel insert (pusher pedestal) was manufactured from the same alloy as the vehicle case and an insert was threaded into the top of the pedestal. A raised spigot on the inner bore of the insert served to locate the rear end of the vehicle concentrically with the bore of the gun by fitting into a mating cavity in the nozzle housing. The nozzle protruded through the opening the insert. The pedestal was slotted in order to accommodate the fins should the pedestal/ plate assembly cock slightly on exit from the muzzle.

10.4 Test Firings

The test series was commenced in mid-July 1964. Once again the range was instrumented as in previous test series.

It was hoped that with new design criteria, the vehicles would function reliably. It must be remembered that the vehicles were designed such that at the rated maximum level of acceleration, (10,000 g's) no section would have a stress greater than ultimate tensile stress measured statically. In every case where weight was not critical large factors of safety were incorporated. These facts would eliminate the suspicion held from the two previous test series that the vehicle structural was over-stressed.

The wood sabots had been proved previously and were again used. The long pusher pedestal had functioned correctly in model testing and every confidence was held that they would function correctly with the full scale vehicles.

The propellant performance had been markedly improved by the addition of aluminum powder and the nozzle performance had been improved with elimination of the erosion problem.

10.4.1 PROGRAM TEST FIRING RESULTS

SHOT #1 MARTLET IIIB Arvida July 15, 1964

a) Basic Data

Vehicle Weight	314.0 lbs.
Projectile Weight	666.6 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	365.0 lbs. (WM .245)
Payload	3 - Magnetometers
	1 - Rocket pressure gauge Telemetry Package

b) Predicted Interior Ballistics

Muzzle Velocity	3,600 fps
Maximum Breech Pressure	26,000 psi
Maximum Acceleration	6,600 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,600
Ignition	14.0	34,500	9,980	1,930
Burn Out	23.3	61,485	19,315	4,409
Apogee	150.5	315,326	202,151	1,434
Impact	206.6	0	405,069	2,310

d) Results

Muzzle Velocity	~~3,730~~ 3350 fps
Maximum Breech Pressure	27,300 psi
Maximum Acceleration	6,900 "g"

Vehicle launched with damage

e) Discussion

From the high speed cameras and visual observations (as well as audio) the rocket emerged from the muzzle already ignited. The motor appeared to function correctly despite the pre-ignition although, positive confirmation could not be made. Tracking instrumentation was unable to readjust quickly enough to acquire the vehicle. The telemetry did not transmit any signals. On close examination of the photographs, it became evident that considerable damage had been done to the vehicle in the barrel. One fin had been removed and was recovered. The antennae was badly damaged which accounted for lack of telemetry signal.

f) Conclusion

It was concluded that through poor obturation, gases from the burning gun propellant had leaked past the obruator and into the motor cavity causing pre-ignition.

The ignited rocket had lifted partially clear of the sabotry while in the barrel and resulting damage had occurred. The vehicle structure appeared to have performed adequately despite the loss of one stabilizing fin.

The cause of the poor obturation was concluded to be lack of interference between the rear polyethylene sealing obturator and the gun bore. The obturator had been manufactured to incorporate approximately 0.050" interference between the disc and bore. Due to a series of shots just preceding this test, the gun bore had increased in diameter to a point where only approximately 0.020" interference remained.

g) Action

A new obturator was manufactured to incorporate a larger interference.

In order to prevent any possible leakage of gun gases through the nozzle the slots in the pusher pedestal were blanked off by inserting a tight fitting block of wood in the central cavity of the pedestal.

The next shot was a continuation of the series with increased charge.

SMEAR PHOTO SHOWING PRE IGNITION
AND ANTENNA DAMAGE

FIGURE 20A

10.4.2 PROGRAM TEST FIRING RESULTS

SHOT #2 MARTLET IIIB Escuminac July 17, 1964

a) Basic Data

Vehicle Weight	313.5 lbs.
Projectile Weight	746.0 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	400.0 lbs. (WM .245)
Payload	3 - Magnetometers
	1 - Rocket burning pressure gauge Telemetry Package

b) Predicted Interior Ballistics

Muzzle Velocity	4,000 fps
Maximum Breech Pressure	35,000 psi
Maximum Acceleration	7,900 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	4,000
Ignition	14.0	38,934	11,167	2,234
Burn Out	23.3	68,788	21,196	4,754
Apogee	163.4	374,425	234,771	1,522
Impact	321.8	0	470,153	2,653

d) Results

Muzzle Velocity	(Not recorded)
Maximum Breech Pressure	34,800 psi
Maximum Acceleration	7,850 "g"

Vehicle disintegrated in gun

e) Discussion

Despite the modifications made in the light of the previous shot, the vehicle disintegrated. The nose cone emerged apparently intact since weak telemetry signals were picked up. It was not clear what had caused the failure. It was felt that if the rocket motor was auto igniting by some means, the modifications which had been performed would have in effect made the vehicle a sealed pressure vessel. The accelerating forces of the gun gases would have forced the vehicle against the pusher pedestal thus, sealing any possible large scale gas flow side ways. The slots in the pusher pedestal, as well as the central cavity, had been filled thus, removing any volume into which gas could flow. If this set of circumstances occurred then the auto ignited vehicle would have been able to generate sufficient pressure to burst the rocket case.

The high speed photographs indicate only fragments emerging from the muzzle. It was impossible to detect the mode of failure from them. The recovered fragments while badly mangled and torn did not give any positive indication of failure mode.

f) Conclusion

The actual mode of failure was indeterminate. Grain collapse and self-ignition was suspected. Due to the high launch acceleration the fuse which was rated at 7,500 "g's" also became suspect.

g) Action

A dummy nose cone machined from solid bar stock aluminum was substituted for the experimental nose cones and the series was continued at an intermediate charge to attempt to pin down the failure mechanism. The wood plug was removed from the pusher pedestal but the higher interference obturator was retained.

SMEAR PHOTO OF SHOT NO. 2
TYPICAL OF CATASTROPHIC FAILURES

FIGURE 20B

10.4.3 PROGRAM TEST FIRING RESULTS

SHOT #3 MARTLET IIIB MTV I July 18, 1965

a) Basic Data

Vehicle Weight	309.5 lbs.
Projectile Weight	688.5 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	385.0 lbs. (WM .245)
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	3,800 fps
Maximum Breech Pressure	31,000 psi
Maximum Acceleration	7,100 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,800
Ignition	14.0	36,717	10,571	2,079
Burn Out	23.3	65,098	20,242	4,579
Apogee	156.9	344,137	218,039	1,478
Impact	309.1	0	436,835	2,481

d) Results

Muzzle Velocity	(Not recorded)
Maximum Breech Pressure	30,800 psi
Maximum Acceleration	7,100 "g"

Vehicle disintegrated in the gun

e) Discussion

From high speed camera photographs and fragments of the vehicle which were recovered, it was evident that the vehicle had again disintegrated deep in the barrel. Neither the photographs or fragments offered any positive identification of failure mechanism. The launch acceleration was well below the design limit although, above the level of Shot #1 which was partially successful. The problem of obturation from gun gases was a possible cause of failure although, indications were more that the rocket propellant was malfunctioning.

f) Conclusion

No positive conclusion could be made with regard to the cause of failure of the vehicle. It was felt that the double base propellant possibly would not sustain the launch accelerations as had been hoped for.

g) Action

The first of the vehicles with Picatinny Arsenal propellant and nozzles was then scheduled at a reduced gun charge. An aluminum cone was fitted in the pusher pedestal. When the vehicle was assembled with the pusher sabot, the aluminum cone protruded into the expansion cone of the nozzle. The cone which incorporated an "O" ring seal was fabricated and fitted to block any possible gun gases from reaching the rocket motor.

Again, a solid aluminum dummy nose cone was mounted.

10.4.4 PROGRAM TEST FIRING RESULTS

SHOT #4 MARTLET IIIB MTV 2 July 20, 1964

a) Basic Data

Vehicle Weight	318.25 lbs.
Projectile Weight	683.75 lbs.
Motor Weight	112.0 lbs.
Gun Propellant Weight	375 lbs. (WM .245)
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	3,700 fps
Maximum Breech Pressure	29,000 psi
Maximum Acceleration	6,900 "g"
Muzzle Elevation	75°

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,700
Ignition	14.0	35,621	10,276	2,004
Burn Out	23.3	63,281	18,775	4,493
Apogee	153.7	329,547	210,009	1,456
Impact	302.8	0	420,742	2,399

d) Results

Muzzle Velocity	(Not recorded)
Maximum Breech Pressure	29,200
Maximum Acceleration	6,900 "g"

Vehicle disintegrated

e) Discussion

The high speed cameras again indicated a catastrophic failure in the barrel despite all modifications. It was noted that the acceleration level did not vary markedly from Shot #2 (Arvida) which had been partially successful. Since the acceleration levels were approximately equal the stresses throughout the vehicle should have been essentially the same levels. It had been suggested that the motors manufactured by C.A.L. were faulty or unable to sustain the high launch acceleration. If this were true, the Picatinny Arsenal motor which was mechanically stronger and thus, presumably better able to withstand the launch environment should not have failed at the same loading level at which a weaker motor had been successful. As great precautions had been taken to eliminate the possibility of gun gas pre-ignition, it was felt with justification that this was not the cause of the failure.

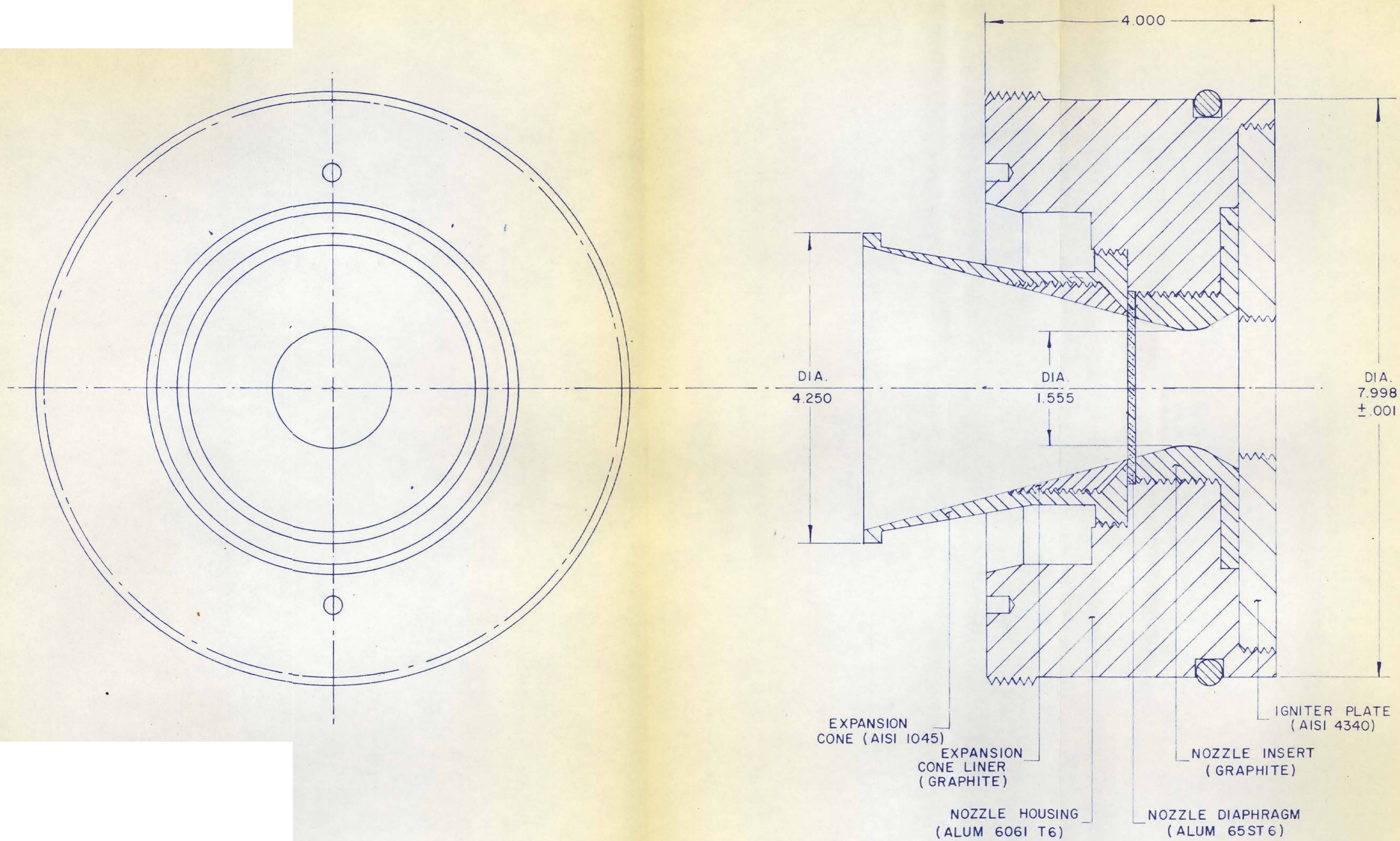
f) Conclusion

Again no definite cause of failure could be pinpointed. Obturation difficulty appeared not to be the cause of failure.

The Picatinny Arsenal grain stresses were equal approximately to the successful C.A.L. shot (Arvida). This led to the conclusion that the Picatinny Arsenal motor should have survived the launch acceleration. The possibility of bond failure was considered and the nozzle was modified to give better support.

g) Action

Another vehicle with a C.A.L. motor was scheduled at reduced charge. The nozzle housing was reworked to give a better bearing surface for the grain to rest against during launch. A steel plate of 4340 was threaded into the top of a solid aluminum housing. The regular nozzle profile was retained. The modifications are shown in Figure 21.



MARTLET 3B
MODIFIED NOZZLE

FIGURE 21

10.4.5 PROGRAM TEST FIRING RESULTS

SHOT #5 MARTLET IIIB MTV 3 July 22, 1964

a) Basic Data

Vehicle Weight	319.0 lbs.
Projectile Weight	689.0 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	365 lbs. (WM .245)
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	3,600 fps
Maximum Breech Pressure	27,000 psi
Maximum Acceleration	6,500 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,600
Ignition	14.0	34,500	9,980	1,930
Burn Out	23.3	61,485	19,315	4,409
Apogee	150,5	315,326	202,151	1,434
Impact	296.6	0	405,069	2,310

d) Results

Muzzle Velocity	(Not recorded)
Maximum Breech Pressure	26,700 psi
Maximum Acceleration	6,450 "g"

Vehicle disintegrated completely

e) Discussion

From the high speed photographs it was evident that the vehicle had failed catastrophically in the barrel in exactly the same way as the previous shot. The acceleration level was marginally below the first shot Arvida. This meant that the stresses in the motor were less than in a successful shot.

Neither the photographs or fragments offered any clue to the reason for failure.

f) Conclusion

No conclusion could be made as to the reason for failure. Rocket motor failure and self-ignition was primarily suspected.

g) Action

The next vehicle scheduled carried a Picatinny Arsenal motor. The gun charge was reduced again to try to determine the threshold for a successful flight.

10.4.6 PROGRAM TEST FIRING RESULTS

SHOT #6 MARTLET IIIB Chicoutimi July 22, 1964

a) Basic Data

Vehicle Weight	313.0 lbs.
Projectile Weight	680.0 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	310 lbs. (WM .245)
Payload	2 - Sun seekers Telemetry Package

b) Predicted Interior Ballistics

Muzzle Velocity	3,200 fps
Maximum Breech Pressure	20,000 psi
Maximum Acceleration	5,000 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,200
Ignition	14.0	30,262	8,835	1,049
Burn Out	23.3	54,509	17,550	4,083
Apogee	137.9	262,051	172,696	1,348
Impact	272.1	0	345,922	1,992

d) Results

Muzzle Velocity	~~3,150~~ 3000 fps
Maximum Breech Pressure	19,000 psi
Maximum Acceleration	4,800 "g"

Vehicle launched intact

e) Discussion

From the high speed photographs the vehicle appeared to have launched cleanly. The level of acceleration was well below the Arvida flight and in fact, below the level of acceleration of the first successful Martlet IIIA Mod.I flight.

The motor did not ignite until approximately 21 seconds after launch and the MPS 19 radar set tracked the vehicle to an apogee of 115,000 feet and back to impact at 184 seconds.* It is obvious that the planned trajectory was not followed.

The on board telemetry transmitted a weak signal.

f) Conclusion

The vehicle launched intact. The ignitor malfunctioned and ignition was erratic burning with resultant poor motor performance thus, accounting for the very low apogee.

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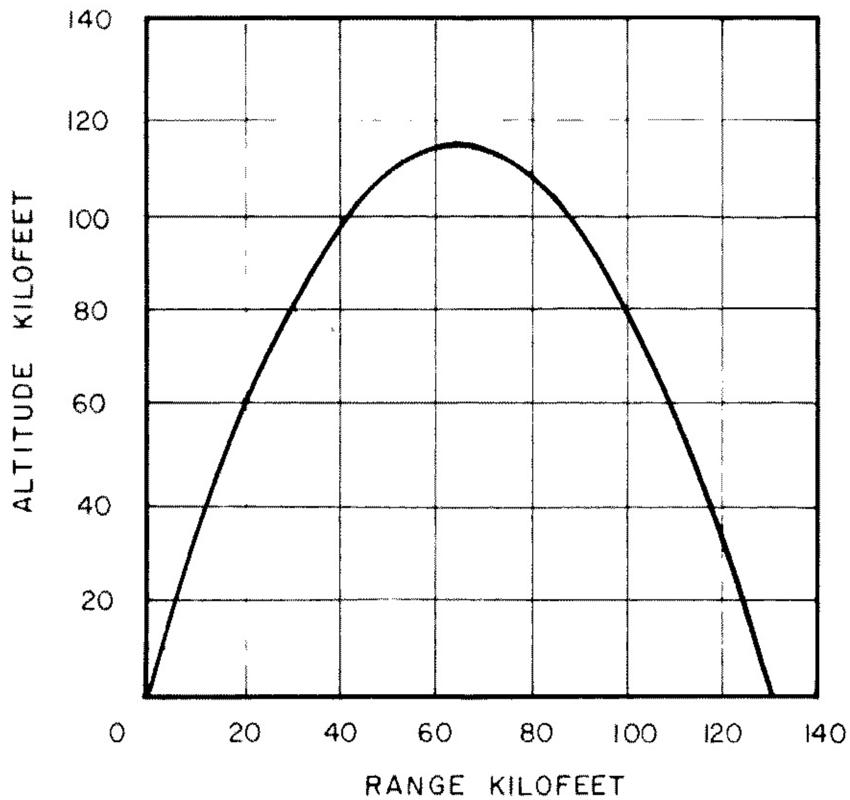
* See Figure 22



RADAR TRACK FOR VEHICLE
CHICOUTIMI

FIGURE 22

The flight pattern also indicated marginal stability.

g) Action

The next vehicle scheduled was a repeat of this test using a C.A.L. motor. However, since the ignitor may have malfunctioned, it was removed entirely in order to try to pinpoint the cause of failure.

10.4.7 PROGRAM TEST FIRING RESULTS

SHOT #7 MARTLET IIIB MTV 4 July 23, 1964

a) Basic Data

Vehicle Weight	308.0 lbs.
Projectile Weight	676.0 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	310.0 lbs.
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	3,200 fps
Maximum Breech Pressure	19,000 psi
Maximum Acceleration	4,800 "g"
Muzzle Elevation	75°

c) Predicted Exterior Ballistics

Event	Time secs	Altitude ft	Range ft	Velocity ft/sec
Launch	0	0	0	3,200
Ignition	14.0	30,262	8,835	1,049
Burn Out	23.3	54,509	17,550	4,083
Apogee	137.9	262,051	172,696	1,348
Impact	272.1		345,922	1,992

d) Results

Muzzle Velocity	(Not recorded)
Maximum Breech Pressure	18,800 psi
Maximum Acceleration	4,760 "g"

Vehicle totally disintegrated

e) Discussion

The vehicle failed in the barrel much the same as the other failures had occurred. The ignitor apparently had no bearing on the failure mechanism since the vehicle failed without an ignitor aboard. The level of acceleration was lower than the previous flight indicating that C.A.L. motors were inferior to Picatinny Arsenal motors. The level of acceleration had been successfully exceeded in two previous tests, Shot #1 Arvida, and Shot #1 of the January 1964 series, using an aluminum vehicle.

f) Conclusion

Several pieces of the rear portion of the rocket motor propellant were recovered. These fragments indicated severe plastic shear flow of the propellant at the center of the grain. It was then postulated that the motor under launch conditions was extruding into the nozzle throat and auto-igniting probably due to friction heating.

g) Action

The series proceeded with the charge reduced for the next round in order to determine the level at which failures could be overcome.

10.4.8 PROGRAM TEST FIRING RESULTS

SHOT #8 MARTLET IIIB Brome July 23, 1964

a) Basic Data

Vehicle Weight	306.0 lbs.
Projectile Weight	666.5 lbs.
Motor Weight	112.0 lbs. (Picatinny Arsenal)
Gun Propellant Weight	275.0 lbs. (WM .245)
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	~~2,900~~ 2750 fps
Maximum Breech Pressure	16,000 psi
Maximum Acceleration	4,100 "g"
Muzzle Elevation	75^o

c) Predicted External Ballistics

Unfortunately in compiling predicted launch conditions with the IBM computer no attempt was made to include a range of velocities below 3,000 fps since vehicles had already flown at velocities well above 3,000 fps. Consequently, predicted exterior ballistics were not available at launch time.

d) Results

Muzzle Velocity	2,900 fps
Maximum Breech Pressure	15,470 psi
Maximum Acceleration	4,050 "g"

Vehicle launched intact

e) Discussion

From the photographs, the vehicle appeared to have launched intact, however, one fin was detached and was later recovered. The motor ignited at the correct time and burning appeared regular. The flight path appeared most irregular. The vehicle described a large spiral just after ignition and appeared to stabilize towards the end of the burning period. The trajectory was well below that which would normally be expected. Consequently, the vehicle was not tracked.

f) Conclusion

The vehicle launched properly. The combination of low launch velocity (hence very low velocity at motor ignition) and loss of a fin caused a coning action which was evidenced by the spiral trail just after ignition.

The Picatinny Arsenal motor appeared to perform better than the C.A.L. motor at equivalent launch accelerations.

g) Action

The series continued with the next shot scheduled using a C.A.L. motor with further reduced charge.

10.4.9 PROGRAM TEST FIRING RESULTS

SHOT #9 MARTLET IIIB MTV 5 July 24, 1964

a) Basic Data

Vehicle Weight	329.0 lbs.
Projectile Weight	700.5 lbs.
Motor Weight	103.0 lbs.
Gun Propellant Weight	240.0 lbs. (WM .245)
Payload	Dummy Nose Cone

b) Predicted Interior Ballistics

Muzzle Velocity	~~2,600~~ 2500 fps
Maximum Breech Pressure	11,000 psi
Maximum Acceleration	2,800 "g"
Muzzle Extension	75^{o}

c) Predicted Exterior Ballistics

Unfortunately, in compiling predicted launch conditions with the IBM computer no attempt was made to include a range of velocities below 3,000 fps since vehicles had already flown at velocities well above 3,000 fps. Consequently, predicted exterior ballistics were not available at launch time.

d) Results

Muzzle Velocity	2,620 fps
Maximum Breech Pressure	10,900 psi
Maximum Acceleration	2,800 "g"

Vehicle launched intact

e) Discussion

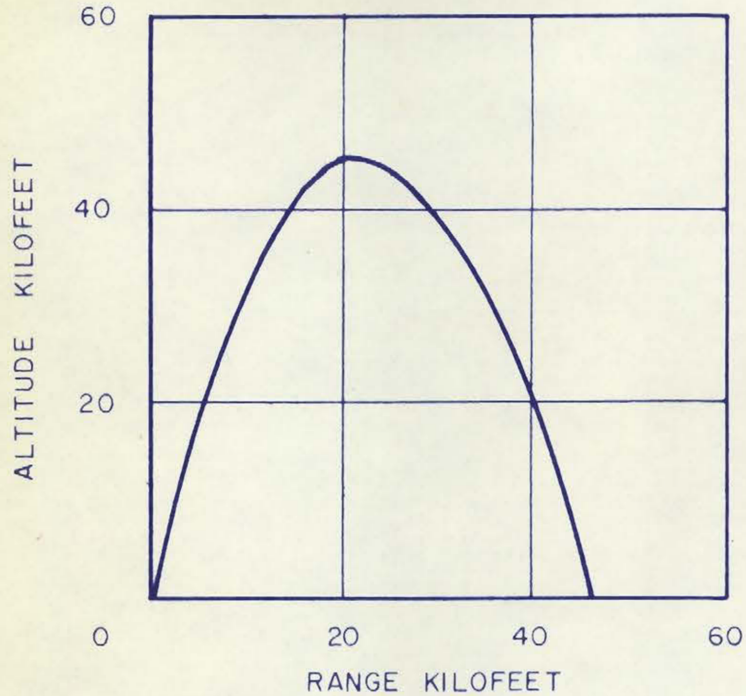
The vehicle launched cleanly with no fin damage at a low velocity as determined by the high speed photographs.

The motor did not ignite or burn. The MPS 19 radar tracked the vehicle to an apogee of 50,000 feet and back to impact some 113 seconds after launch.

The acceleration level was less than half that of other vehicles which had been flown successfully.

f) Conclusion

The ignitor or obturator in the nozzle had failed resulting in non-ignition. The vehicle was launched perfectly without any damage to fins.

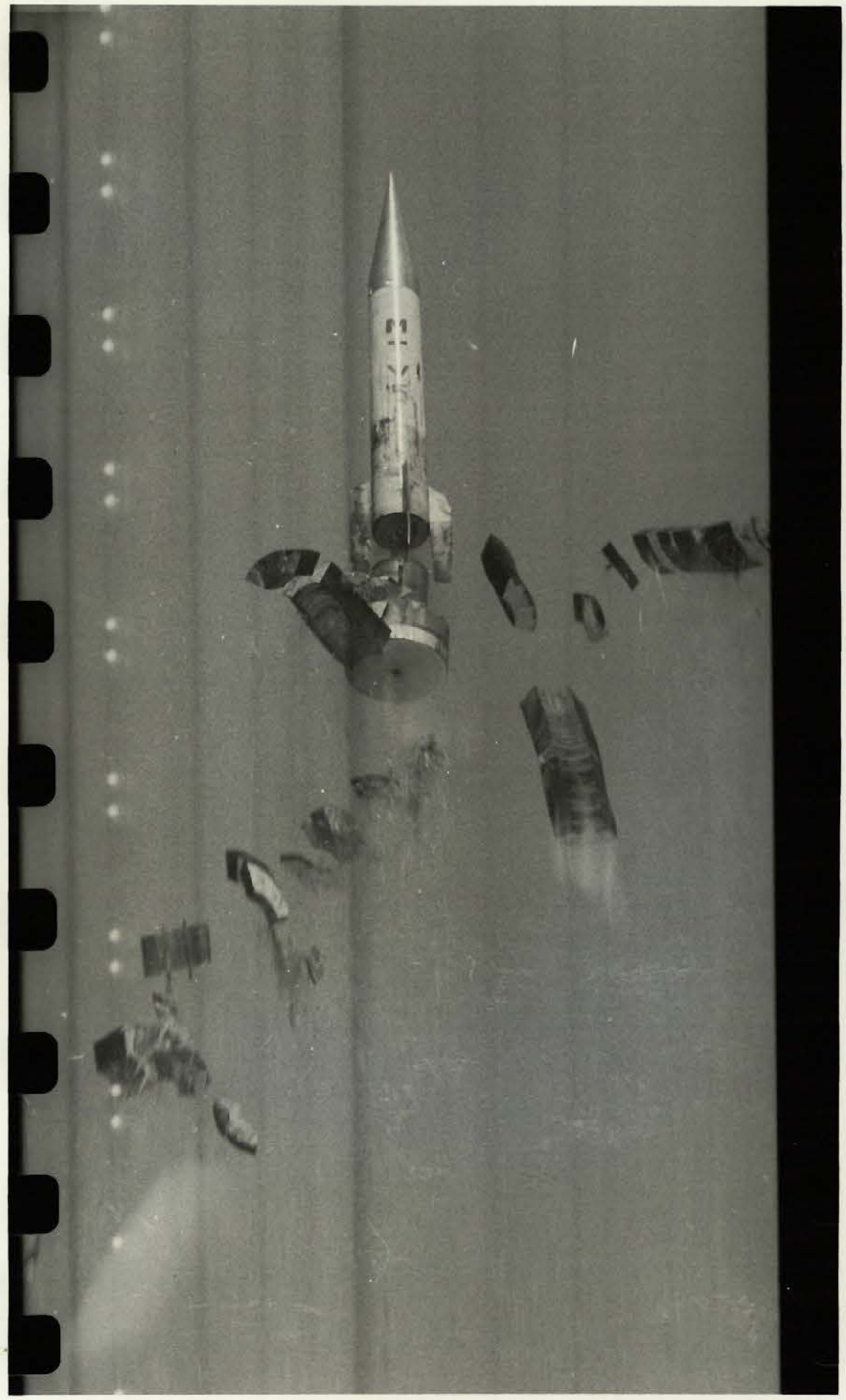


RADAR TRACK FOR MOTOR
TEST VEHICLE
NUMBER 5

FIGURE 23

g) Action

The series returned to the final vehicle with a Picatinny Arsenal motor. It was planned to increase the charge slightly.



SMEAR PHOTO OF SHOT 9

FIGURE 23A

10.4.10 PROGRAM TEST FIRING RESULTS

SHOT #10 MARTLET IIIB Fontainbleau July 24, 1964

a) Basic Data

Vehicle Weight	315.0 lbs.
Projectile Weight	679.0 lbs.
Motor Weight	112.0 lbs.
Gun Propellant Weight	255.0 lbs.
Payload	2 - Sun seekers Telemetry Package

b) Predicted Interior Ballistics

Muzzle Velocity	2,600 fps
Maximum Breech Pressure	13,500 psi
Maximum Acceleration	3,500 "g"
Muzzle Elevation	75^{o}

c) Predicted Exterior Ballistics

Unfortunately, in compiling predicted launch conditions with the IBM computer no attempt was made to include a range of velocities below 3,000 fps since vehicles had already flown at velocities well above 3,000 fps. Consequently, predicted exterior ballistics were not available at launch time.

d) Results

Muzzle Velocity	2,550 fps
Maximum Breech Pressure	13,300 psi
Maximum Acceleration	3,460 "g"

Vehicle launched intact

e) Discussion

The photographs indicated a clean launch at relatively low velocity. The motor ignited at the proper time and burning was regular. The flight was irregular and visual observations indicated the vehicle far off expected trajectory. This was later confirmed by the recovery of the vehicle fragments which had impacted on the island.

The sun seekers and telemetry functioned well.

f) Conclusion

The vehicle which launched cleanly, was unstable at ignition. This condition occurred probably when the vehicle passed through the transonic speed range. Due to the very low launch velocity (which could not be exceeded due to launch acceleration limitations) and the drag forces, the vehicle velocity fell into the transonic range inducing instability and a coning action.

SMEAR PHOTO OF SHOT NO. 10

FIGURE 23B

The motor ignited at the instant the vehicle's path intersected the island of Barbados. The vehicle then accelerated under the rocket thrust and impacted on land.

g) Action

Since higher launch velocities could not be obtained it was decided to discontinue the series of shots.

10.5 Conclusions

It was concluded that a very serious problem existed with the center cavity type of rocket motor. At launch, the propellant was extruding or collapsing into the nozzle throat opening and then igniting, causing a catastrophic failure. The level of acceleration at which failure did not occur was very low resulting in very low launch velocities and poor overall performance. It was concluded that center cavity rocket grains were not suited for use in gun launched projectiles and that any further efforts to rocket assist a projectile should be made with solid motors supported at the base.

The vehicle structure appeared to function correctly except for the loss of stabilizing fins in certain cases. It was felt that heavier welds would solve this problem.

Obturation of the gun gases had been a first thought the cause of the failures but with modifications to prevent any leakage this theory was discarded.

It is interesting to note the shear stress level at the motor case wall and to compare it to the previous series of shots.

Shot #1	Arvida = 795 psi	Partial success
Shot #2	Escuminac = 920 psi	Failure
Shot #3	MTV I = 830 psi	Failure
Shot #4	MTV 2 = 805 psi*	Failure
Shot #5	MTV 3 = 755 psi	Failure
Shot #6	Chicoutimi = 560 psi*	Successful launch
Shot #7	MTV 4 = 555 psi	Failure
Shot #8	Brome = 475 psi*	Successful launch
Shot #9	MTV 5 = 330 psi	Successful launch
Shot #10	Fountainbleau = 405 psi*	Successful launch

* denotes Picatinny Arsenal Motor

In all cases, the shear stress was under that expected for the bonding material indicating that bond failure was not the cause of the vehicle malfunction.

11. FINAL TEST SERIES AND CONCLUSIONS

The remaining two vehicles were modified and two more fabricated with exactly similar dimensions to the flight vehicles just flown. A brief series of four shots were performed in order to confirm the previous conclusions. The series was written up in detail in references 25, 26.

An outline of the experiments is presented here.

The two remaining vehicles were modified as follows. The dummy nose cones were removed and replaced by light-weight caps. At launch these caps could not cause the motor case to fail as had been suggested because of the low stresses generated. The nozzles were capped with steel plates effectively sealing the base of the vehicle from any hot gas leakage. The vehicles were fired at 9500 and 6150 "g's" respectively and both suffered catastrophic failures similar to previous failures.

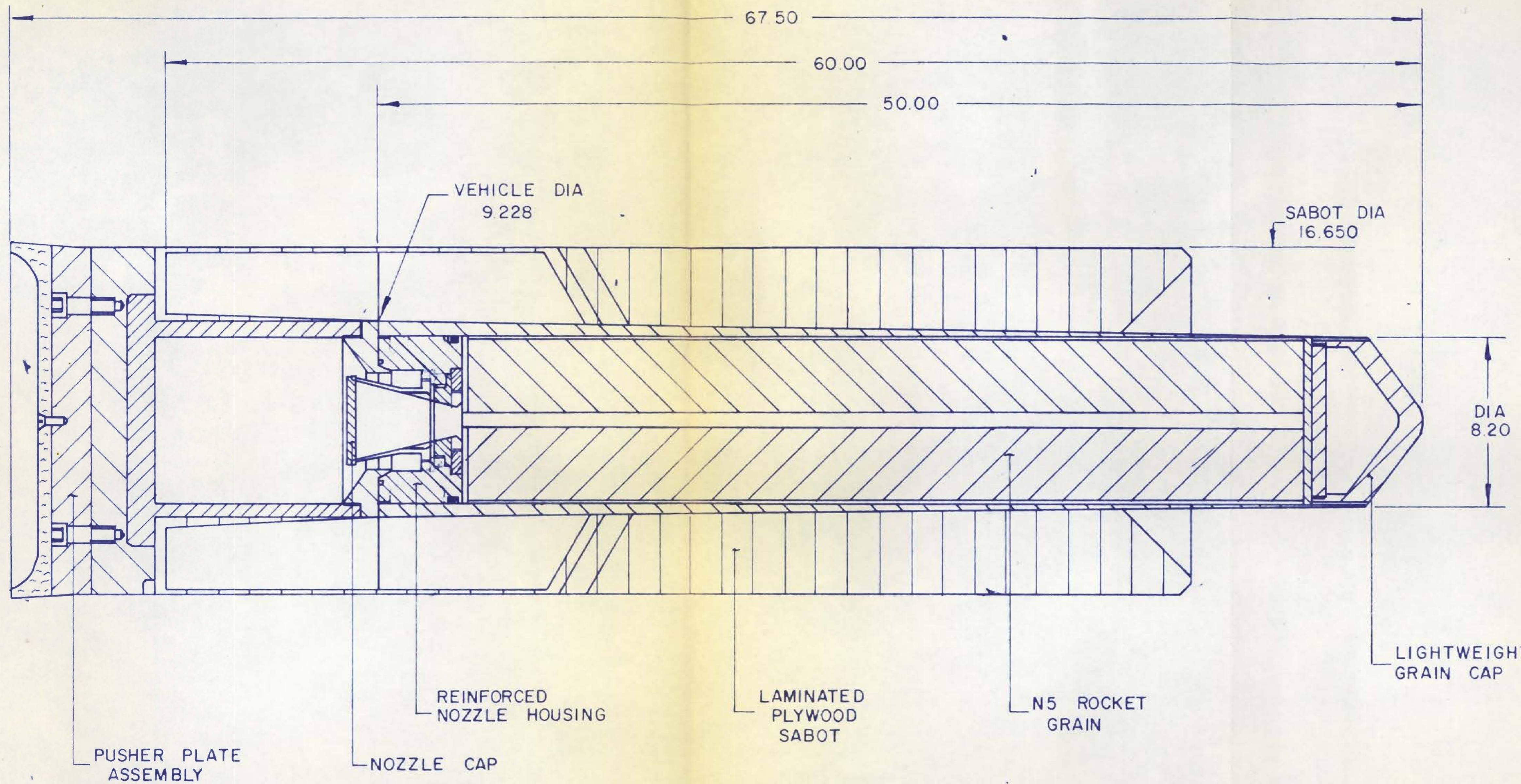
The two new vehicles were exact duplicates of previous vehicles complete with dummy nose cones. In place of a regular propellant motor, a dummy motor of the same weight was fabricated and bonded into the vehicle, as the regular motors had been, after wrapping with ethyl cellu-lose tape. The vehicles were launched at 6800 and 10,500 "g's" respectively. The first vehicle launched cleanly with only the loss of a fin. The second vehicle launched cleanly, but the nose cone was detached along again with one fin. The fact that the nose cone was detached is inconclusive since the vehicle was launched at an acceleration level slightly over the maximum designed limit. However, the fact that the motor case remained intact and was not fragmented at that "g" level indicates that structural failure was not the cause of the failures.

The success of these rounds indicates that the sabots could not have caused failure.

Again the possibility of gun gas leakage causing the failures had been eliminated by capping the nozzles.

Since no igniter was aboard during any of the four tests, it was positively concluded that the ignitor was not the cause of failure.

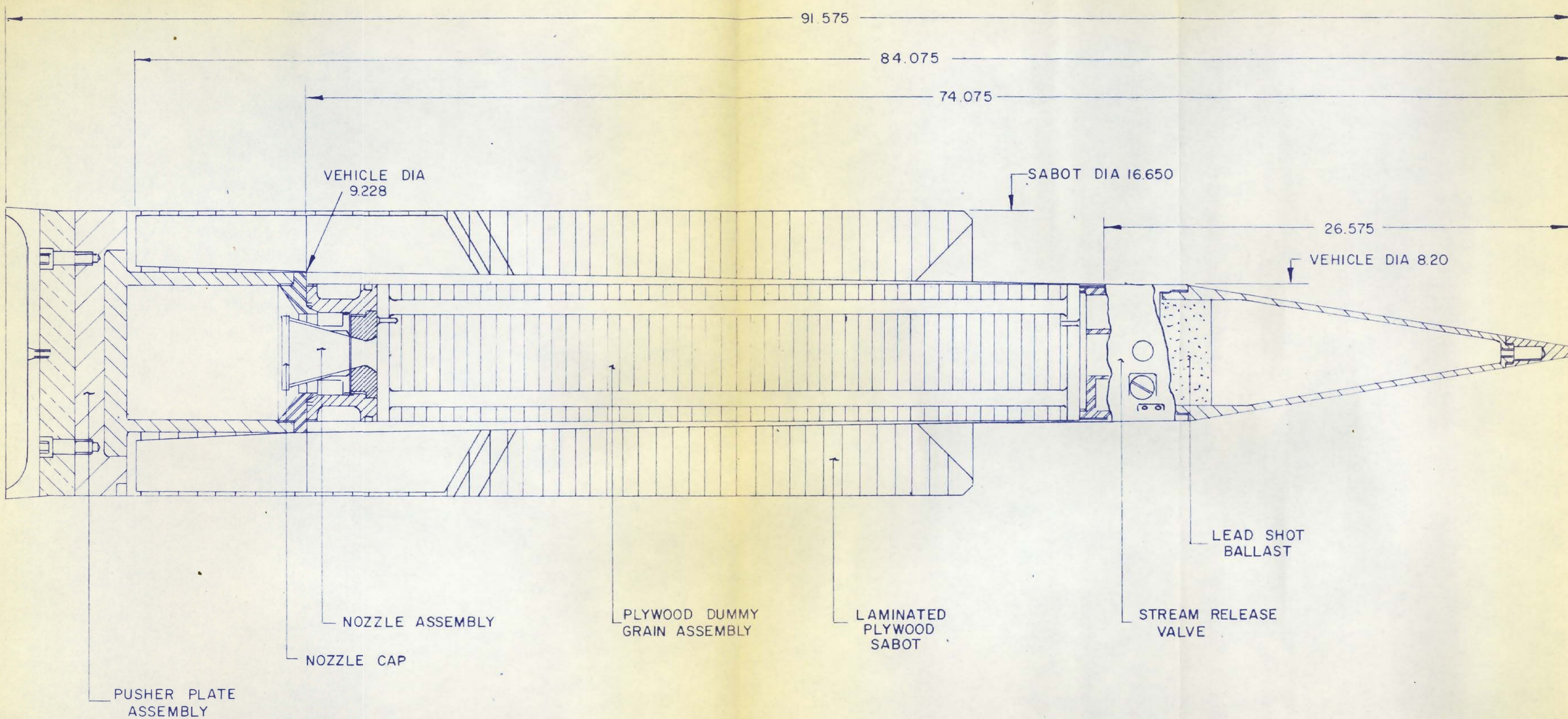
The bond strength generated in the two final tests 795 psi (shear) and 1230 psi (shear) indicates that the bonding material behaved as was anticipated.



MARTLET 3B
MODIFIED ASSEMBLY

LIGHTWEIGHT CONE
NOZZLE CAPPED
NO IGNITION

FIGURE 24



MARTLET 3B
MODIFIED ASSEMBLY

DUMMY CONE
DUMMY GRAIN
NO IGNITOR

FIGURE 25

12. SUMMARY OF DEVELOPMENT

The initial objective of launching a rocket boosted projectile from a smooth bore cannon was achieved. The launching factor of performance was the rocket propellant.

In the development of the program, the following facts were established:

1) Side Sabotry - Laminated plywood sabots perform well in the launch regime encountered by these tests. Solid grained wood sabots are totally unreliable. Wide slots for the fins helps to alleviate the problem of fin clipping, due to petalling sabots.

2) Pusher Sabots - Pusher sabots should have a length to diameter ratio of at least 0.3 in order to prevent cocking in the barrel during loading or at launch.

3) Materials - No component should be expected to carry more than static ultimate stresses notwithstanding the possibility of increased performance due to high rates of strain.

4) Structures and Components - The graphite nozzle linings perform well in limiting nozzle erosion.

As well, graphite survives the high launch acceleration. The bond technique used provides bond strengths equalling the static test levels achieved.

The ignition system used is reliable both in static and dynamic tests.

Fin attachment via slots is weak and easily damaged. Long overhanging fins with an enclosed pusher pedestal are undesirable. For better stability and more reliable retention of fin at launch, flip-out fins are suggested.

The antenna performs adequately.

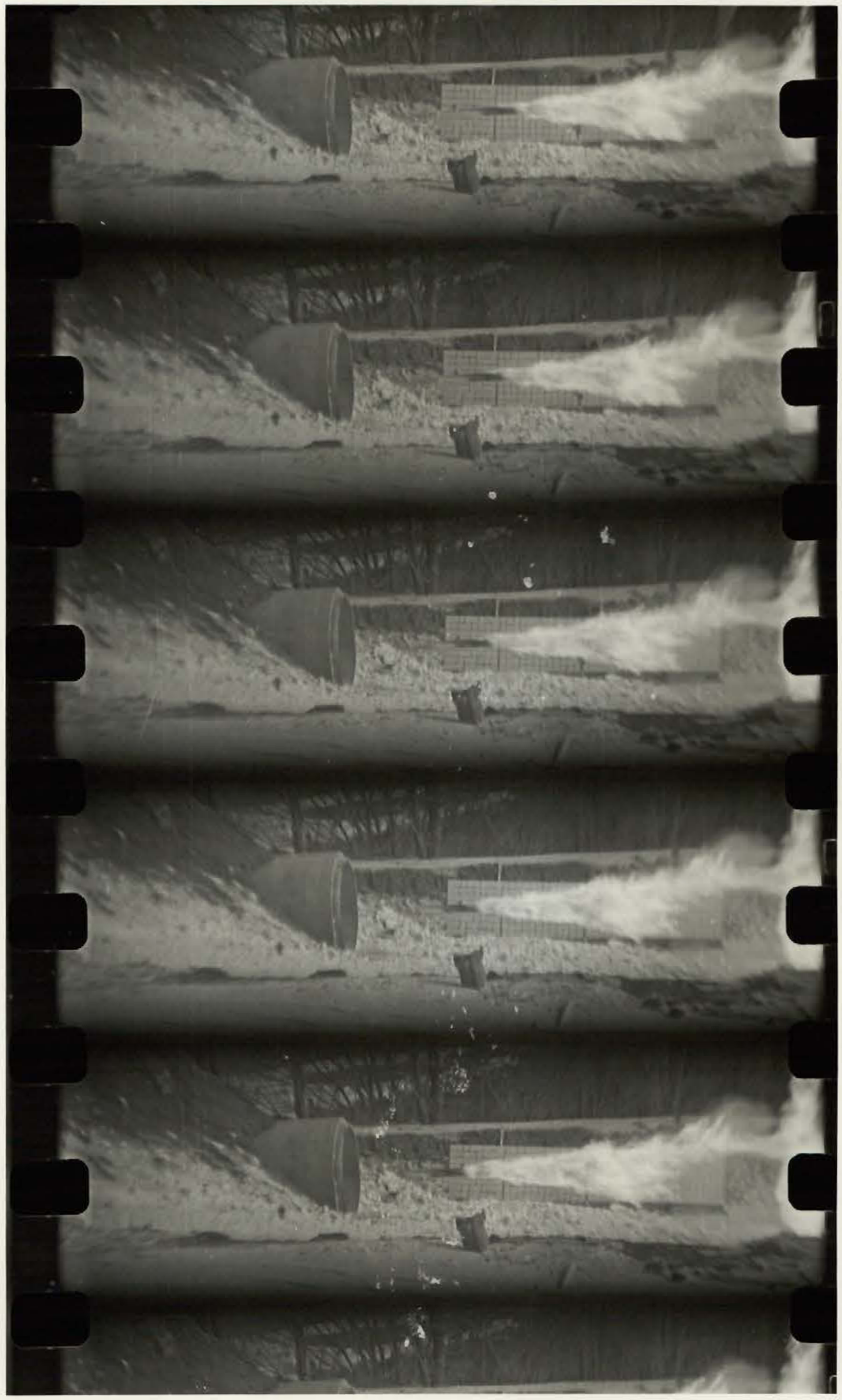
5) Rocket Propellant - Double base propellant with center cavity does not lend itself to wall bond support techniques in the gun launch environment. It is apparently unable to sustain more than 300 - 400 psi in shear at any section. The weakness of the propellant limits the overall vehicle performance to an extent that it does not achieve altitudes of scientific interest. It is therefore, felt that no further development should be undertaken on the present concept.

13. CONTINUING PROGRAM

Preliminary work carried out in the HARP 6" testing facility at Highwater has indicated that solid motors have promising performance from the point of view of ability to withstand high launch accelerations.

In three preliminary tests the following results were obtained. A 5" diameter by 40" long solid motor was assembly (no interference fit) into an aluminum case. The first vehicle was allowed to temperature cycle several times between - 30^{o}F and 80^{o}F and was then fired. It disintegrated much as the previous vehicles had done. The second and third rounds were handled very carefully and not cycled more than $\pm$ 10^{o} about 65^{o}F mean. Both of these vehicles were launched intact at acceleration levels of approximately 9000 "g's".

It is felt that this concept offers excellent potential for rocket vehicle improvement.



TEST VEHICLE WITH SOLID GRAIN
LAUNCH ACCELERATION 9000 "g"

FIGURE 25A

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TABLE I

BRAND	TYPE	STRENGTH (shear)	
Epoxy Products	#2200/#125	953 psi	Best-easy to handle
Shell Canada	A8	830 psi	Good-difficult to handle
Bostic	G-5-2omD5-50	Low	Poor
Xylors Rubber	Loxtite 602-621	Low	Poor

APPENDIX I

ROCKET MOTOR STATIC TESTS

STATIC FIRING #1

Purpose:	Instrumentation check-out
Date:	June 15, 1963
Propellant:	N5
Nozzle:	1.275" dia. throat (start) 1.432" dia. throat (finish)
Nozzle Material:	Tool Steel - Ultimo-4 (Atlas)
Divergent Section:	Nil
Grain Weight:	53.7 lbs.
Grain Diameter:	5.86"
Grain Length:	40"
Grain Configuration:	Internal star 8 point Major O.D. - 2.15" Minor O.D. - 1.50"
Pressure Time Integral:	
Burning Time:	
Total Impluse:	
Specific Impulse:	
Burning Pressure:	
Thrust:	
Remarks:	Instrumentation failed, but motor appeared to function correctly. Burn time measured with stop watch was 4.9 secs.

STATIC FIRING #2

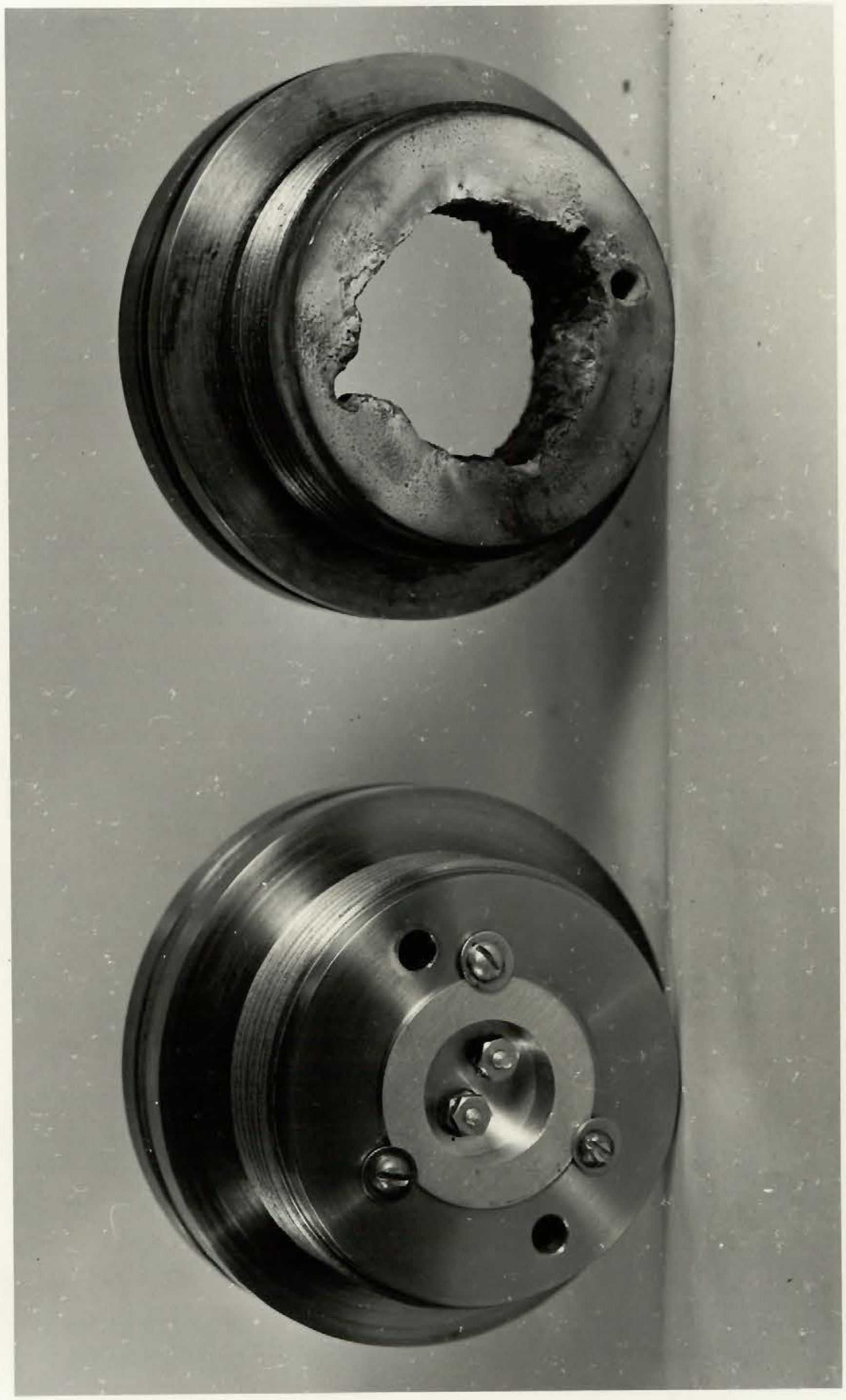
Purpose:	Instrumentation check-out
Date:	June 17, 1963
Propellant:	N5
Nozzle:	1.275" dia. throat (start) 1.437" dia. throat (finish)
Nozzle Material:	Tool Steel - Ultimo-4 (Atlas)
Divergent Section:	Nil
Grain Weight:	53.7 lbs.
Grain Diameter:	5.86"
Grain Length:	40"
Grain Configuration:	Internal star 8 point Major O.D. - 2.15" Minor O.D. - 1.50"
Pressure Time Integral:	4911 lb. secs. per sq. in.
Burning Time:	4.9 secs.
Total Impulse:	10,963 lbs. (f) secs.
Specific Impulse:	204 lbs. (f) secs. per lb.

TIME	PRESSURE	THRUST
0.04 secs.	600 lbs/sq.in	975 lbs.
1.00 secs.	850 lbs/sq.in	1500 lbs.
2.00 secs.	1100 lbs/sq.in	1775 lbs.
3.00 secs.	1275 lbs/sq.in	2450 lbs.
4.00 secs.	1350 lbs/sq.in	2950 lbs.
4.60 secs.	1350 lbs/sq.in	3000 lbs.

Discharge Coefficient: 7.42×10^{-3}

Thrust Coefficient: 1.51

Remarks: The test was successful. The ignition, obturator and nozzle performed well. The nozzle was subject to heavy erosion but rocket performance not too much effected.



TOOL STEEL NOZZLE BEFORE AND AFTER FIRING - 6" N5 MOTOR

FIGURE 26A

STATIC FIRING #3

Purpose:	Test X8 grain
Date:	June 26, 1963
Propellant:	X8
Nozzle:	1.55" dia. throat (start) 1.79" dia. throat (finish)
Nozzle Material:	Tool Steel Keewatin (Atlas)
Divergent Section:	1.55" dia. throat to 4.06 dia. exit
Grain Weight:	56¼ lbs.
Grain Diameter:	5.83"
Grain Length:	40"
Grain Configuration:	Internal star 8 point Major I.D. - 2.200 Minor I.D. - 1.376
Pressure Time Integral:	2991 lb. sec. per sq. in.
Burning Time:	2.77 secs. (pressure gauge) 2.85 secs. (thrust gauge)
Specific Impulse:	196

TIME	PRESSURE	THRUST
0.04 secs.	565 lbs/sq.in.	2626 lbs.
1.00 secs.	904 lbs/sq.in.	3232 lbs.
2.00 secs.	994 lbs/sq.in.	4646 lbs.
2.50 secs.	1605 lbs/sq.in.	6262 lbs.

Discharge Coefficient:	8.7×10^{-3}
Thrust Coefficient:	1.67
Total Impulse:	10,997 lbs.secs.
Average Thrust:	3859 lbs.

Remarks: In order to achieve better performance, a new propellant X8 was tested. It was basically the same as N5 but slightly more powerful. Again, the test was successful from all points of view. The nozzle material was changed to a high speed tool steel but erosion still was considerable.

STATIC FIRING #4

Purpose:	Test with Reduced Throat Diameter
Date:	July 3, 1963
Propellant:	X8
Nozzle:	1.45" dia. throat (start) 1.61" dia. throat (finish)
Nozzle Material:	Tool Steel Keewatin (Atlas)
Divergent Section:	1.45" dia. throat to 4.5" dia. exit
Grain Weight:	57.1 lbs.
Grain Diameter:	5.876."
Grain Length:	40"
Grain Configuration:	Major I.D. - 2.20 Minor I.D. - 1.35
Pressure Time Integral:	3676 lb. sec. per sq. in.
Burning Time:	2.82 (thrust record) 2.76 (pressure record)
Specific Impulse:	197

TIME	PRESSURE	THRUST
0.04 secs.	1726 lbs/sq.in	3832 lbs.
1.00 secs.	1315 lbs/sq.in	3832 lbs.
2.00 secs.	1397 lbs/sq.in	4819 lbs.
2.50 secs.	1370 lbs/sq.in	5056 lbs.

Discharge Coefficient:	8.4×10^{-3}
Thrust Coefficient:	1.63
Total Impulse:	11,258
Average Thrust:	3992

Remarks: In order to bring the internal burning pressure up, a nozzle of reduced diameter was tested. The test was successful. Nozzle erosion was large but predictable.

STATIC FIRING #5

Purpose:	Test with grain approx. .010" interference fit in tube.
Date:	July 16, 1963
Propellant:	X8
Nozzle:	1.450" dia. throat (start) 1.695" dia. throat (finish)
Nozzle Material:	Ultimo-4 steel (Atlas) plated with chromium .010
Divergent Section:	1.450
Grain Weight:	58.4 lbs.
Grain Diameter:	5.892"
Grain Length:	40.5"
Grain Configuration:	Internal star 8 point Major I.D. - 2.10 Minor I.D. - 1.30
Pressure Time Integral:	4512 lb. sec. per sq. in.
Burning Time:	2.66 secs. (pressure gauge) 2.67 secs. (thrust gauge)
Specific Impulse:	179.5

TIME	PRESSURE	THRUST
0.50 secs.	1166 lbs/sq.in	2928 lbs.
1.20 secs.	1496 lbs/sq.in	3660 lbs.
1.45 secs.	2178 lbs/sq.in	4978 lbs.
2.00 secs.	2178 lbs/sq.in	5270 lbs.
2.45 secs.	1826 lbs/sq.in	5380 lbs.

Discharge Coefficient:	6.62×10^{-3}
Thrust Coefficient:	1.18
Total Impulse:	10,483 lbs.secs.
Average Thrust:	3929 lbs.

Remarks: This test was made in order to monitor the burning characteristics of a grain which had an interference fit with the static test bed case. This was necessary since it had been decided to install interference fit grains in the flight vehicles. The interference was considered necessary in order to allow the bonding epoxy to be as thin as possible thus assuring the acceleration loading would be in shear not in tension or combined shear/tension.

Except for an unusual pressure rise at 1.2 seconds until 1:45 seconds when the pressure rose to 3720 psi and thrust to 7610 lbs. the test was normal and successful.

The nozzle was plated with chromium in an attempt to reduce erosion. Instead the erosion was measurably increased.

STATIC FIRING #6

Purpose:	Test of whole configuration including McGill design nozzle
Date:	July 17, 1963
Propellant:	X8
Nozzle:	1.55" dia. throat (start) 1.65" dia. throat (finish)
Nozzle Material:	
Divergent Section:	1.53" dia. throat to 4.00" dia. exit
Grain Weight:	57.3 lbs.
Grain Diameter:	5.852"
Grain Length:	40.5"
Grain Configuration:	Internal 8 point star Major I.D. - 2.15 Minor I.D. - 1.35
Pressure Time Integral:	4308
Burning Time:	2.78 secs. (pressure gauge) 2.88 secs. (thrust gauge)
Specific Impulse:	215.8

TIME	PRESSURE	THRUST
0.50 secs.	994 lbs/sq.in	3115 lbs.
1.00 secs.	1501 lbs/sq.in	3473 lbs.
1.50 secs.	1833 lbs/sq.in	4690 lbs.
2.00 secs.	1969 lbs/sq.in	5979 lbs.
2.50 secs.	1852 lbs/sq.in	6516 lbs.

Discharge Coefficient:	5.19×10^{-3}
Thrust Coefficient:	1.12
Total Impulse:	12.365 lbs.secs.
Average Thrust:	4293

Remarks: This firing was made to test the nozzle final design configuration. The nozzle material was changed to cast mild steel (SAE 1020). The erosion was reduced considerably with resulting improvement in rocket thrust.

STATIC FIRING #7

Purpose:	Test of N5 propellant with 10% Al. powder added
Date:	November 25, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.275" dia. throat (start) 2.000" dia. throat (finish)
Divergent Section:	1.275" dia. throat to N.A. dia. exit
Grain Weight:	57.3 lbs.
Grain Diameter:	5.832"
Grain Length:	40"
Pressure Time Integral:	4307 lb. sec. per sq. in.
Burning Time:	9.56 secs. (pressure gauge) 9.55 secs. (thrust gauge)
Specific Impulse:	166
Initial Thrust:	3017 lbs.
Average Thrust:	998.1 lbs.
Initial Pressure:	1773 psi
Average Pressure:	450 psi
Discharge Coefficient:	6.02×10^{-3}
Thrust Coefficient:	1.00

Remarks:

A regular mild steel casting (SAE 1020) was machined for this test. As a precaution, the convergent section was flame sprayed with a coating of Al_2O_3 in order to try to reduce erosion damage.

The coating, however, did not prevent the erosion from being excessive. The throat diameter increased from 1.275 to approximately 2.00. This reduced the motor performance to an unacceptable level as can be seen from the low specific impulse.

STATIC FIRING #8

Purpose:	Test of N5 (10% Al.) propellant with revised nozzle
Date:	November 26, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.2" dia. throat (start) 2.0" dia. throat (finish)
Divergent Section:	1.2" dia. throat to 3 15/16" dia. exit
Grain Weight:	56.8 lbs.
Grain Diameter:	5.832"
Grain Length	40"
Pressure Time Integral:	4452 lb.sec. per sq. in.
Burning Time:	9.00 sec. (pressure gauge) 9.12 secs. (thrust gauge)
Specific Impulse:	203.3 lb.sec. per lb.
Initial Thrust:	6787 lbs.
Average Thrust:	1266 lbs.
Initial Pressure:	3559 psi
Average Pressure:	495 psi
Discharge Coefficient:	5.96×10^{-3}
Thrust Coefficietn:	1.20

Remarks:

A switch was made to a modular iron type of material (Meehanite) which was reputed to have very good erosion resistance. Again it was flame sprayed with Al_2O_3. The same results were realized as in test seven, excepting that the erosion was more severe.

The throat section was eroded completely away leaving the nozzle separated in two pieced. The wall thickness at the throat was not less than 3/4".

STATIC FIRING #9

Purpose:	Test N5 (10% Al.) with ablating nozzle
Date:	December 2, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.20" dia. throat (start)
	2.25" dia. throat (finish)
Divergent Section:	
Grain Weight:	57.0 lbs.
Grain Diameter:	5.832"
Grain Length	40"
Pressure Time Integral:	
Burning Time:	.748 sec. (pressure gauge) while pressure
	.719 sec. (thrust gauge) readable
Initial Thrust:	2385 lbs.
Initial Pressure:	1713 psi

Remarks: From previous tests using the aluminized propellant, it was decided to try a nozzle of ablating material. A cast nylon nozzle impregnated with Al_2O_3 was tried with poor results. The nozzle remained intact for approximately 3/4 of a second and then eroded rapidly. Reducing the test data was impossible as the motor experienced chuffing phenomena.

STATIC FIRING #10

Purpose:	Test of regular N5 with Meehanite nozzle
Date:	December 3, 1963
Propellant:	N5 without Al.
Nozzle:	1.275" dia. throat (start)
	1.55" dia. throat (finish)
Divergent Section:	1.275" dia. throat to 4.0" dia. exit
Grain Weight:	55.0 lbs.
Grain Diameter:	5.831"
Grain Length:	40"
Pressure Time Integral:	4297 lb.sec. per sq. in.
Burning Time:	4.62 secs. (pressure gauge)
	4.65 secs. (thrust gauge)
Specific Impulse:	200.1 lb. sec. per lb.
Initial Thrust:	2309 lbs.
Thrust at 1.00 secs.	1757 lbs.
2.00 secs.	2435 lbs.
3.00 secs.	2937 lbs.
4.00 secs.	3213 lbs.
Average Thrust:	2367 lbs.
Initial Pressure:	1203 psi
Average Pressure:	930 psi
Discharge Coefficient:	8.09×10^{-3}
Thrust Coefficient:	1.61
Remarks:	Due to the pressing schedule (Test series scheduled for Jan.1, 1964) it was decided to test a regular grain (N5 - non-aluminized) in order to determine the erosion characteristics of heat treated Meehanite. This test indicated the Meehanite suffered least erosion of any material tested to date with non-aluminized propellant. On this basis, it was decided to conduct the next series of tests using Meehanite nozzles and regular N5 propellant.

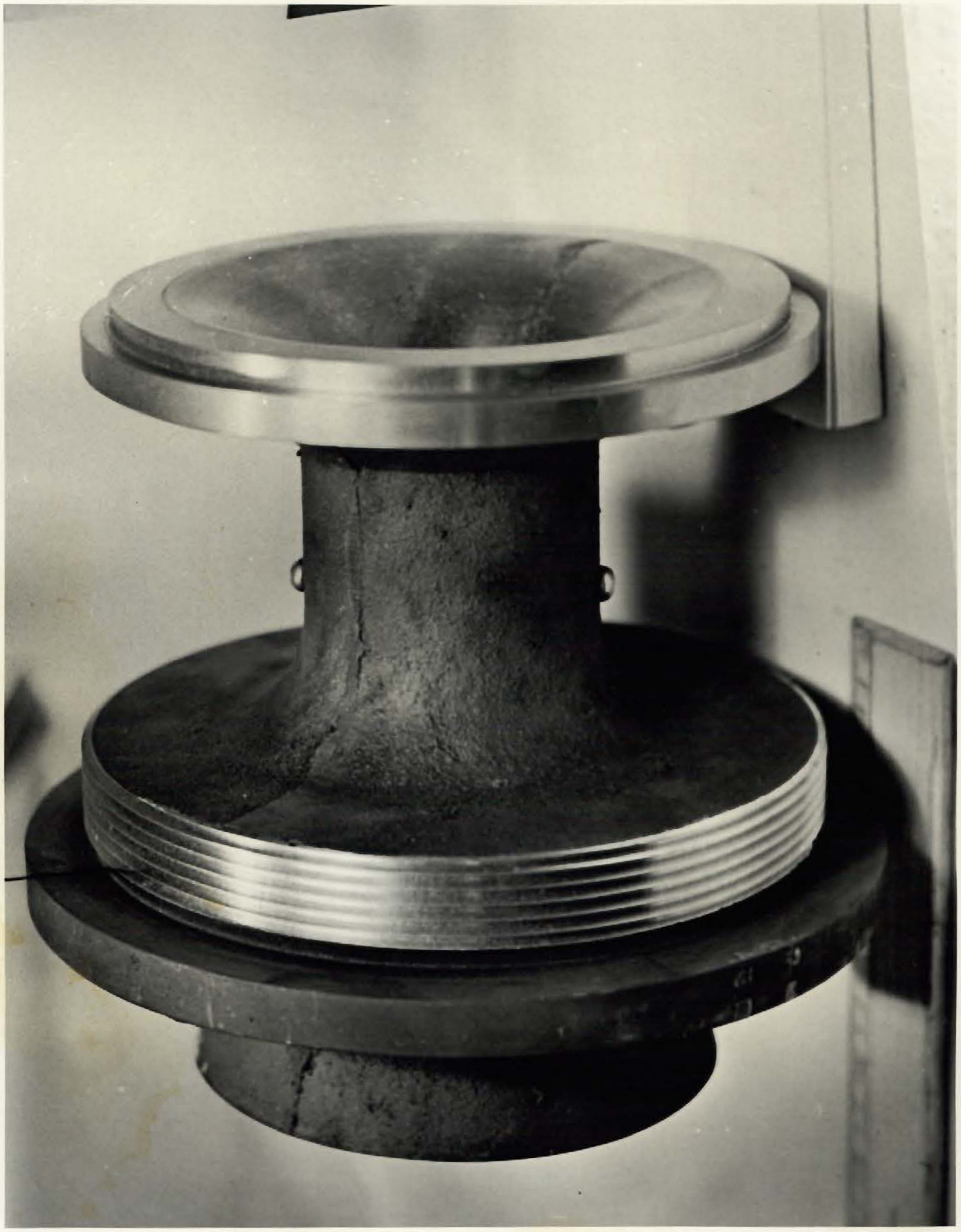
STATIC FIRING #11

Purpose:	Confirmation of test #10
Date:	December 9, 1963
Propellant:	N5 without Al.
Nozzle:	1.275" dia. throat (start) 1.59" dia. throat (finish)
Divergent Section:	1.275" dia. throat to 4" dia. exit
Grain Weight:	57.5 lbs.
Grain Diameter:	5.896"
Grain Length	40"
Pressure Time Integral:	4152 lb. sec. per sq. in.
Burning Time:	4.62 sec. (pressure gauge) 4.72 sec. (thrust gauge)
Specific Impulse:	190.3 lbs. sec. per lb.
Initial Thrust:	1781 lbs.
Thrust at 1.00 sec.	1879 lbs.
2.00 sec.	2342 lbs.
3.00 sec.	2513 lbs.
4.00 sec.	3416 lbs.
Average Thrust:	2318 lbs.
Initial Pressure:	1065 psi
Average Pressure:	899 psi
Discharge Coefficient:	8.69×10^{-3}
Thrust Coefficient:	1.62

Remarks:

An unusual thrust peak (5175 lbs) and pressurepeak (1840 psi) occurred at 3.68 seconds.

The test was conducted to confirm the previous result obtained with the Meehanite nozzle. It can be seen that the test was successful. Heat treated Meehanite material was measurably better in erosion resistance than unheat treated Meehanite.



MEEHANITE NOZZLE BEFORE FIRING

FIGURE 26B

STATIC FIRING #12

Purpose:	Test N5 (10% Al.) with coated Meehanite nozzle
Date:	December 12, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.2" dia. throat (start) 1.9" dia. throat (finish)
Divergent Section:	1.2" dia. throat to 4"dia. exit
Grain Weight:	57.2 lbs.
Grain Diameter:	5.832"
Grain Length:	40"
Pressure Time Integral:	3840 lbs. sec. per sq. in.
Burning Time:	8.64 sec. (pressure gauge) 8.66 sec. (thurst gauge)
Specific Impulse:	188.3
Initial Thrust:	4576
Average Thrust:	1244
Initial Pressure:	2579
Average Pressure:	444
Discharge Coefficient:	7.52×10^{-3}
Thrust Coefficient:	1.41

Remarks:

In view of the improved performance of the Meehanite material when heat treated, it was decided to conduct one more test with such a nozzle with all internal surfaces coated with .010" thick layer of Al_2O_3.

Performance was again poor and the nozzle was separated into two sections as the throat wall (3/4" thickness minimum) was eroded completely away.

MEEHANITE NOZZLE AFTER FIRING
N5 - ALUMINIZED MOTOR

FIGURE 26C

STATIC FIRING #13

Purpose:	First test of graphite nozzle
Date:	December 13, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.2" dia. throat (start)
Grain Weight:	57.5 lbs.
Grain Diameter:	5.832"
Grain Length:	40"
Pressure Time Integral:	2985
Burning Time:	2.59 sec. (pressure gauge)
	2.58 sec. (thrust gauge)
Specific Impulse:	75.4
Initial Thrust:	4040
Average Thrust:	1680
Initial Pressure:	3251
Average Pressure:	1153

Remarks:

It was decided to test a new nozzle configuration incorporating a graphite throat insert. A solid block of tool steel was machined to accept a graphite convergent section and throat. No divergent section was attached. The graphite was machined from a solid block of AGFX graphite type electrode.

The test was not successful as at about 2.5 seconds the nozzle blew out. The pressure trace indicated a nozzle blockage and the pressure rose to 4300 psi just at blow out. The motor "chuffed" several times before extinguishing.

STATIC FIRING #14

Purpose:	Test of graphite nozzle
Date:	December 20, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.5" dia. throat (start) 1.5" dia. throat (finish)
Divergent Section:	Not applicable
Grain Weight:	50.0 lbs.
Grain Diameter:	5.832"
Grain Length:	40"

1st PART OF IGNITION

Pressure Time Integral:	133 lb.sec./sq.in.
Burning Time:	.26 sec (pressure gauge) .30 sec (thrust gauge)
Impulse:	230 lb.secs.

Time between 1st and 2nd part for Pressure Curve: 2.10 secs.
Time between 1st and 2nd part for Thrust Curve: 2.05 secs.

2nd PART OF IGNITION

Pressure Time Integral:	2501 lb.sec./sq.in.
Burning Time:	6.75 sec (pressure gauge) 6.66 sec (thrust gauge)
Impulse:	8805 lb.secs.

1st & 2nd Part of Ignition Totalled

Pressure Time Integral:	3634 lb.sec./sq.in.
Burning Time:	7.01 sec (pressure gauge) 6.96 sec (thrust gauge)
Specific Impulse:	158.5 lb.sec/lb.
Initial Thrust:	1776 lbs.
Average Thrust:	1298 lbs.
Initial Pressure:	650 psi
Average Pressure:	518 psi
Discharge Coefficient:	8.88×10^{-3}
Thrust Coefficient:	1.42

REMARKS: In order to avoid a nozzle blow out the throat diameter was increased to 1.5 inches.

The test was unsuccessful. Ignition appeared to be poor. This may have been due to a poor ignitor or failure of the obturator. The motor re-ignited and burned out, with poor overall performance. The second ignition and burn appeared to be normal.

The nozzle suffered no erosion. From this it was assumed that the nozzle in the previous test had not suffered erosion. This would account for the high pressures generated and the nozzle blow out. The results of this test indicated a very promising solution to the throat erosion problem.

STATIC FIRING #15

Purpose:	Test of graphite nozzle
Date:	December 28, 1963
Propellant:	N5 (10% Al.)
Nozzle:	1.35" dia. throat (start) 1.35" dia. throat (finish)
Divergent Section:	Mild Steel - exit dia. 4 1/16"
Grain Weight:	57.7 lbs.
Grain Diameter:	5.831"
Grain Length:	40"
Pressure Time Integral:	5767 lb.sec./sq.in.
Burning Time:	6.31 sec (pressure gauge) 6.35 sec (thrust gauge)
Specific Impulse:	216 lb.sec/lb.
Initial Thrust:	3371 lbs.
Average Thrust:	1962 lbs.
Initial Pressure:	1782 psi
Average Pressure:	914 psi
Discharge Coefficient:	6.99×10^{-3}
Thrust Coefficient:	1.50

Remarks:

This test was conducted with a complete flight nozzle. The assembly consisted of a steel housing, graphite insert comprizing the convergent section (3½" O.D.) and throat (1.35" dia.) with a mild steel divergent section (1.35" dia. to 4 1/16" dia.)

The test was successful in all aspects. The throat section was not measurably eroded. Motor performance was improved approximately 10%.

The divergent section was badly spalled by gas flow but remained intact. Some erosion damage was evident in the convergent section at the joint between the steel housing and the graphite insert. It was not considered serious.

STATIC FIRING #16

Purpose:	To test 6" motor manufactured by lamination technique.
Date:	January 9, 1964
Propellant:	N5 laminated
Nozzle:	1.275" dia. throat (start) 1.33" dia. throat (finish)
Divergent Section:	4.0" dia. at exit
Grain Weight:	55.3 lbs.
Grain Length:	40 13/16"
Grain Diameter:	6.097"
Pressure Time Integral:	5490 lb.sec./sq.in.
Burning Time Pressure:	4.82 sec.
Burning Time Thrust:	4.91 sec.
Total Impulse:	10.754 lbs.sec
Specific Impulse:	194 lb.sec./lb.
Initial Pressure:	542 psi
Final Pressure:	1527 psi
Average Pressure:	1139 psi
Initial Thrust:	1260 lbs.
Final Thrust:	3255 lbs.
Average Thrust:	2190 lbs.
Discharge Coefficient:	7.55×10^{-3}
Thrust Coefficient:	1.44
Remarks:	The motor performed perfectly as can be seen with a comparison of a test of a regular extruded motor (static tests 10, 11)

STATIC FIRING #17

Purpose:	Test N5 (10% Al.) grain manufactured by lamination technique.
Date:	February 10, 1964
Propellant:	10% Al. in N5 laminated
Nozzle:	1.35" dia. throat (graphite) (start) 1.35" dia. throat (finish)
Grain Weight:	55.3 lbs.
Grain Length:	40"
Grain Diameter:	5.83"
Pressure Time Integral:	5720 lb.sec./sq.in
Burning Time Pressure:	8.05 sec.
Burning Time Thrust:	7.66 sec.
Total Impulse:	8950 lb.sec.
Specific Impulse:	162 lb.sec./lb.
Initial Pressure:	375 psi
Final Pressure:	1500 psi
Average Pressure:	710 psi
Initial Thrust:	700 lbs.
Final Thrust:	2700 lbs.
Average Thrust:	1165 lbs.
Discharge Coefficient:	6.77×10^{-3}*
Thrust Coefficient:	1.15

* Pressure trace obscure

Remarks:	The motor apparently experienced poor ignition. Serious chuffing occurred before steady burning. The nozzle was not damaged or eroded thus, indicating a failure of either obturator or ignition device.

STATIC FIRING #18

Purpose:	First firing of 8" diameter laminated motor
Date:	April 21, 1964
Propellant:	10% Al. in N5 laminated
Nozzle:	1.55" dia. throat (graphite) (start) 1.55" dia. throat (finish)
Grain Weight:	102.4 lbs.
Grain Length:	41"
Grain Diameter:	7.858"
Pressure Time Integral:	7900 lb.sec./sq.in.
Burning Time	8.52 sec.
Total Impulse:	21,550 lb.sec.
Specific Impulse:	210 lb.sec./lb.
Initial Pressure:	600 psi
Final Pressure:	1800 psi
Average Pressure:	927 psi
Initial Thrust:	2150 lb.
Final Thrust:	5375 lb.
Average Thrust:	2530 lb.
Discharge Coefficient:	7.12×10^{-3}
Thrust Coefficient:	1.50
Remarks:	The test was successful in all aspects.

STATIC FIRING #19

Purpose:	Confirmation test of 8" motor performance
Date:	May 7, 1964
Propellant:	10% Al. in N5 laminated
Nozzle:	1.55" dia. throat (graphite) (start) 1.55" dia. throat (finish)
Grain Weight:	104.9 lbs.
Grain Length:	40½"
Grain Diameter:	7.899
Pressure Time Integral:	6740 lb.sec./sq.in.
Burning Time:	9.9 sec.
Total Impulse:	19,000 lb.sec.
Specific Impulse:	181 lb.sec/lb.
Initial Pressure:*	360 psi
Final Pressure:	1350 psi
Average Pressure:	680 psi
Initial Thrust:*	1300 lbs.
Final Thrust:	3800 lbs.
Average Thrust:	1921 lbs.
Discharge Coefficient:	8.26×10^{-3}
Thrust Coefficient:	1.49

* Initial pressure and thrust measured after steady burning begins

Remarks: The ignitor appeared to malfunction. Chuffing of the motor occurred before steady burning with resultant low performance. The ignitor configuration was modified as shown in Fig.21. The divergent section of the nozzle was badly eroded near the throat. A graphite liner was included for the next test.

STATIC FIRING #20

Purpose:	Check out of new ignitor configuration
Date:	May 21, 1964
Propellant:	N5 (10% Al.) laminated
Nozzle:	1.55" dia. throat (graphite) (start) 1.55" dia. throat (finish)
Divergent Section:	Graphite & Steel - 3.895" dia. exit
Grain Weight:	105.3 lbs.
Grain Length:	40.5"
Grain Diameter:	7.898"
Pressure Time Integral:	7315 lb.sec./sq.in.
Burning Time Pressure:	9.34 sec.
Burning Time Thrust:	9.45 sec.
Total Impulse:	23,389 lbs.sec.
Specific Impulse:	222.1 lb.sec/lb.
Initial Pressure:	557 psi
Final Pressure:	1484 psi
Average Pressure:	783 psi
Initial Thrust:	3259 lbs.
Final Thrust:	4921 lbs.
Average Thrust:	2475 lbs.
Discharge Coefficient:	7.63×10^{-3}
Thrust Coefficient	1.68
Remarks:	The new ignitor configuration appeared to have solved the ignition problem as indicated by the success of this test. The expansion cone liner functioned well.

STATIC FIRING #21

Purpose:	Confirmation of results of test 20
Date:	June 5, 1964
Propellant:	N5 (10% Al.) laminated
Nozzle:	1.55" dia. throat (graphite)(start)
	1.55" dia. throat (finish)
Divergent Section:	Graphite & Steel - 3.955" exit dia.
Grain Weight	104.0 lbs. (before wrapping without end plates)
	107.4 lbs. (after wrapping including end plates)
Grain Length:	40.5" (without end plates)
	41.0" (including end plates)
Grain Diameter:	7.894" (before wrapping)
	8.003" (after wrapping)
Pressure Time Integral:	7428 lb.sec./sq.in.
Burning Time pressure:	9.36 sec.
Burning Time Thrust:	9.31 sec.
Total Impulse:	21,767 lb.sec.
Specific Impulse:	209.3 lb.sec./lb.
Initial Pressure:	644 psi
Pressure at 2.0 secs.	614 psi
4.0 secs.	673 psi
6.0 secs.	936 psi
Final Pressure:	1521 psi
Average Pressure:	794 psi
Initial Thrust:	6629 lbs.
Thrust at 2.0 secs.	1848 lbs.
4.0 secs.	2103 lbs.
6.0 secs.	2964 lbs.
Final Thrust:	4621 lbs.
Average Thrust:	2338 lbs.
Discharge Coefficient:	7.42×10^{-3}
Thrust Coefficient:	1.56
Remarks:	Entire system performed perfectly.