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REPORT NO. 1598

BALLISTICS TECHNOLOGY REVIEW (U)

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BALLISTICS TECHNOLOGY REVIEW (U). (8)

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BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1598

Aberdeen Proving Ground, Md.
July 1972

(UNCLASSIFIED) BALLISTICS TECHNOLOGY REVIEW (U)

ABSTRACT

This report documents a briefing by the chiefs of various laboratories within the Ballistic Research Laboratories at AMC Headquarters on 25 August 1971. The subject of the briefing was the status of ballistics technology. Selected topics covering developments in Terminal, Exterior, and Interior Ballistics were discussed.

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I. INTRODUCTION (U)

This is a status report on "ballistics" technology by AMC laboratories. In view of the scope of the subject, a comprehensive treatment is not given or attempted. However, examples of ongoing work are presented to provide a reasonable description of problems currently facing the AMC laboratories in the field of ballistics and to examine the approaches and prospects for solving these problems. The three basic divisions of ballistics will be discussed: interior ballistics, exterior ballistics, and terminal ballistics. (See Figure 1.)

The discussion of interior ballistics will be limited to propulsion by guns and rockets and includes ignition and combustion of the propellant, the gas dynamics of the combustion products, the mechanics of acceleration of the missile and the dynamic stresses imposed upon the missile and the launcher as a result of the acceleration process. Specifically excluded is the interaction between the launcher and its platform even though this interaction is frequently considered to be a portion of the overall ballistics technology.

Exterior ballistics is interpreted as encompassing the transition between guided, accelerated motion in the launcher and free flight. The free flight portion of exterior ballistics concentrates mainly on aerodynamics and rigid body mechanics of flight.

Terminal ballistics generally encompasses the mechanics of warhead functioning. This applies particularly to explosive-actuated warheads and the effects of warhead or penetrator upon a target. For the purpose of this review, the discussion of terminal ballistics will be limited to the mechanics of warhead or penetrator interaction with materials, including armor, and will exclude overall lethality of the munition. Munition lethality - the inverse of target vulnerability - is treated as a separate technology area.

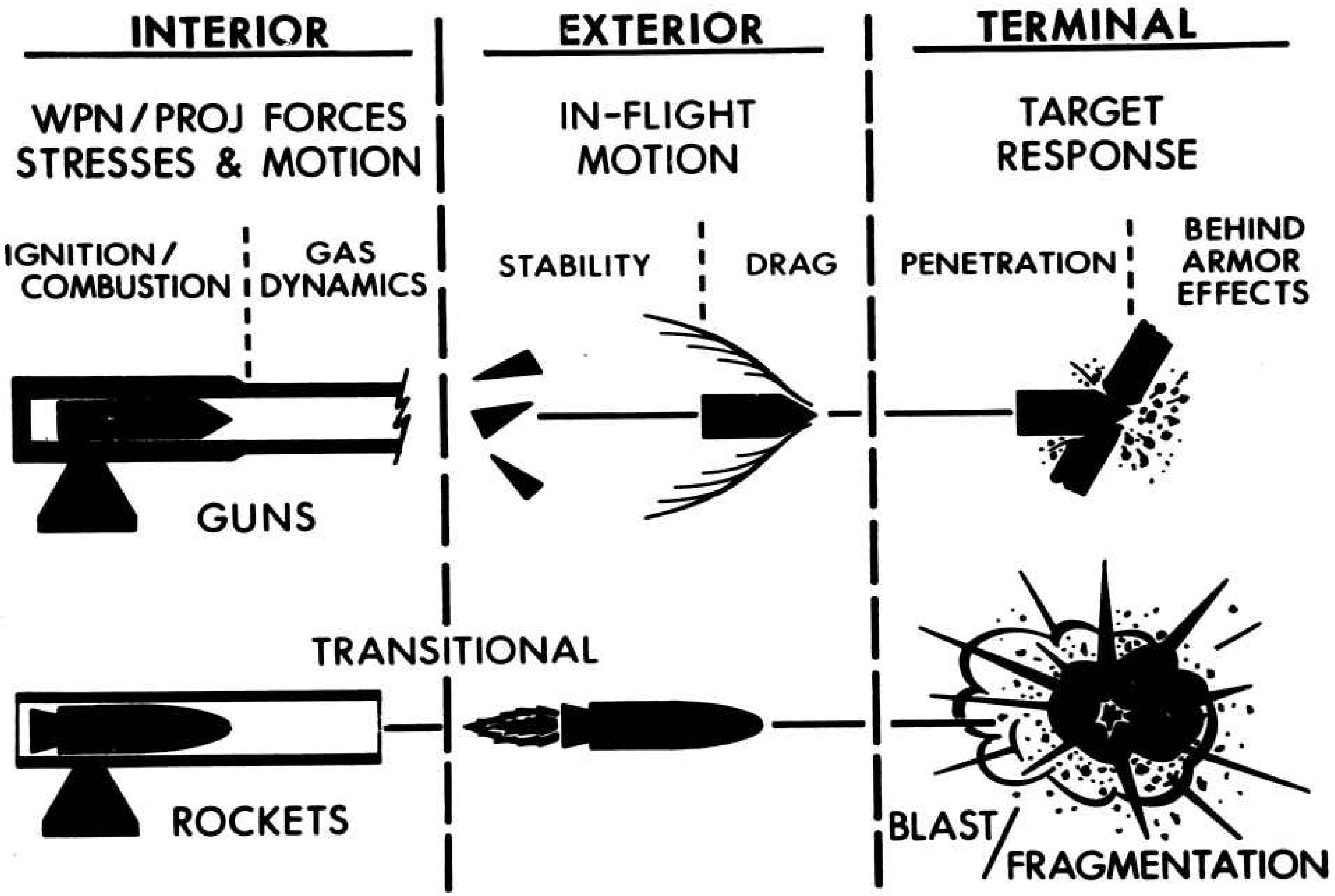


Figure 1. (U) Ballistic Cycle

By our definition, ballistics is clearly not a self-sufficient technology (see Figure 2). The development of a modern weapon system requires inputs from many other technology areas in addition to ballistics, as for example, mobility technology. Since the ballistics of a weapon interacts with the weapon platform, forces exerted upon the platform must, therefore, be taken into account in the design and employment of the platform, and in the protection of the platform, be it a helicopter or a tank. Fire control includes not only target acquisition, pointing, aiming and tracking, but also guidance and control, and terminal homing, all of which interact very strongly with ballistics. Human factors, materials, vulnerability characteristics of intended targets, fuze technology, and weapon kinematics and dynamics, interact strongly with the ballistics technology in complex and sometimes mysterious ways.

This review will address these peripheral aspects of ballistics only obliquely while concentrating on the central technology area. Nevertheless, we acknowledge that the recent rapid evolution in peripheral technologies has had a very profound effect upon ballistics during the past two decades. Advances in electronics have led not only to more sophisticated fuzes and terminal guidance but to a fresh look at earlier concepts which were discarded as unprofitable or not feasible. The advent of new materials has opened the door to many new applications.

Ballistics is undergoing still another, equally profound, change as a result of developing computer technology. It is well known that the original electronic computer ENIAC was developed by, and for, the Army to handle firing table computations, one aspect of exterior ballistics. It is not so well known that the greatest impact of computer technology upon ballistics awaits the advent of the generation of computers only now entering the market. This new generation will, as an example, permit the ballistician to exploit models that realistically describe multi-dimensional, transient, high-pressure phenomena. This is a critical step in the conversion of ballistic theory into useful engineering tools that can be put in the hands of weapon designers.

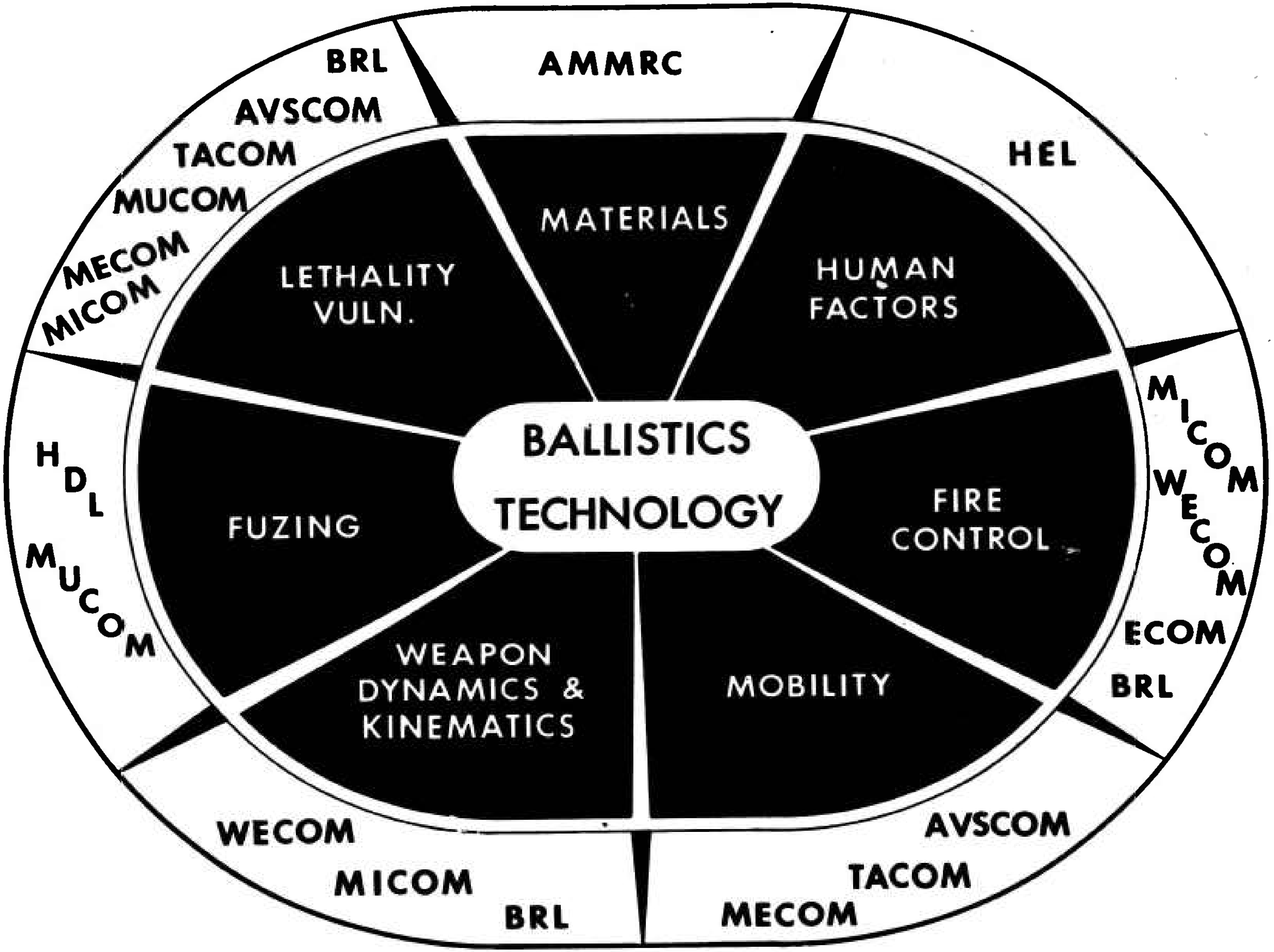
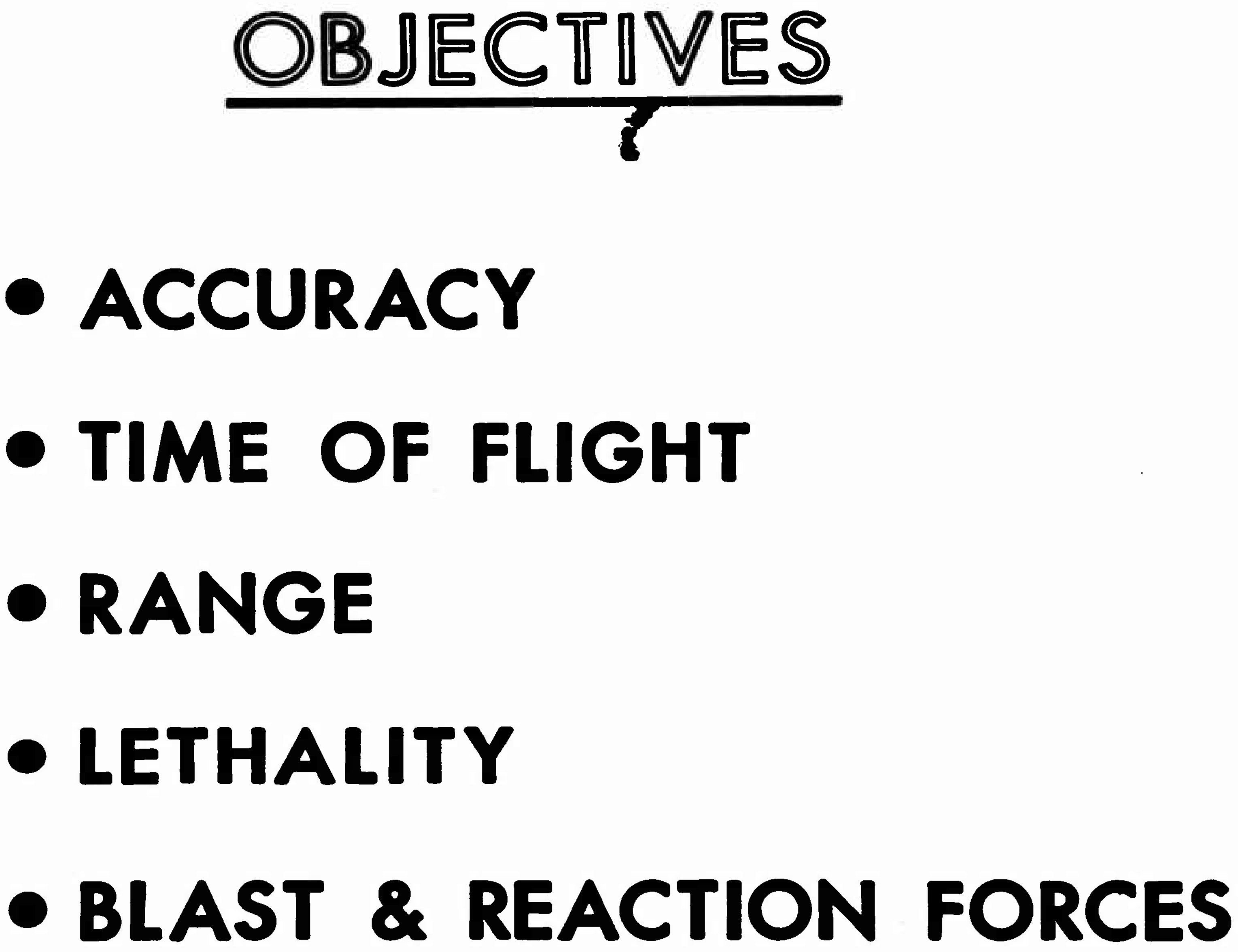


Figure 2. (U) Weapons System Envelope

In anticipation of the millennium, a large part of the recent effort in AMC laboratories in ballistics research has been devoted to refinement and formulation of ballistics theory in computer terms with our ultimate objective of providing the resultant computer programs to weapons engineers. The presentations that follow are not specifically directed to this underlying thrust of the ballistics program, but will make references to specific instances of the modeling approach.

Despite the rather drastic changes taking place in ballistics technology at the present time, its chief objective has remained the same for over two centuries (see Figure 3): to deliver munitions with the greatest possible accuracy in the shortest time at the greatest range possible with the maximum effect upon the target - with minimal effect upon the weapon's environment and with minimum expenditure of effort and money. This objective will be examined to some degree. In some cases, the examples to be presented are described in the context of specific weapon systems. The results of the investigations have general applicability insofar as they contribute to the common base of ballistics technology.

The three divisions of ballistics will be treated in the reverse of the common order in the following presentations, proceeding from terminal effects through the free flight of the missile to the propulsion system. (See Figure 4.) This is the order in which weapon characteristics are actually treated in the conceptual stage of system definition. Once the target spectrum is selected which the weapon is expected to defeat, the warhead or penetrator required to achieve the desired effect is defined. Then the missile configuration required to carry the payload with minimum energy loss and dispersion to the target is determined; and finally, the most efficient propulsion system to accelerate the missile and provide the necessary initial flight conditions is chosen. The process of design is invariably an iterative one since the requirements for performance, flight, and terminal effect interact strongly and are mutually competitive. The initial result is a sub-optimization



OBJECTIVES

- ACCURACY
- TIME OF FLIGHT
- RANGE
- LETHALITY
- BLAST & REACTION FORCES

Figure 3. (U) Objectives of Ballistics Technology

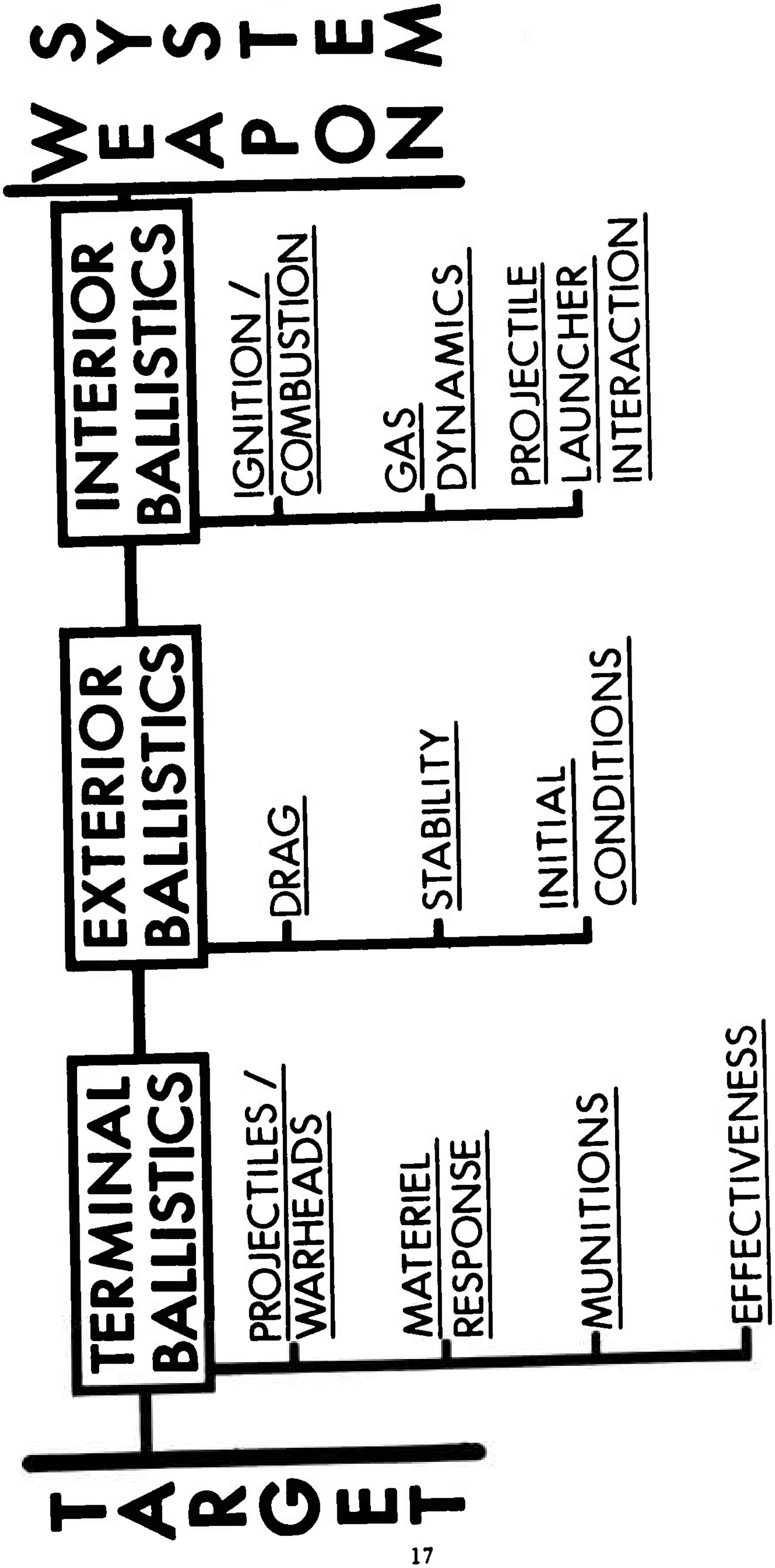


Figure 4. (U) Ballistics Technology Interfacing

that is invariably subjected to further compromise and further iteration which takes into account the influence of the peripheral technologies mentioned earlier.

The sections which follow will pose typical problems, discuss opportunities for weapon system improvement, and describe certain specific innovations that are recent products of the ballistics technology in the AMC laboratories.

(CONFIDENTIAL) II. TERMINAL BALLISTICS TECHNOLOGY REVIEW (U)

Ballistics technology has been introduced in terms of its components - interior, exterior, and terminal ballistics. The functions of ballistics technology and its relations to allied technologies have been described. A review of the terminal ballistics portion of that technology follows in two stages: first, it is necessary to place terminal ballistics in perspective in order to describe its scope (see Figure 5). Second, detailed attention will be devoted to some key aspects of the technology - in particular, projectiles and warheads in terms of problems, opportunity areas, and payoffs of these devices. Emphasis will also be placed on the objectives of terminal ballistics to give technology and science the bases through which innovation and rational evaluation procedures can be employed to optimize systems.

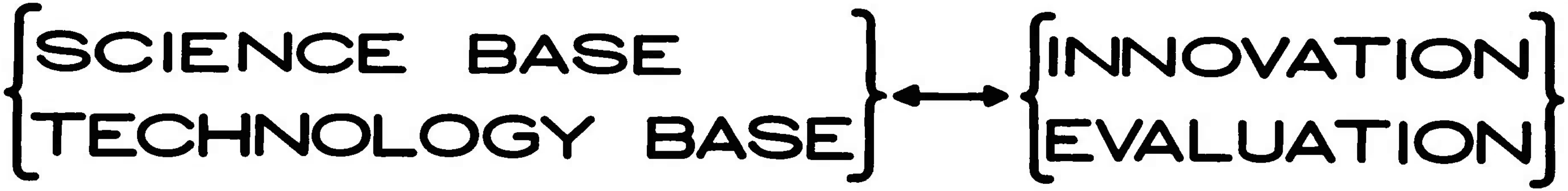
Terminal ballistics is the science, art, and technology of damage-producing devices such as projectiles, warheads, and munitions - and the interactions of these devices with targets. (See Figure 6.) The objective is to improve effectiveness through the best means for inflicting damage on the enemy and through optimum protection from enemy firepower.

This functional categorization of terminal ballistics has been chosen because it conveniently singles out as a key area projectiles, warheads, and their effectiveness, to be discussed shortly in greater detail. This area is most closely connected with the sister technologies of

SCOPE

PROJECTILES AND WARHEADS

- PROBLEMS
- OPPORTUNITY
- PAYOFFS



SCIENCE BASE
TECHNOLOGY BASE
↔
INNOVATION
EVALUATION

Figure 5. (U) Terminal Ballistics Technology

FUNCTIONAL AREAS

PROJECTILES AND WARHEADS

- KINETIC ENERGY PENETRATORS, BLAST/FRAGMENTATION, SHAPED CHARGES

MUNITIONS

- MINES, GRENADES, BOMBS

TARGETS

- ARMOR, PERSONNEL, MATERIEL

EFFECTIVENESS

- BEHIND ARMOR, LETHALITY, VULNERABILITY

Figure 6. (U) Terminal Ballistics Functional Areas

interior and exterior ballistics and is of great importance in current efforts. Kinetic energy penetrators, blast-fragmentation warheads and shaped charges will now be taken up in that order.

A. Kinetic Energy Penetrators

The first kinetic energy penetrators were probably rocks that our ancestors hurled at one another. Today, rifle bullets and armor-piercing ammunition are more sophisticated examples. With such a long history and such a wide application, we might speculate that what can be learned about these penetrators has been learned, and that what can be done with them has been done. And, indeed, there is a vast amount of catalogued information available to a weapons designer in both theoretical and experimental results. However, that all is known is not the case. Technological advances in weaponry have opened areas for exploitation of kinetic energy penetrators not previously available, and improvements in systems analysis techniques demand data not previously gathered. Three current areas of KE penetrator technology are considered of paramount importance: length-to-diameter ratio, high (l/d) penetrators, behind-armor effects, and penetrator performance in soft media. (See Figure 7.)

Existing and anticipated advances in gun technology provide a potential for higher projectile velocities. This potential must be exploited to obtain kinetic energy penetrator kills of hard targets for cases where kills of this type were not previously possible. New opportunities include an improved tank cannon, and weapons in the 20 to 40mm class with substantially increased capability against hard targets.

Penetrators with high l/d ratios are the strongest candidates to exploit the advances in gun technology. Recently, important factors have been identified for optimizing the kill potential of KE penetrators. The two most important features are: the properties of the penetrator material - such as density and strength, and the length-to-diameter ratio.

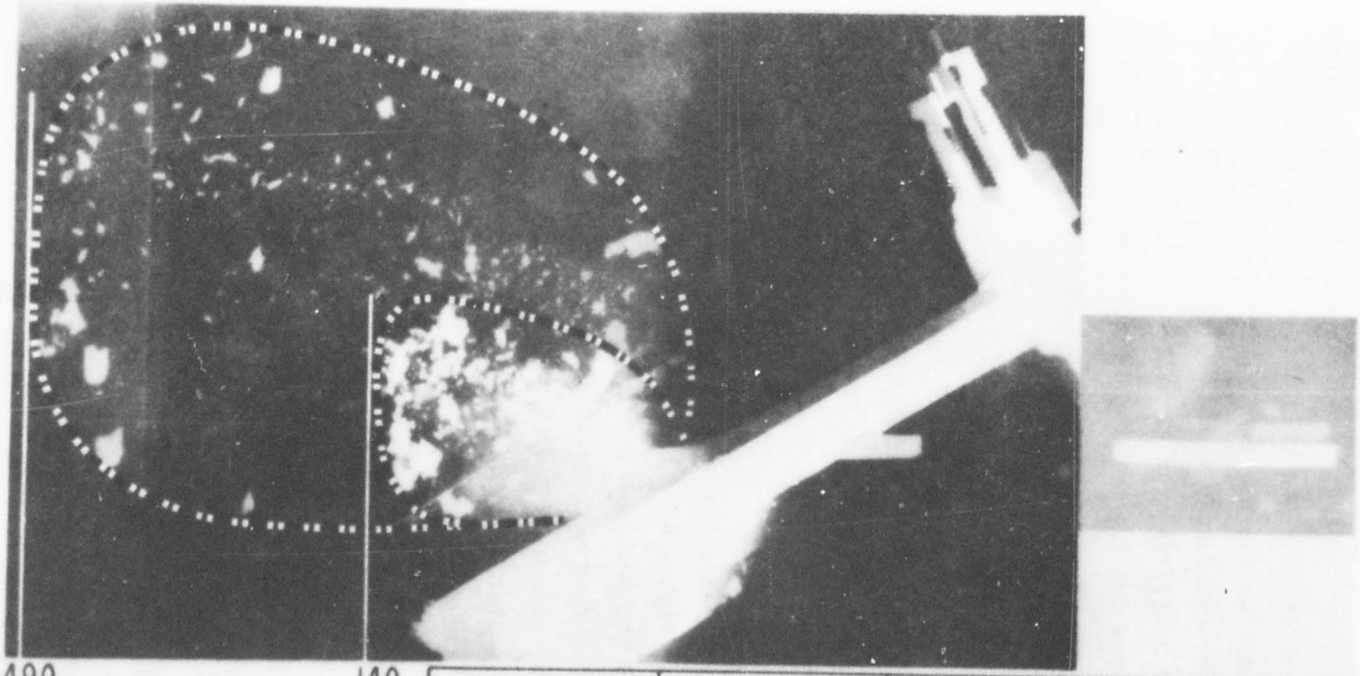
PROBLEM	OPPORTUNITY AREA	PAYOFF
HIGH VELOCITY HIGH DENSITY HIGH ℓ/d PENETRATORS	EXPLOIT GUN TECHNOLOGY ADVANCES TO DEFEAT HARD TARGETS, IMPROVED TANK CANNON, PYROPHORIC EFFECTS	APDS AMMUNITION
BEHIND ARMOR EFFECTS BULLETS, AP, FRAGMENTS, FLECHETTES	INCREASED DAMAGE, VULNERABILITY REDUCTION, IMPROVED EFFECTIVENESS	SYSTEMS OPTIMIZATION
PENETRATOR PERFORMANCE IN SOFT MEDIA	OPTIMIZED BULLETS, BUNKER DEFEAT	M-16 TERMINAL EFFECTIVENESS SPIW

Figure 7. (U) Kinetic Energy Penetrator Technology

A flash X-ray technique is used to perform experiments against Rolled Homogeneous Armor (RHA) with candidate penetrators. Multiple flash exposures provide data which give the velocity of the rod at impact - the rod penetrator is seen at the right in Figure 8 - as well as detailed information of the consequences of the impact. In fact, the speed and the weight of every fragment generated by the impact can be unraveled by virtue of the two exposures made subsequent to impact. The spall pattern for each of the two exposures is highlighted by the dashed lines.

Results from this program show that at the impact velocities tested, the denser the rod, the greater the penetrating power. Thus depleted uranium has been found to be better than tungsten as a rod material. Furthermore, careful control of alloying and processing of the rod material, all other factors remaining constant, produces substantial gains in performance.

The effect of variation in l/d on performance of steel rods of equal weight is shown in Figure 9. Striking velocity is plotted on the horizontal axis and the residual velocity of the largest projectile fragment emitted from the rear surface of the target is plotted on the vertical axis. Data for rods with l/d values of 10 and 20 do not differ substantially. In particular, both of these curves meet the horizontal axis at just less than 1100m/sec; below this velocity, the rods do not perforate the target. Rods with l/d values of 5 penetrate at velocities down to 900m/sec, however; on this basis, we might conclude that these penetrators are the best of the lot. But if we did so, we would be wrong - for two reasons: (1) simple penetration of armor is not a particularly good measure of the target-damaging effectiveness of a penetrator, and (2) we have not taken into account an advantage enjoyed by the more slender penetrators - namely their reduced drag in flight owing to their reduced diameter. To give these factors their due is



STRIKING VELOCITY METERS / SEC	RESIDUAL VELOCITY METERS / SEC	RESIDUAL WEIGHT GRAMS	REMARKS
1137	701	8.1	ROD
	706	1.7	SPALL, FASTEST
	178	7.8	SPALL, SLOWEST

Figure 8. (U) 65 Gram Depleted Uranium Rod, L/D = 10, Attacking 25.4mm Thick Rolled Homogeneous Steel Armor, BHN 370, at 60° Obliquity

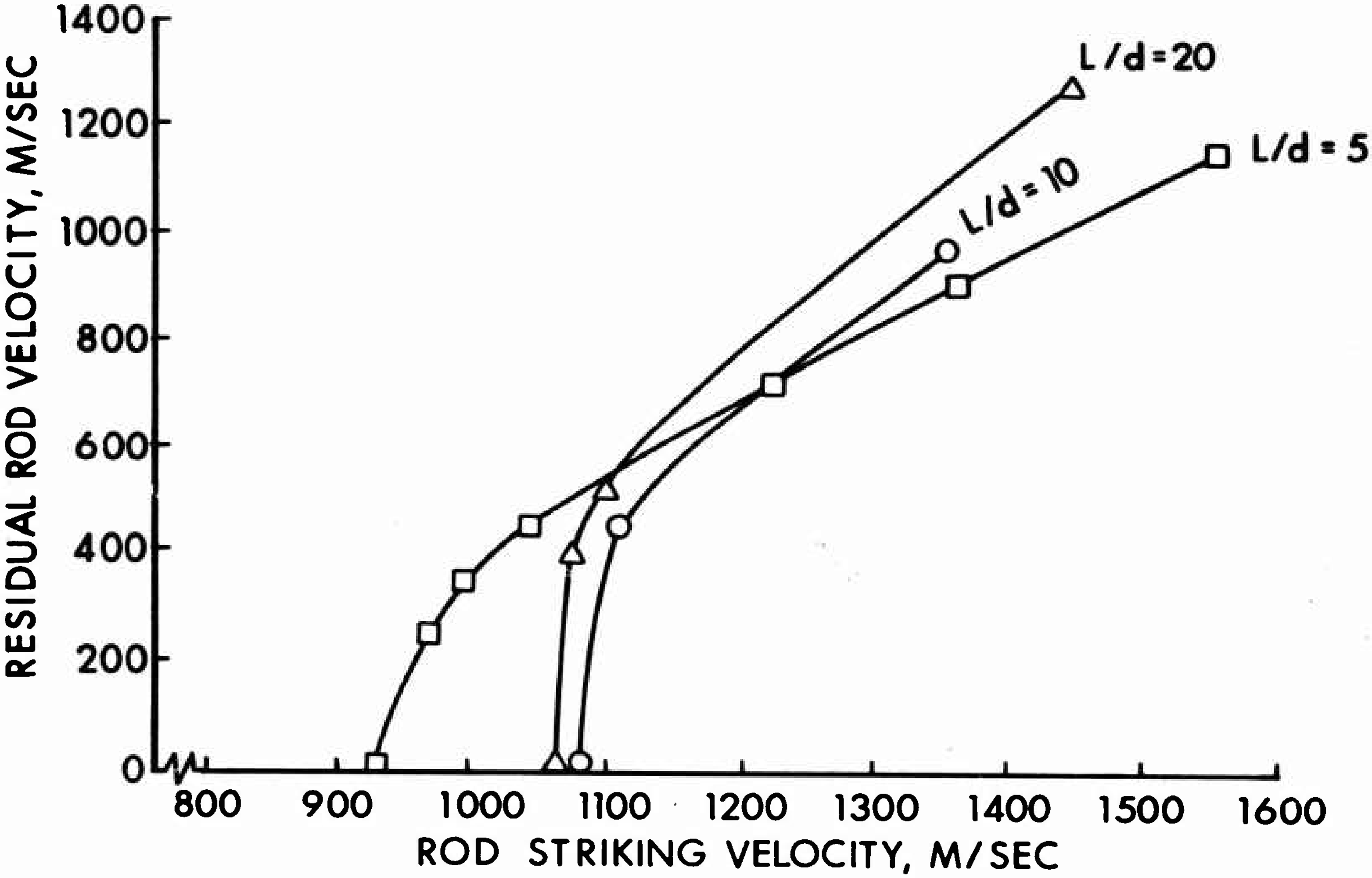


Figure 9. (U) Velocity of 7.78 Gram Steel Rods After Defeat of 6.35mm RH Armor (BHN 400) at 0° Obliquity

critically important. We have introduced the problem area of Behind-Armor Effects. The principal mechanisms for damage behind the armor must be accounted for quantitatively to give systematic, well-founded evaluation of effectiveness - whether it be the lethal power of our munitions or the vulnerability of our systems. To be specific, a more meaningful evaluation of the l/d effects of rod penetrators is given through data showing the kinetic energy of all the fragments generated behind the armor as a function of range.

In Figure 10, the kinetic energy plotted on the vertical axis is estimated by use of the previously shown x-ray pictures. The range information is obtained by assuming the rods all have the same muzzle velocity and weight; acknowledgement is made of the lower drag of the more slender projectiles. We now see that the longer rods are considerably more effective than the shorter ones.

The results given apply specifically to projectiles in the 0.30 caliber range. Guided by these results, work is now under way to determine whether the conclusions reached concerning the benefits of high density materials also apply for penetrators appropriate for 105mm guns.

As a last comment on measures of effectiveness, kinetic energy behind the target is by no means a proper measure to evaluate all penetrators against all targets. For example, it gives no credit to incendiary benefits in depleted uranium penetrators.

Appreciation of the importance of behind-armor-effects and the identification of important features for damage mechanisms serve a purpose beyond evaluation - they can also be the seed for innovation. This innovation is displayed in Figure 11 in the form of a projectile designed to generate a large number of fragments behind a relatively soft target. It consists of a bundle of metallic rods encased in epoxy. Results of a laboratory test of the idea are shown in the bottom flash x-ray photograph. For a size perspective, the experimental

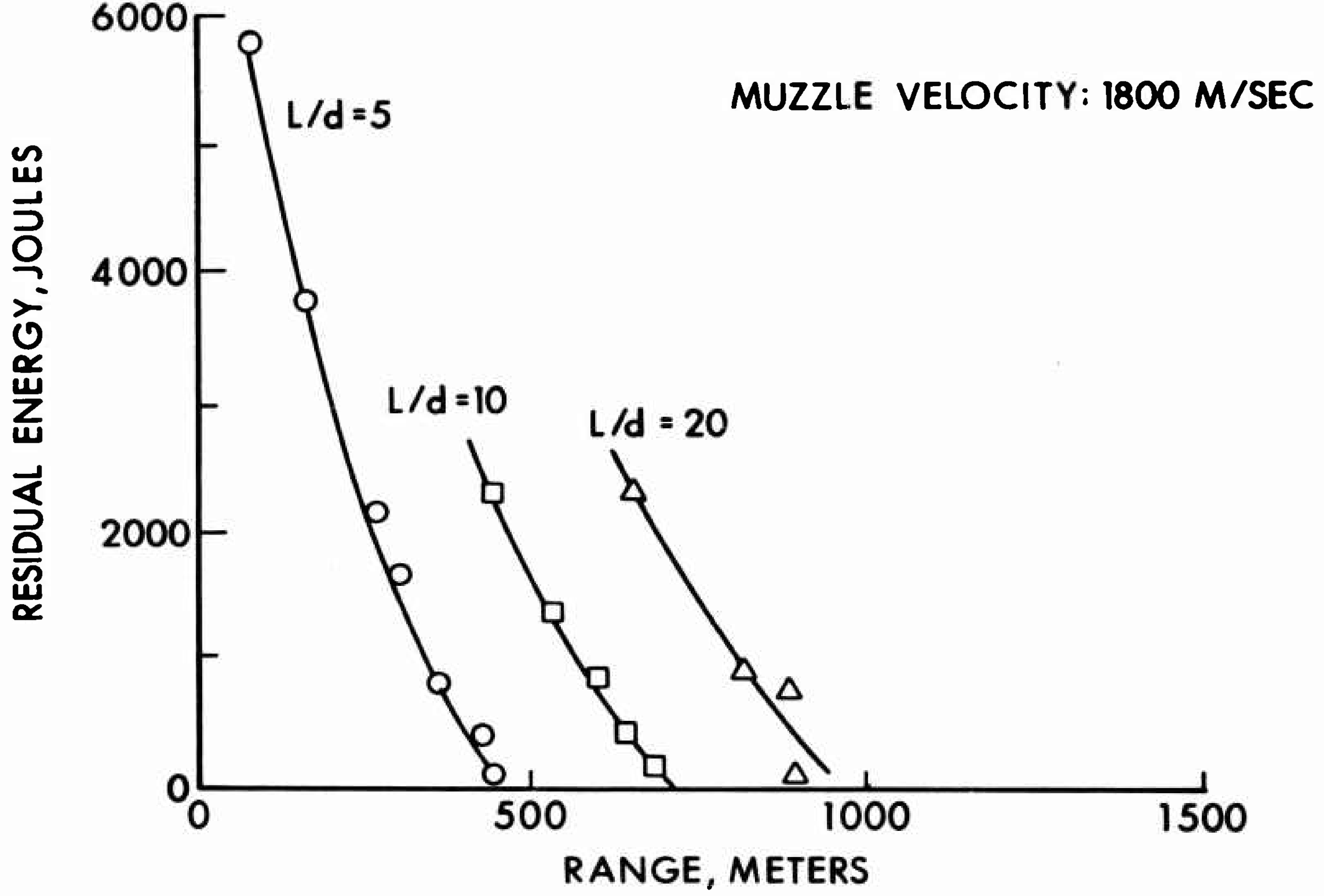


Figure 10. (U) Behind Armor Effects for 7.78 Gram Steel Rod After Defeat of 6.35mm RH Armor (BHN 400) at 0° Obliquity

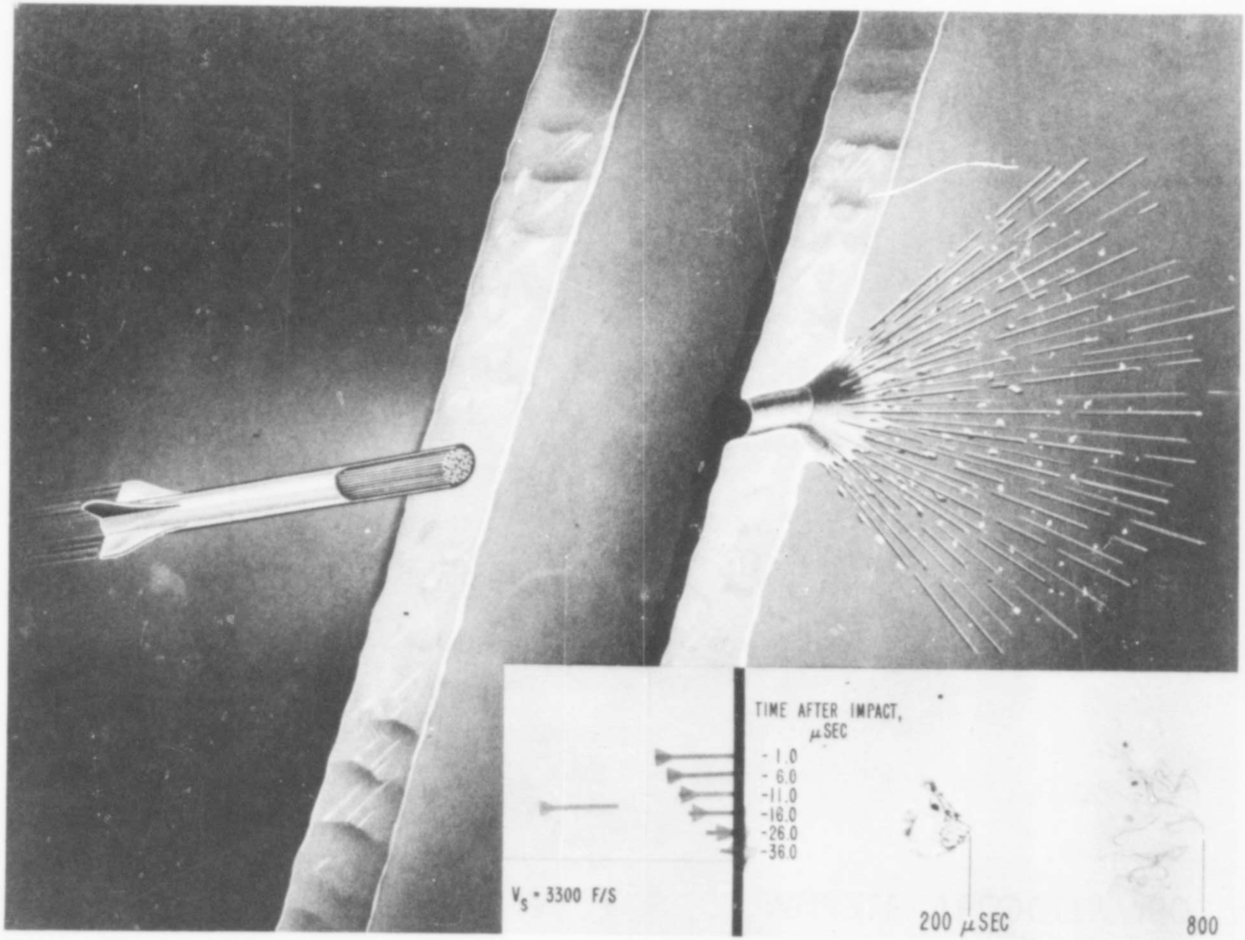


Figure 11. (U) Multi Wire Rod

projectile used a soda straw as a mold. An encouraging pattern of fragments has been achieved. This concept is being examined further. With variations in design, we may be able to develop versions that are effective against hard targets.

The performance of bullets in soft media is an important problem in the design and evaluation of small arms. Against personnel, it is desirable that the bullet be unstable and tumble in order to inflict maximum damage. Bunkers with large earthen covers present an entirely different problem in soft media penetration; here a large stable projectile is preferred for the soft earth for a better chance to get to the bunker interior.

Extensive data exist on the effects of geometry, spin, and the like on bullet performance; profitable use can be made of these data by designers. Flash x-ray pictures are helpful as this example of an M-193 bullet tumbling in a gelatin-simulant of flesh shows in Figure 12. Currently, a much more systematic approach toward small arms development is being made than ever before, creating new demands for information. Theories and models are needed, appropriate to and compatible with other portions of small arms systems developments.

B. Blast-Fragmentation Warheads

Recent advances in fuzing and guidance and control technologies have opened opportunities for the allied blast-fragmentation warhead technology. Improved miss distances and fuzes with sophisticated discrimination hold promise for hard target kills with fragmenting warheads in near-miss situations and structural kill of aircraft. Weapons with high payoffs are visible, e.g., Cannon-Launched Guided Projectile (CLGP), fragmenting warheads for tank cannons, and anti-aircraft weapons which supply immediately identifiable kills. This latter case offers a noteworthy advance beyond the current situation in which structural kill

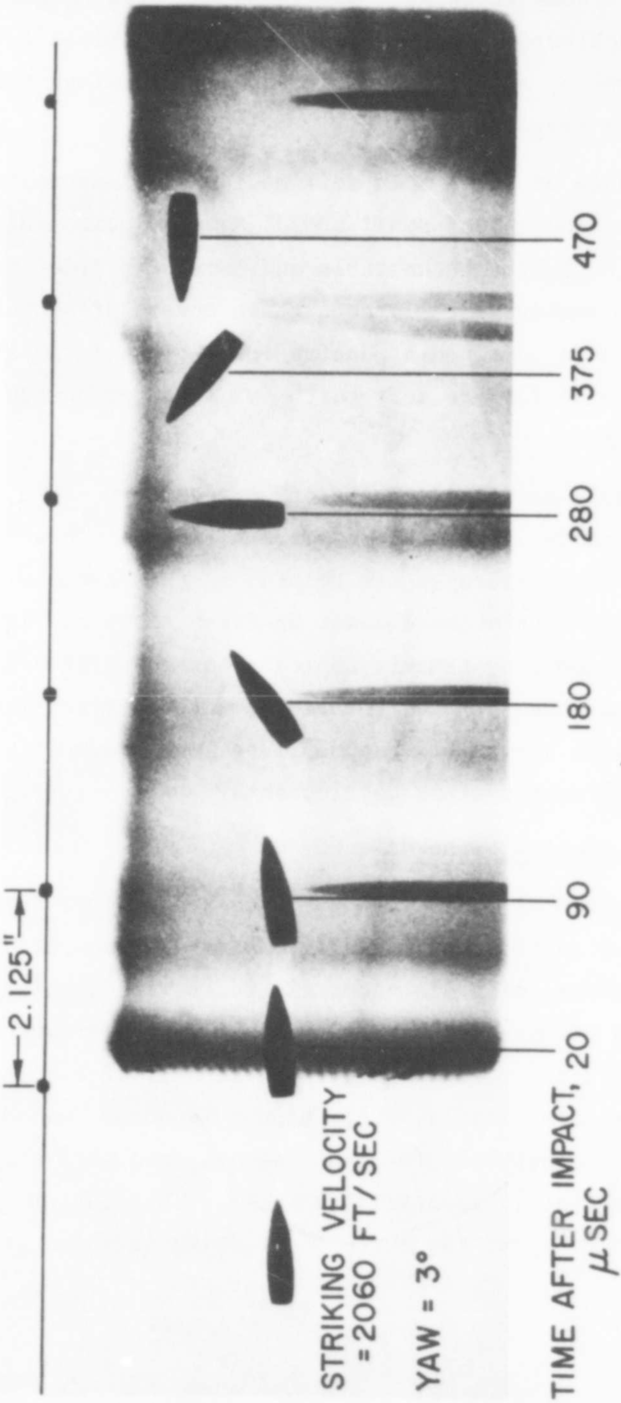


Figure 12. (U) Bullet Penetrating Gelatin

by fragments is not considered an acceptable means to down air targets. Focused blast-fragmentation devices are the most important problem of this warhead technology. There is, of course, a parallel problem in effectiveness evaluation. (See Figure 13.)

The technology of focused fragmentation warheads is ripe for exploitation. There is a waiting storehouse - a technology bank - of proven concepts for directional control of fragments. Their fruitful use depends frequently upon sophisticated fuzing or guidance and control of the fragmenting projectile and optimization of the device for the intended application. Some concepts are shown in Figure 14. Fragment focusing is generally achieved through casing geometry and control of explosive initiation. One of these devices - the lower left-hand one of the group featured in Figure 14 warrants further discussion. The purpose of this warhead, of course, is to provide large, high-velocity fragments to kill hard targets such as tanks. In the 155mm size, up to 120-1/4 pound fragments can be deployed at velocities of 1800m/sec. The flight direction of the fragments relative to the projectile is uniform from round-to-round. A difficulty in applying this concept is the stringent requirement placed on fuzing, guidance and control.

Another warhead concept worthy of mention is an improvement to the 155mm projectile that has been arena-tested in scaled model and transferred to Picatinny Arsenal for proposed use in the XM483. The intention is simply to project more of the available fragments down and forward toward the target area than the conventional warhead does. As shown in Figure 15, this is achieved by a frangible dish, and a hollow, fragment-producing nose cap - both of which provide fragments in the forward sector.

Let us now consider the matter of effectiveness. Understanding the factors influencing the effectiveness of fragmenting projectiles is as critical to their optimum design as appreciation of behind-armor effects is in penetrator design. Furthermore, the ability to gather

PROBLEM	OPPORTUNITY AREA	PAYOFF
FOCUSED BLAST-FRAGMENTATION WARHEAD	KILL CAPABILITY OF HARD TARGETS WITH NEAR MISS OF PROJECTILE; STRUCTURAL KILL	CLGP TANK CANNON NEW ANTI-AIRCRAFT WEAPONS
EFFECTIVENESS	WARHEAD SELECTION CRITERIA WARHEAD OPTIMIZATION	

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Figure 13. (U) Blast-Fragmentation Warhead Technology

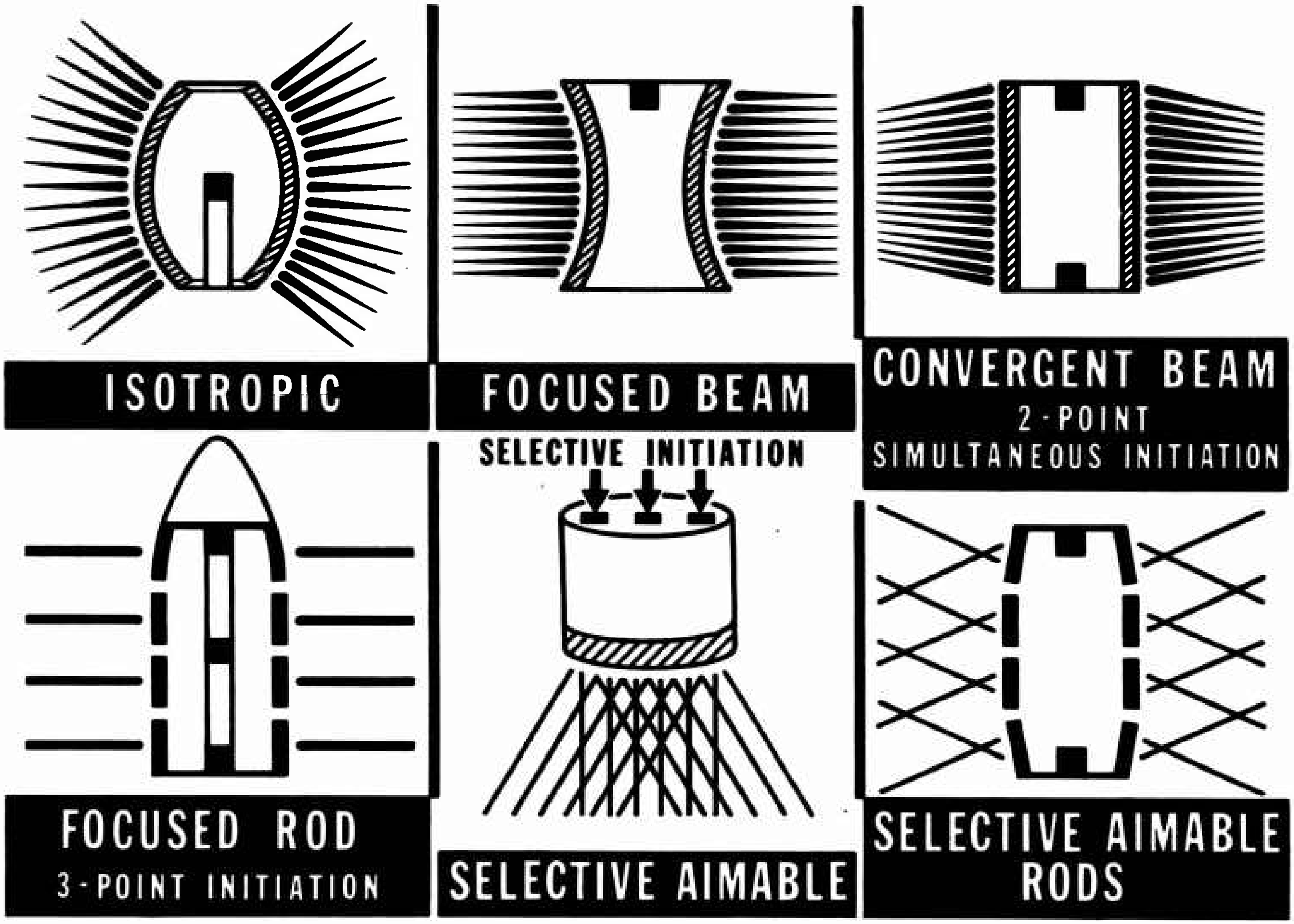
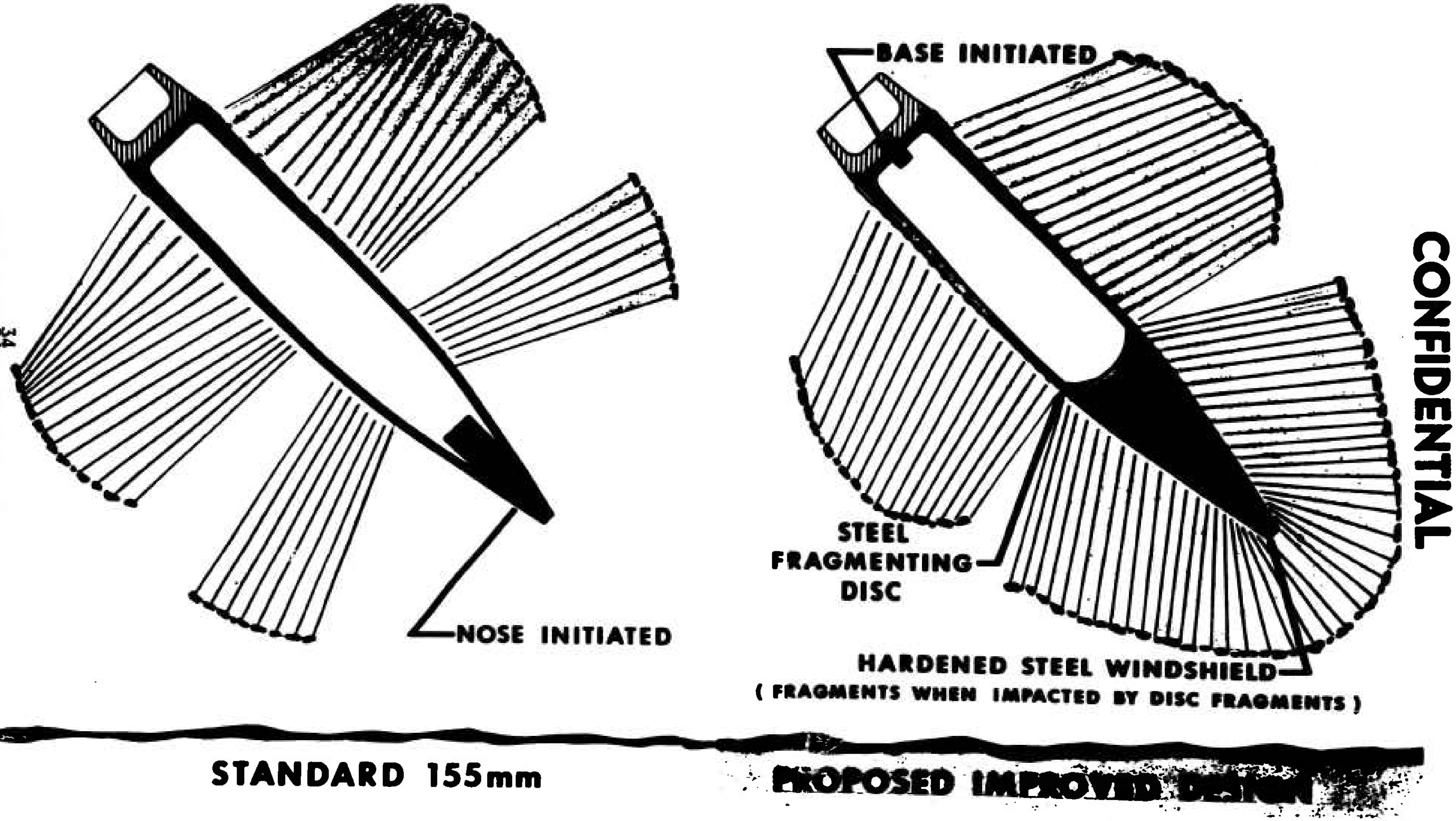


Figure 14. (U) Fragmenting Warhead Concepts



STANDARD 155mm

PROPOSED IMPROVED DESIGN

Figure 15. (C) Focused Blast/Fragmentation (U)

proper data is critical in this matter for warhead selection and optimization. This point is clearly made in the case of the M56E, 20mm projectile. For the roles assigned to this projectile, its effectiveness would be enhanced if it propels a large number of chunky, uniform fragments. (See Figure 16.) On the left is a flash x-ray picture of the detonation of the current service round. It produces long sliver fragments. On the right is a similar experimental round made from an improved steel, this experimental round generates desirable chunky fragments.

Two points are important here. First, use of a relatively new experimental technique gives the means to coordinate warhead function and fragment characteristics for improved design. Second, these results point up a deficiency in current, widely used, data collection methods for assessing small caliber fragmentation warhead performance. The celotex used to catch sliver fragments breaks them and provides erroneous data for effectiveness evaluations.

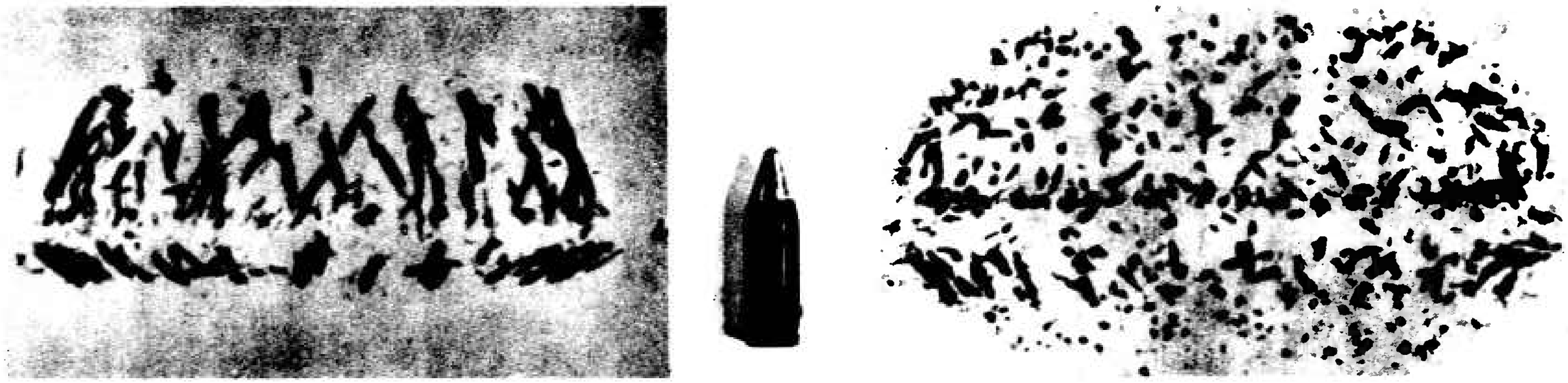
C. Shaped Charges

Three key problems of shaped charge technology have been identified: Behind-Armor Effects, Spin Compensation, and Design Efficiency (see Figure 17). The problem of behind-armor effects parallels that discussed for kinetic energy penetrators.

Effectiveness measures must be established for behind-armor data. Figure 18 shows a flash x-ray of jet and spall egressing the rear of an armor plate. These measures are being established by cooperative efforts from terminal ballisticians and vulnerability analysts. The result will provide quantitative means to assess performance, and give guidelines for best directions for innovation, for example, direction for warhead improvements with pyrophoric follow-through devices.

The problem of degradation of the penetrating power of a shaped charge when it is spinning is well known. As a consequence of this degradation, the use of shaped charges in spin-stabilized projectiles

IMPROVED SHELL FRAGMENTATION



STANDARD
1040 STEEL

20 MM
PROJECTILE
M56E3

IMPROVED
HF-1 STEEL

POOR MASS/NO. DISTRIBUTION
LIMITED SPATIAL DISTRIBUTION

DESIRABLE MASS/NO. DISTRIBUTION
IMPROVED SPATIAL DISTRIBUTION

Figure 16. (U) Improved Shell Fragmentation

PROBLEM	OPPORTUNITY AREA	PAYOFF
BEHIND ARMOR EFFECTS	OPTIMIZE SPALL AND PYROPHORIC EFFECTS; IMPROVED SYSTEMS EVALUATIONS	
SPIN COMPENSATION	IMPROVED HEAT AMMUNITION REDUCED ROCKET DISPERSION BY SPIN	IMPROVED TANK CANNON XM409
QUALITY DEFINITION DESIGN EFFICIENCY	REDUCED COST, REDUCED WEIGHT ROUND-TO-ROUND UNIFORMITY	HIGH PERFORMANCE WARHEADS; DRAGON, LAW

Figure 17. (U) Shaped Charge Warhead Technology

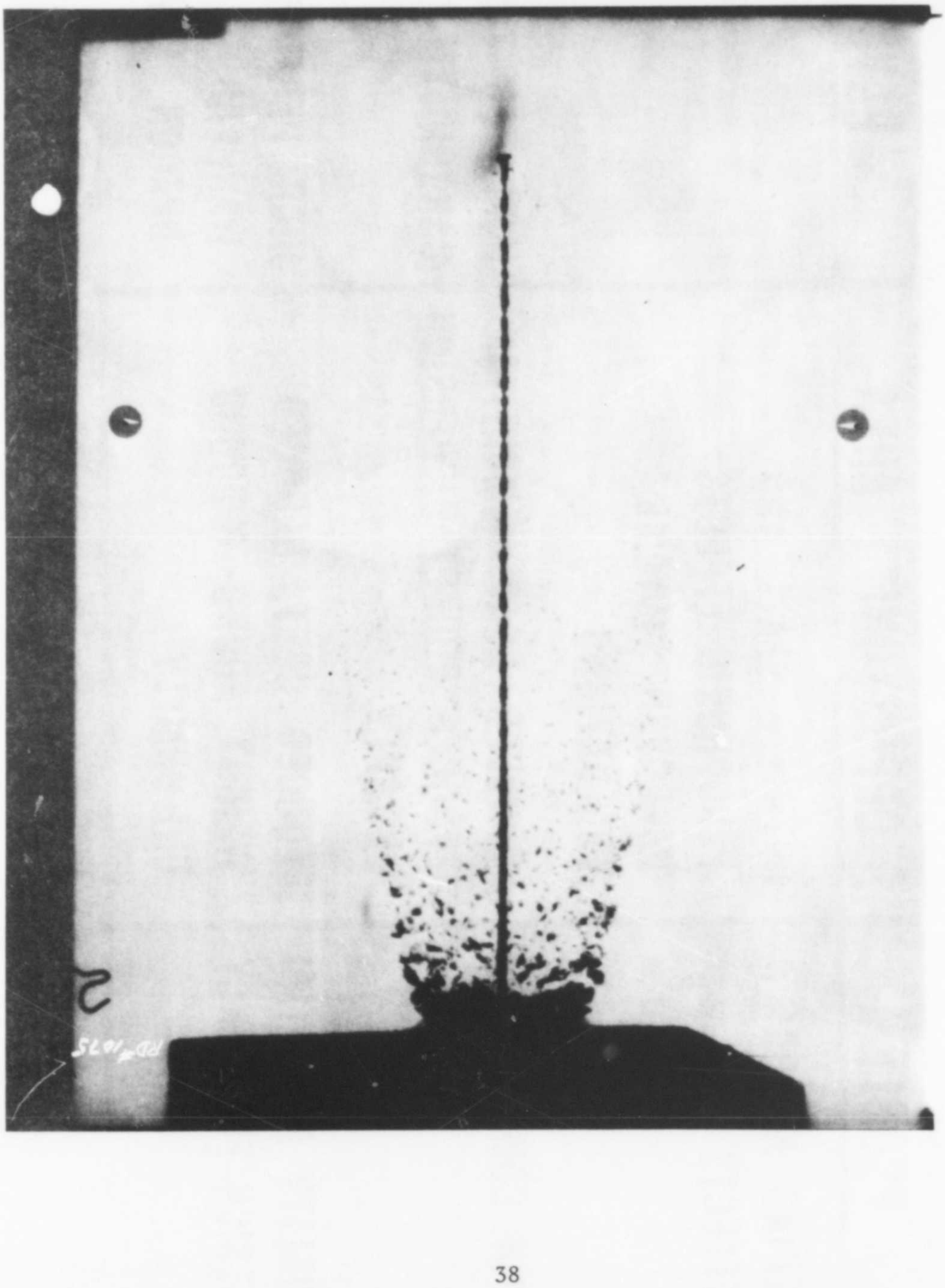


Figure 18. (U) Shaped Charge Jet After Penetration of Armor Plate

is severely limited. Partial solutions to this problem have been found and have provided such payoffs as the XM409, 152mm HEAT projectile. More satisfactory solutions would provide opportunities for even more extensive and far-reaching systems improvements. Also, some existing solutions using metallurgical liner control offer the opportunity to compensate for slowly spinning warheads and could be used to advantage in rockets that are slowly spun to reduce dispersion.

The heart of the spin compensation problem is seen in three flash x-ray pictures (Figure 19) taken of traveling jets produced by 152mm shaped charges. The jet, shown at the top is that of a shaped charge having a smooth copper cone and fired at zero spin rate. The jet is of high quality. It is virtually straight with no waver and can penetrate up to 35 inches of mild steel. The center radiograph shows the jet produced by the same warhead if it is fired when spinning at 95 rps - a spin rate in the range used in the 152mm system. Degradation of the jet is clear. This jet can penetrate no more than 10 inches of mild steel.

The jet pictured at the bottom was made by a 152mm XM409 warhead with a fluted liner and spinning at 95 rps. This is a sectioned sample of the liner. This control of the geometry of the liner overcomes some of the problems of spin. The jet seen here has not suffered gross dispersal of the particles. It displays some waver but can penetrate as much as 24 inches of steel.

A more comprehensive view of the situation is given in Figure 20. In this graph, jet penetration on the vertical axis is plotted against standoff in cone diameters on the horizontal axis. Standoff is defined as the distance of the warhead from the armor at the instant of initiation. The top curve depicts the theoretical performance for this warhead design. The next curve down shows the average results of actual firing of the smooth liner for the no-spin situation. Data for this same liner obtained from the firings at a spin rate of 95 rps are plotted in the bottom curve. This demonstrates the severity of the spin degradation

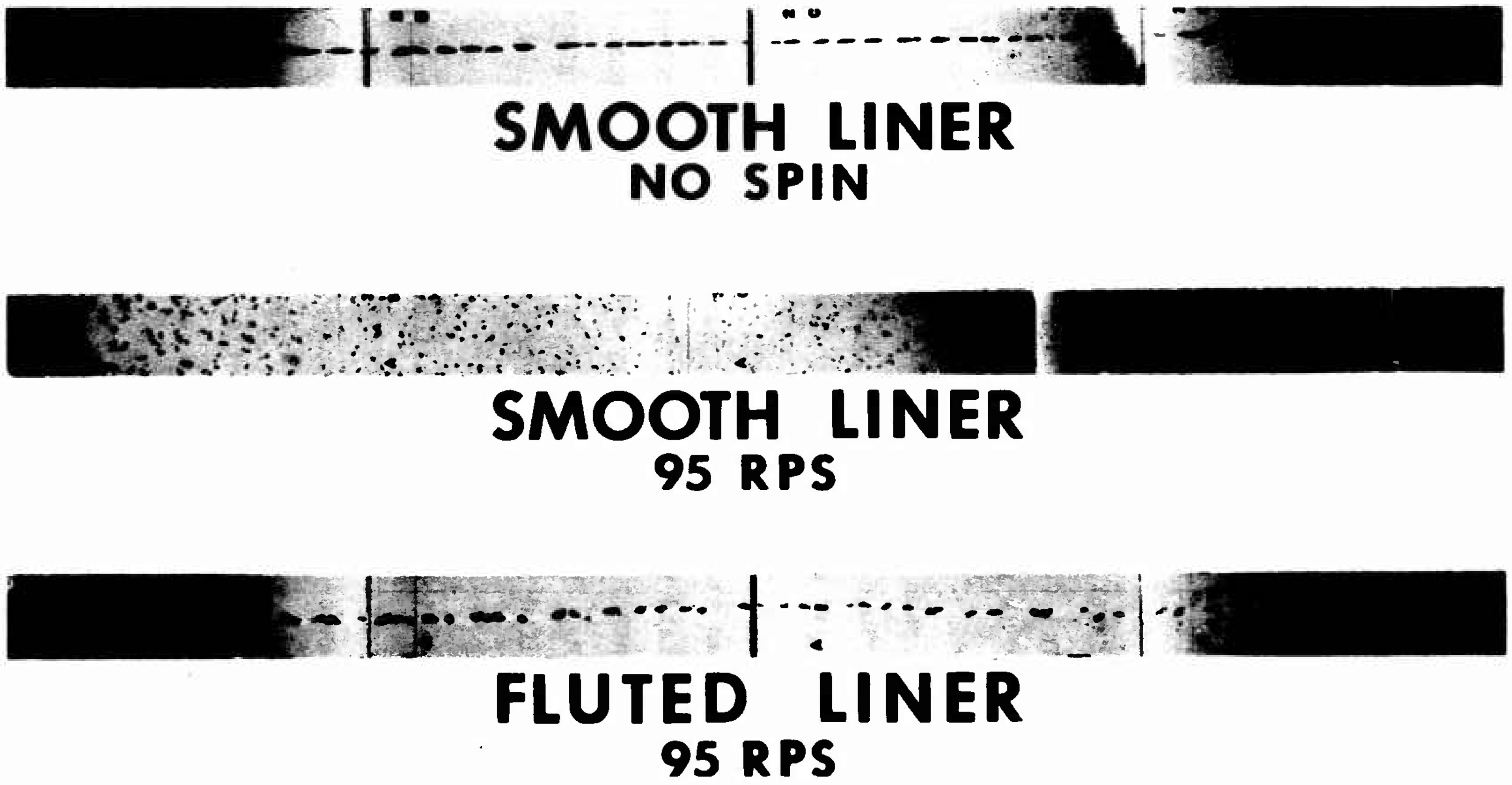


Figure 19. (U) Spin Effects on Shaped Charge Jets

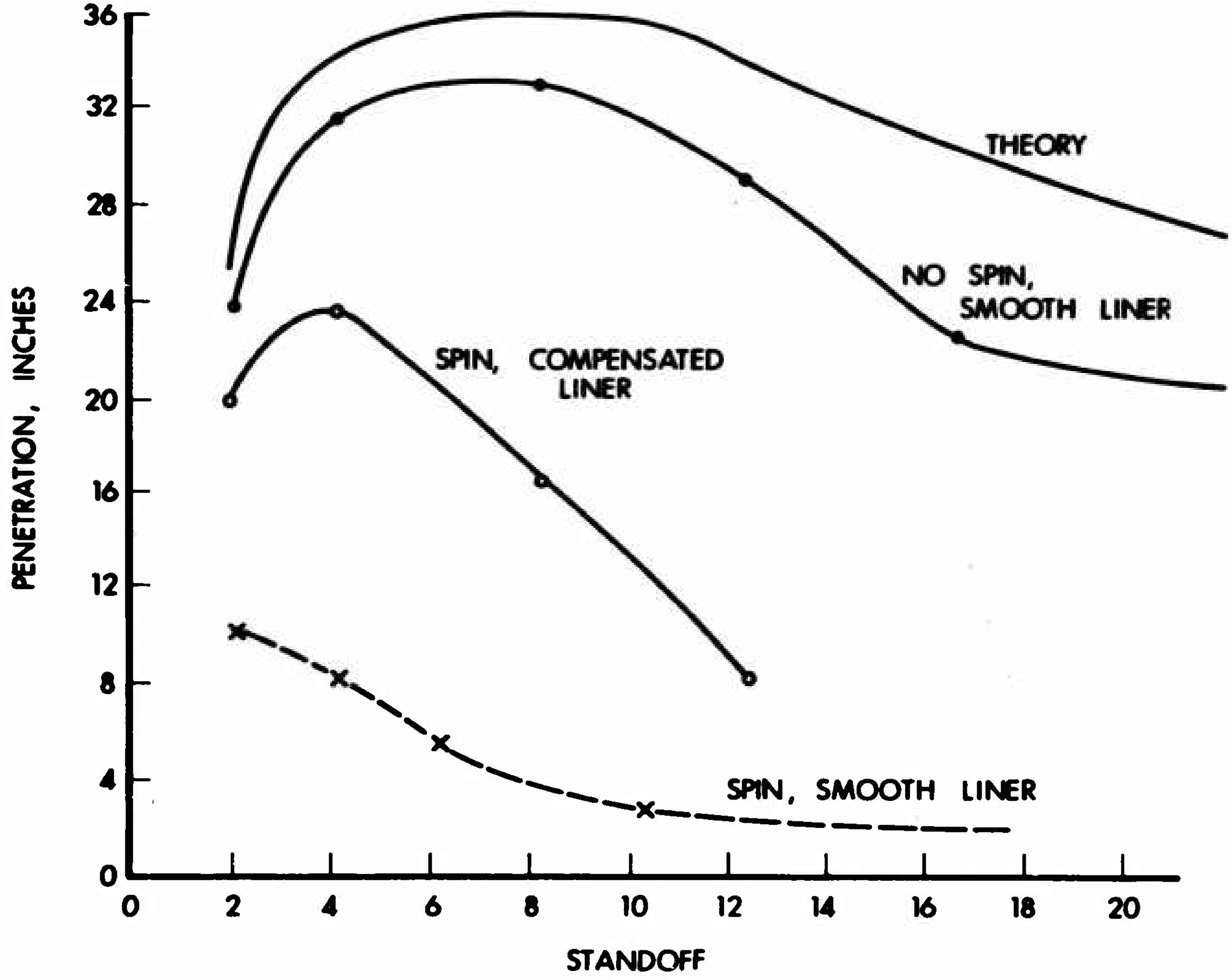


Figure 20. (C) Penetration vs Standoff for 152mm Shaped Charge into Mild Steel

problem. The curve labeled "spin-compensated liner" shows the performance of the XM409 projectile with the fluted liner. The dramatic improvement was sufficient to make the XM409 feasible for the 152mm system. However, there is much room for more improvement - particularly to reduce the rapid falloff in performance at large standoff in the compensated warhead. This is critical in view of the standoffs associated with many armored vehicles. Currently, the means for improved spin compensation are not available.

Aside from design the performance of actual warheads is primarily dependent upon quality control in manufacture of the liner and the explosive-fill. Since controlling factors in production have been identified, x-ray techniques have been introduced into quality assurance procedures for warheads. Furthermore, additional methods for quality assurance of liners are under development as are efforts to pin down critical factors to achieve the highest quality explosive-fill.

The effectiveness of shaped charge systems can be improved through more efficient design to achieve reduced weight or size of warhead. Payoffs and opportunities are manifold and include the LAW and DRAGON systems as well as influences on submissile shaped-charge devices. There are two important and separate features for design efficiency. The first is concept development for warhead improvements to meet specific requirements - for example, reduced weight or size. The second is a general development that affects improvement upon all shaped charge performance - for example, the development of a charge liner material better than the copper now used.

Two cases of improved design falling in the first category are shown in Figure 21. The charge on the left retains the diameter and performance of the LAW warhead with reduced weight. Improvement is obtained by way of novel geometry and explosive initiation. On the right is an innovation made to maintain performance with reduced caliber

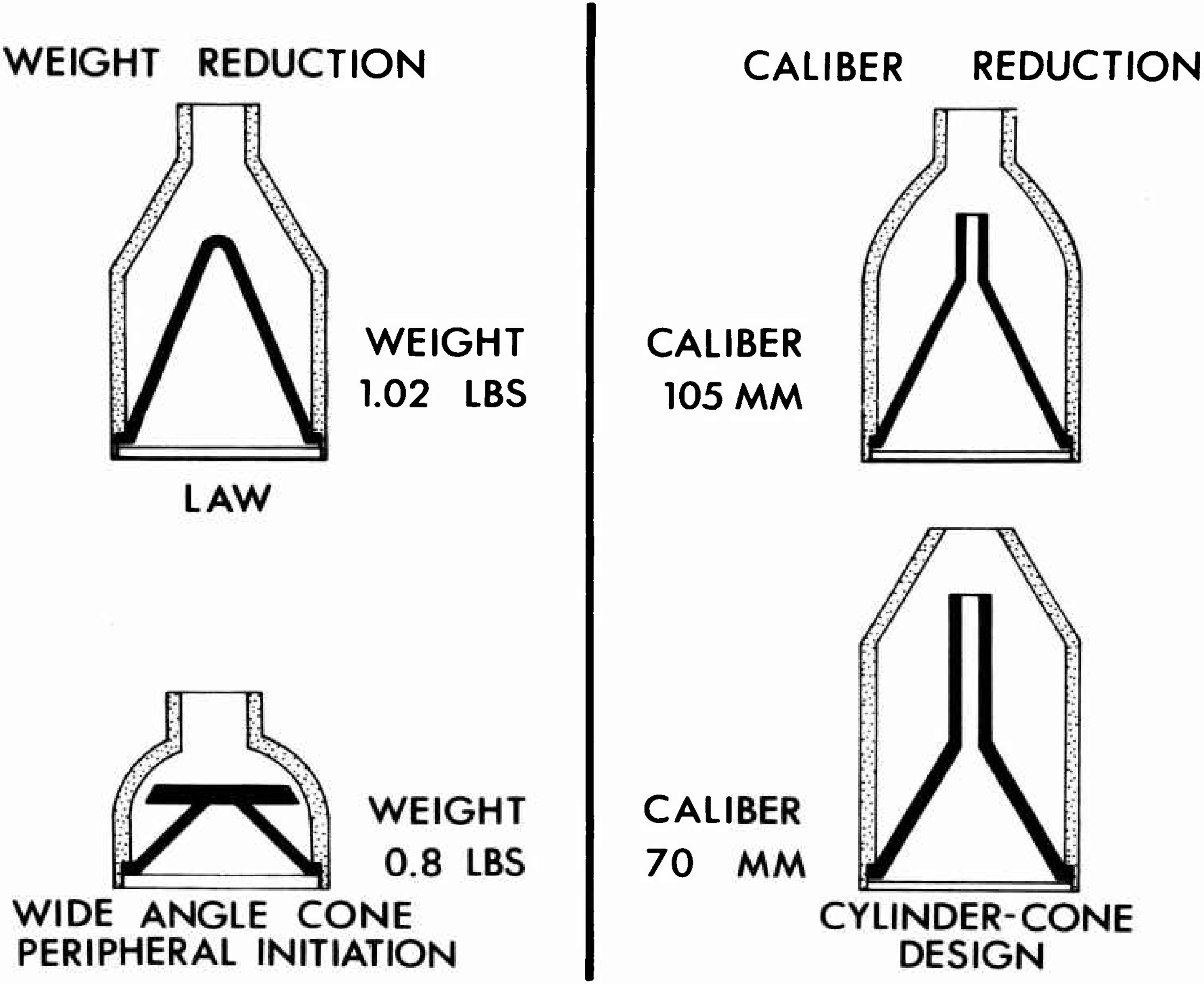


Figure 21. (U) Shaped Charge Warhead Concepts

when weight is not an overriding factor. This innovation offers possibilities for packaging improvements in sub-munitions as well as for reduced system diameter. Very tight manufacturing tolerances remain a problem with this new product.

In the second category of general improvement of shaped charge performance, there are two matters worthy of special attention: improved liner materials and recent advances in analytical capabilities with digital computation. These matters are brought out in the following discussion.

Superductile alloys are metals which can withstand large amounts of deformation without fracture. Interest in such material for shaped charge liners generates from a need to have continuous, non-particulated jets to achieve maximum penetrating power. At 8-cone diameters standoff, the copper jet penetrated about 15 inches of steel armor while the lead-tin penetrated about 24 inches. Disadvantages of the new material include some manufacturing problems and its low strength which could preclude its use in gun-launched warheads.

In the past, our understanding of shaped charge phenomena has relied strongly on information provided through experiments utilizing high speed photographs of the liner collapse and formation of an actual jet. Currently, the opportunity appears for exploiting an impressive advance in analytical ability through use of digital computation.

(CONFIDENTIAL) III. EXTERIOR BALLISTICS TECHNOLOGY REVIEW (U)

Exterior Ballistics as an applied science is the oldest of the three areas of Ballistics. It has one foot in the seventeenth century with the work of Galileo and Newton and has been an important driving force in the development of applied mathematics for two centuries. (See Figure 22.) Exterior Ballistics has the other foot in the space age; for example, witness the firing of projectiles to altitudes in excess of

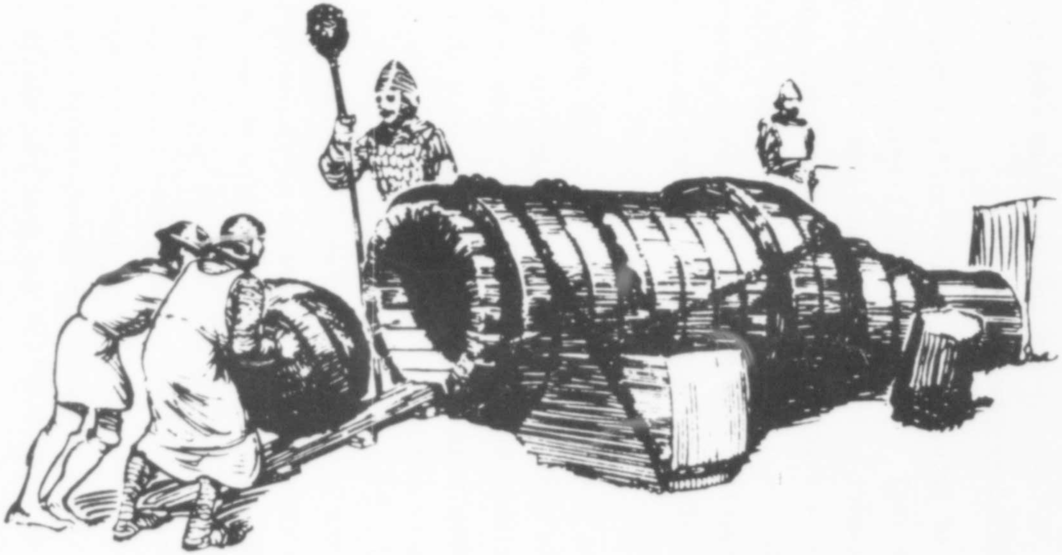


Figure 22. (U) Exterior Ballistics

one hundred miles at Yuma. (See Figure 23.) In order to cover a technical area which extends over three centuries, some specific projects of current interest will be selected for discussion. The primary concern, then, is in what is new in Exterior Ballistics. (See Figure 24.) In particular, in what way can the new techniques be used to improve projectiles and new weapons systems?

The objectives of Exterior Ballistics can be summarized as three in number. (See Figure 25.) The first is the traditional one of properly locating the small impact pattern of the shell when fired from a cannon. The second objective is selecting the optimum striking conditions at the target. The third is devising innovations - new, original ideas - which can have an important impact on Army weapons. Several topics will be described to illustrate these three objectives in current Exterior Ballistics practices.

A very important current topic is that of long-range artillery. There are two ways to achieve extreme ranges: by using rocket-assist and by firing sub-caliber sabot projectiles at increased muzzle velocity. The price paid for long ranges is usually increased dispersion. In some cases of currently designed shell, the percentage dispersion is not being maintained. Even if the percentage dispersion is maintained at extended ranges, the actual physical extent of the dispersion area is unacceptable. We can think of dispersion as involving two inputs: muzzle velocity and transitional ballistics (see Figure 26). These inputs are channeled into a black box which we might identify as projectile response. The output would then be the dispersion of the weapon. The first input - the muzzle velocity - is of obvious importance. The second item - transitional ballistics - covers everything that happens to the projectile from a point in the gun near the muzzle to the point where it begins its free flight state in the earth's undisturbed atmosphere. This includes such items as muzzle tip-off, gun whip, blast and

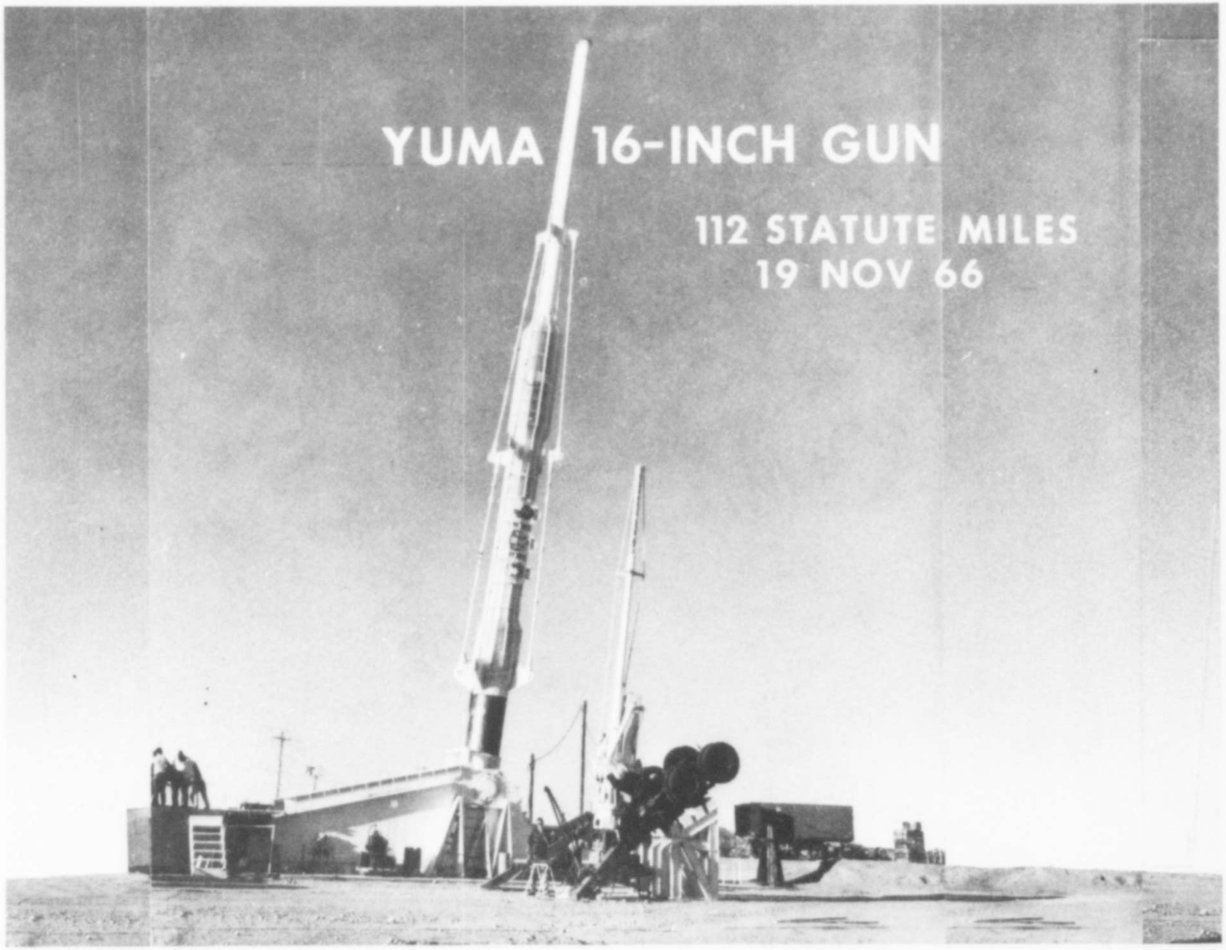
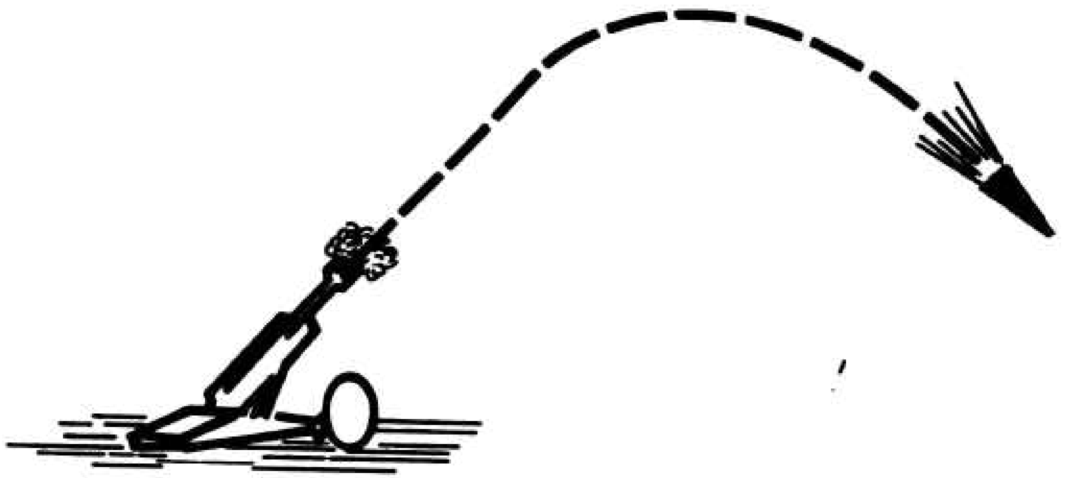


Figure 23. (U) High Altitude Test Facility

WHAT'S NEW IN EXTERIOR BALLISTICS?

1. IMPROVED PROJECTILES
2. NEW WEAPONS SYSTEMS

Figure 24. (U) What's New in Exterior Ballistics?



OBJECTIVES

1. PROPERLY LOCATED, SMALL
   IMPACT PATTERN
2. OPTIMUM STRIKING CONDITIONS
3. INNOVATIONS

Figure 25. (U) Exterior Ballistics Objectives

(1) ROCKET ASSISTED PROJECTILE

(2) SUBCALIBER SABOTED PROJECTILE

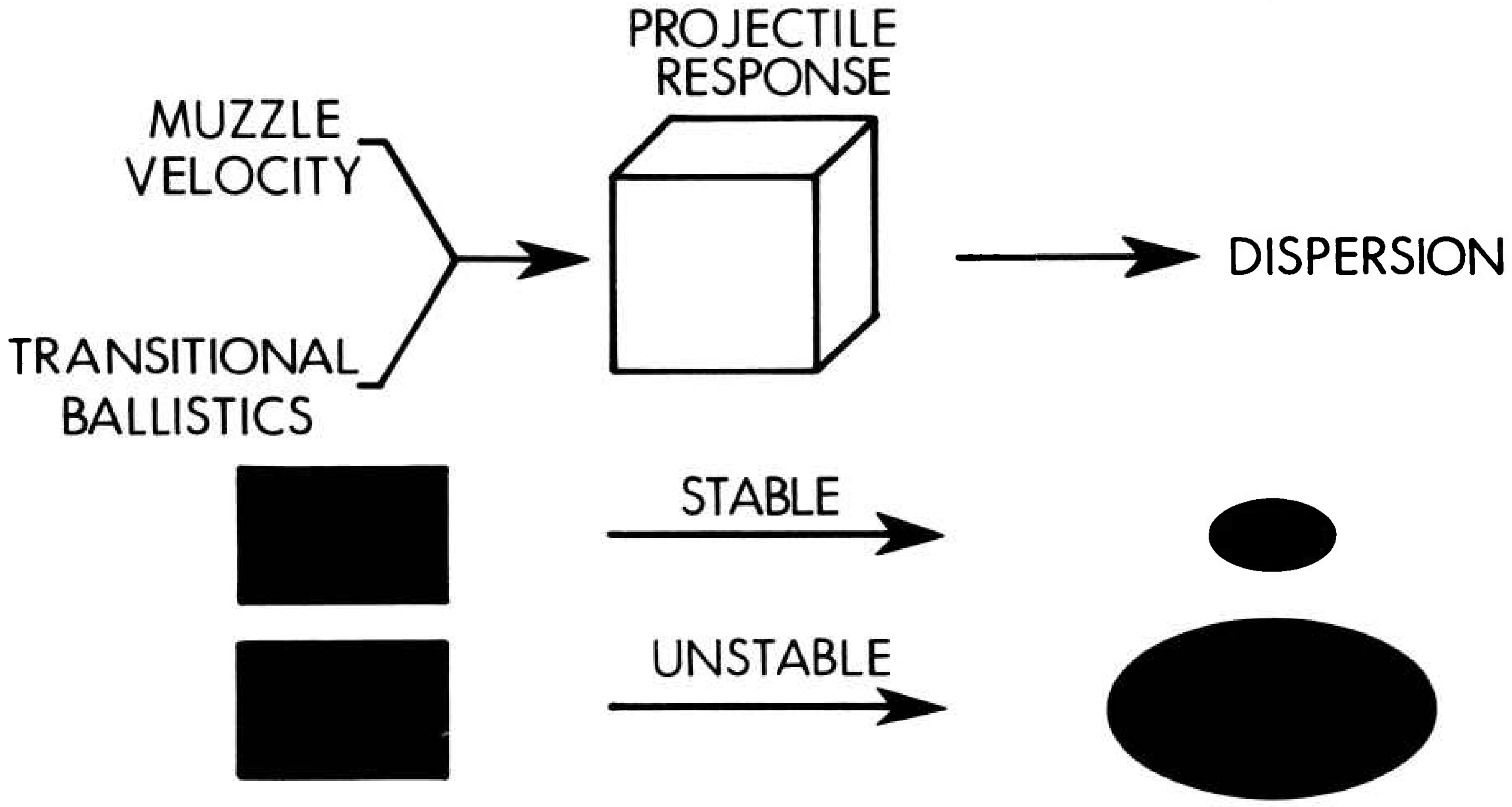


Figure 26. (U) Long Range Artillery

sabot separation. Transitional ballistics thus lies between those areas of interest to the exterior ballistician and to the interior ballistician and, indeed, is a hot potato which the one passes to the other.

The projectile response, the black box, is usually described in terms of stability or instability. As shown in Figure 27, the rectangle represents a spread of impact disturbances which for a stable shell give a small impact pattern, and for unstable shell a much larger pattern. Figure 27 is a photograph of two projectiles of current interest - the XM549 (a RAP projectile) and the extended long-range subcaliber 175mm round. These differ from older conventional M101 shell by having longer, more tapered shapes.

This long steamlined shape can cause stability problems. Primary contributors to this instability are the Magnus force and moment (see Figure 28). The Magnus force arises when a spinning body is flying in such a way that the axis of rotation is inclined with respect to the flight path angle. This Magnus force is important in the flight of a golf ball where the axis of rotation should be parallel to the earth's surface. The force is then vertical, adding lift to the golf ball and increasing range by over 50 percent. An improperly struck golf ball will have an inclined axis of rotation to the earth and will either hook or slice.

For a spinning projectile, the important quantity is the Magnus moment which causes the nose of the projectile to rotate around the trajectory. For some shapes at transonic launch velocities, the Magnus moment is strong resulting in serious instability. At lower Mach numbers, it is weak, and contributes mildly to instability. Figure 29 shows this angular motion as a function of time for two different launch disturbances induced by different interactions of the gun and projectile. One has a first maximum angle of 2° and the second has a first maximum of 8°. The launch instability causes the angle to increase for both cases; however, as the Mach number decreases, the response of the shell becomes quite sluggish and reaches a limit amplitude of angular motion. We see that one shell flies most of the time at

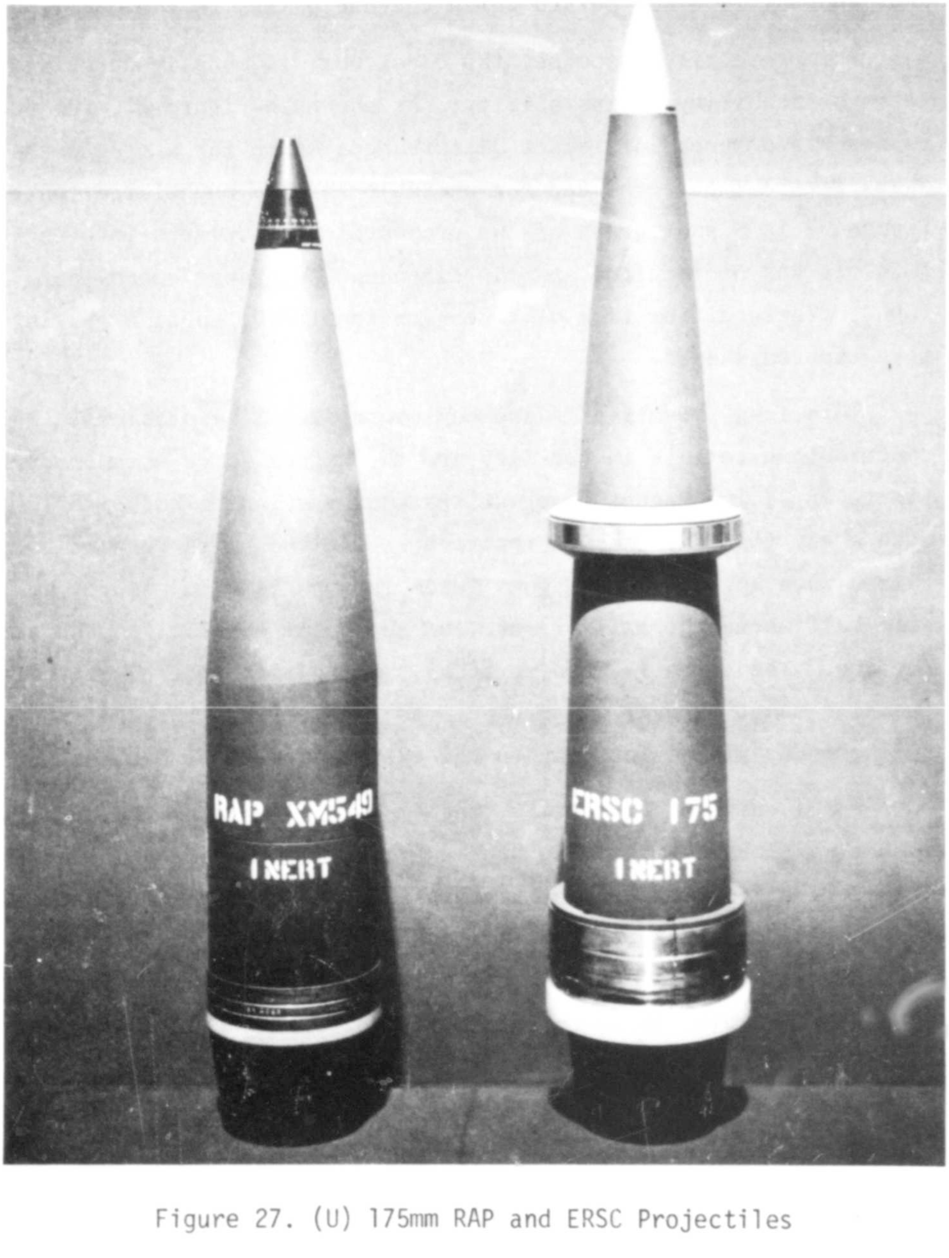
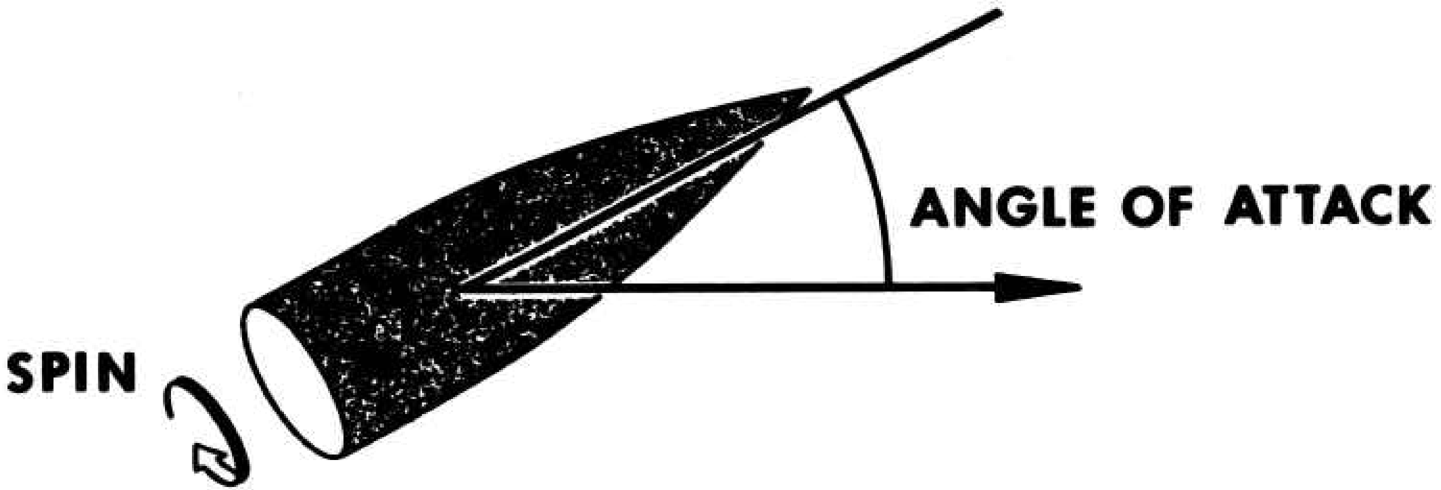


Figure 27. (U) 175mm RAP and ERSC Projectiles

MAGNUS INSTABILITY



MAGNUS MOMENT ROTATES NOSE ABOUT TRAJECTORY

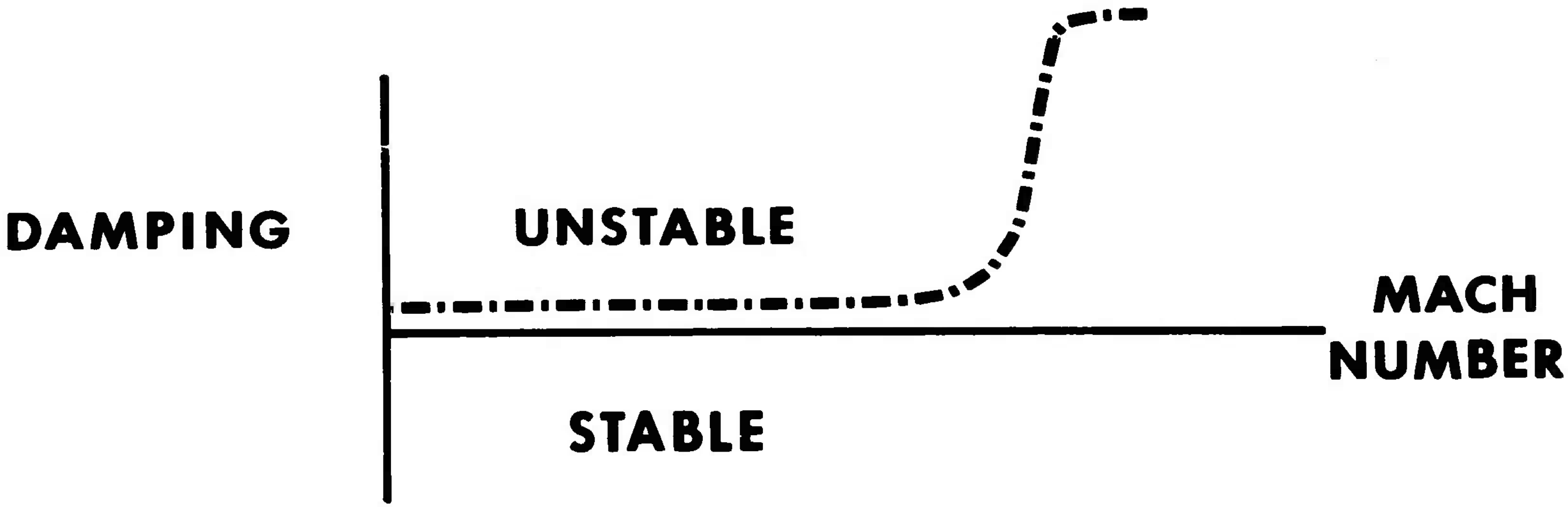


Figure 28. (U) Instability from Magnus Moment

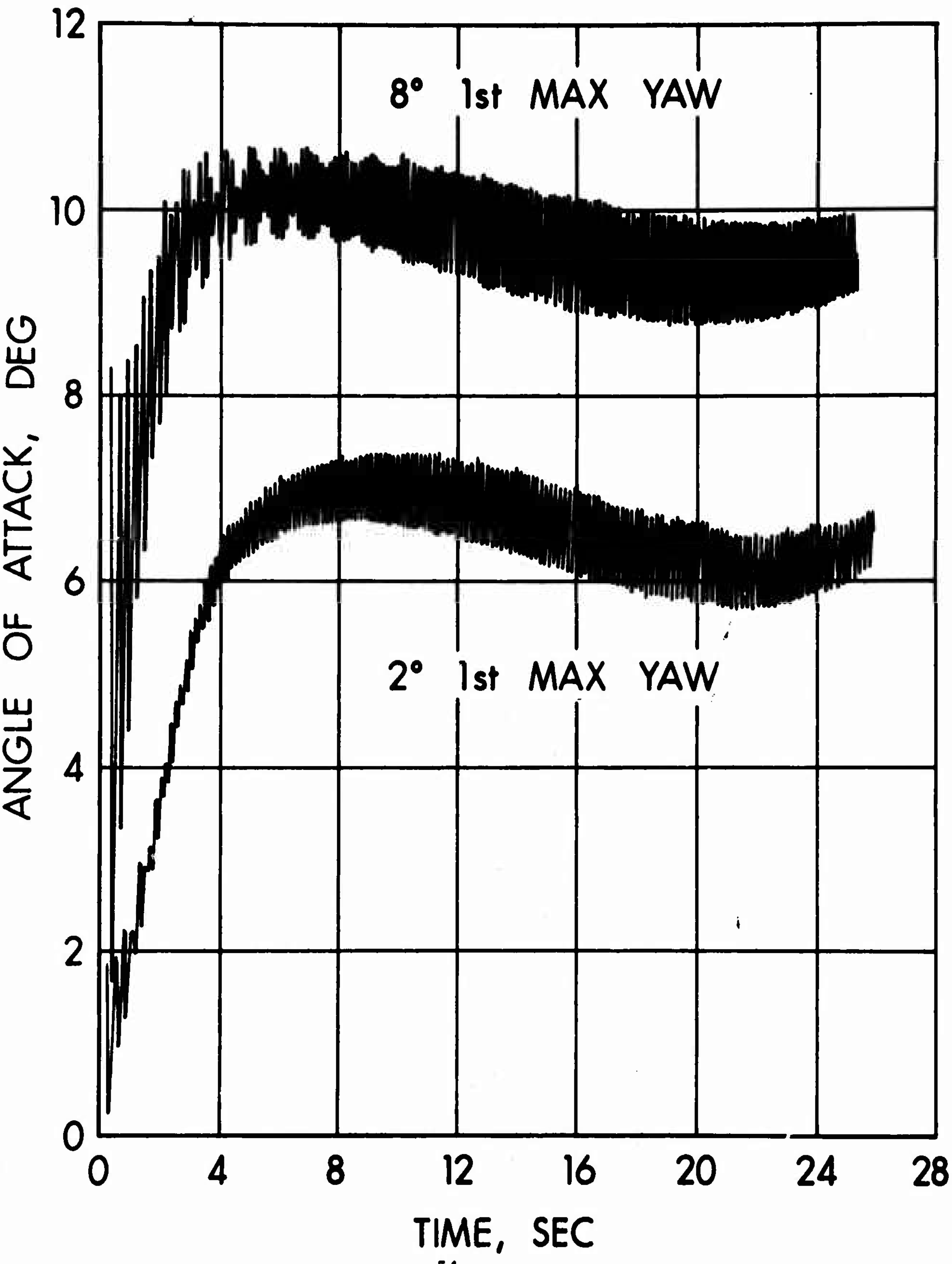


Figure 29. (U) Angle of Attack vs Time for Launch Disturbances of 2° and 1°

about 7° while the second shell flies most of the time at about 10°. This difference in average angle of attack yields a difference in drag of about 30 percent and a difference in range of one kilometer; the end result is an unacceptable dispersion size. The prediction and control of the Magnus moment on these long low-drag shapes are important problems for the exterior ballistician and are the subject of extensive study in wind tunnels and in free-flight testing.

The second objective to be illustrated is that of optimum striking conditions. The example is a small arms weapons. (See Figure 30.) Small arms are normally used at relatively short ranges by relatively unskilled soldiers. A measure of effectiveness of a small arm usually does not lie in its accuracy or precision but in its terminal effects. The idea is to cause the maximum damage to the target by transferring most of the kinetic energy of the projectile into creating a hole in the enemy soldier. The governing factors for terminal effects are striking angle and striking velocity.

The striking angle can be governed by a nonlinear Magnus force. Certain bullets exhibit a limit circular coning motion of 2° to 4° and are, therefore, more effective than bullets flying exactly at 0° angle of attack. To predict this limit behavior, knowledge of the Magnus moment for bullets is important. This problem differs from that of a spinning shell through the presence of full body rifling grooves.

The second item of interest is striking velocity. This we would like to maximize. In the case of ball ammunition, the flow over the base area of the projectile contains a dead water region roughly conical in shape. This region is a volume of low pressure and is an important contribution to the total drag of the projectile. Its relative weight can be as high as 30 to 40 percent of the total drag. In the case of tracer projectiles (see Figure 31), the tracer compound shown burning in the near wake increases the base pressure and thereby decreases the

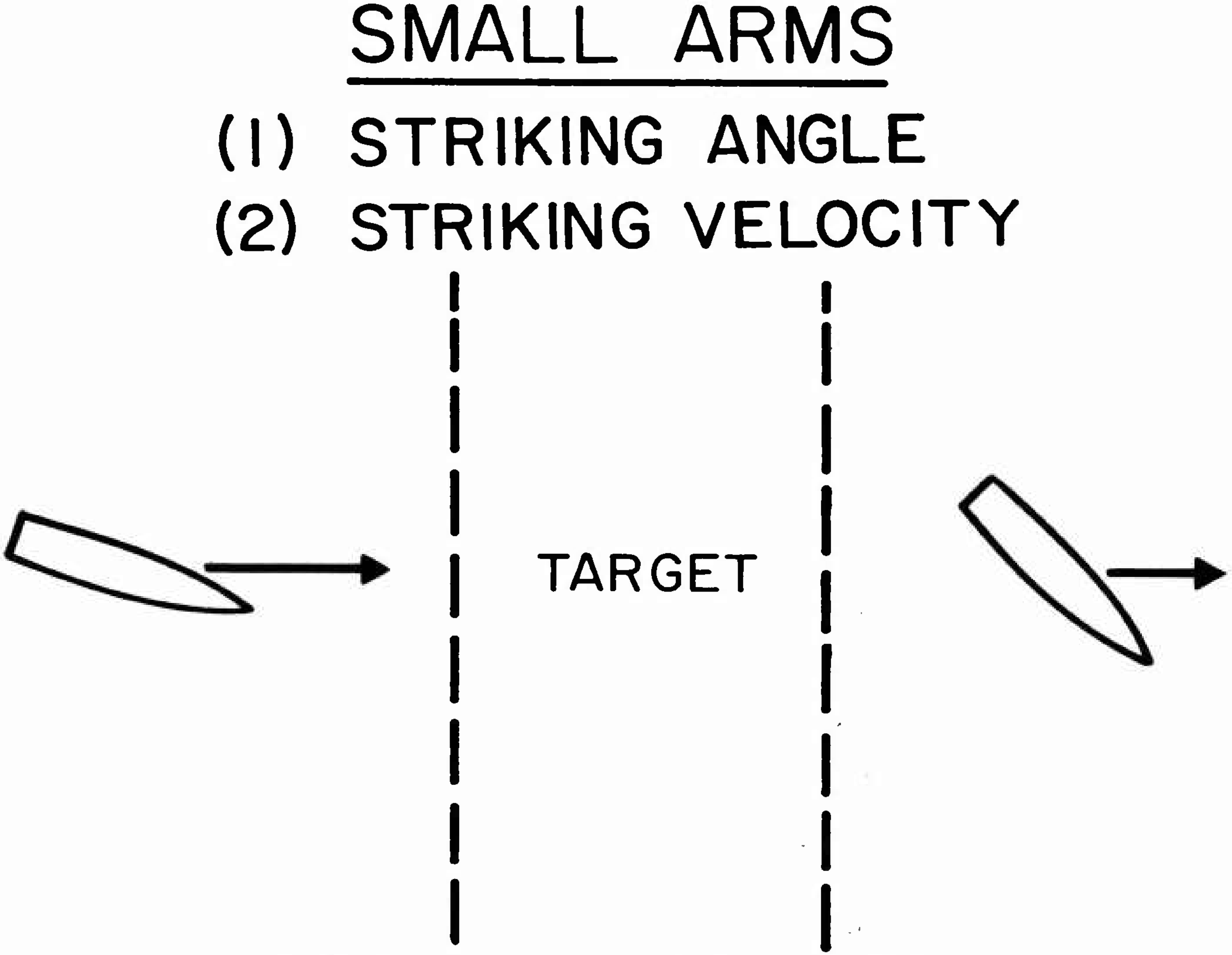


Figure 30. (U) Exterior Ballistics Applied to Small Arms

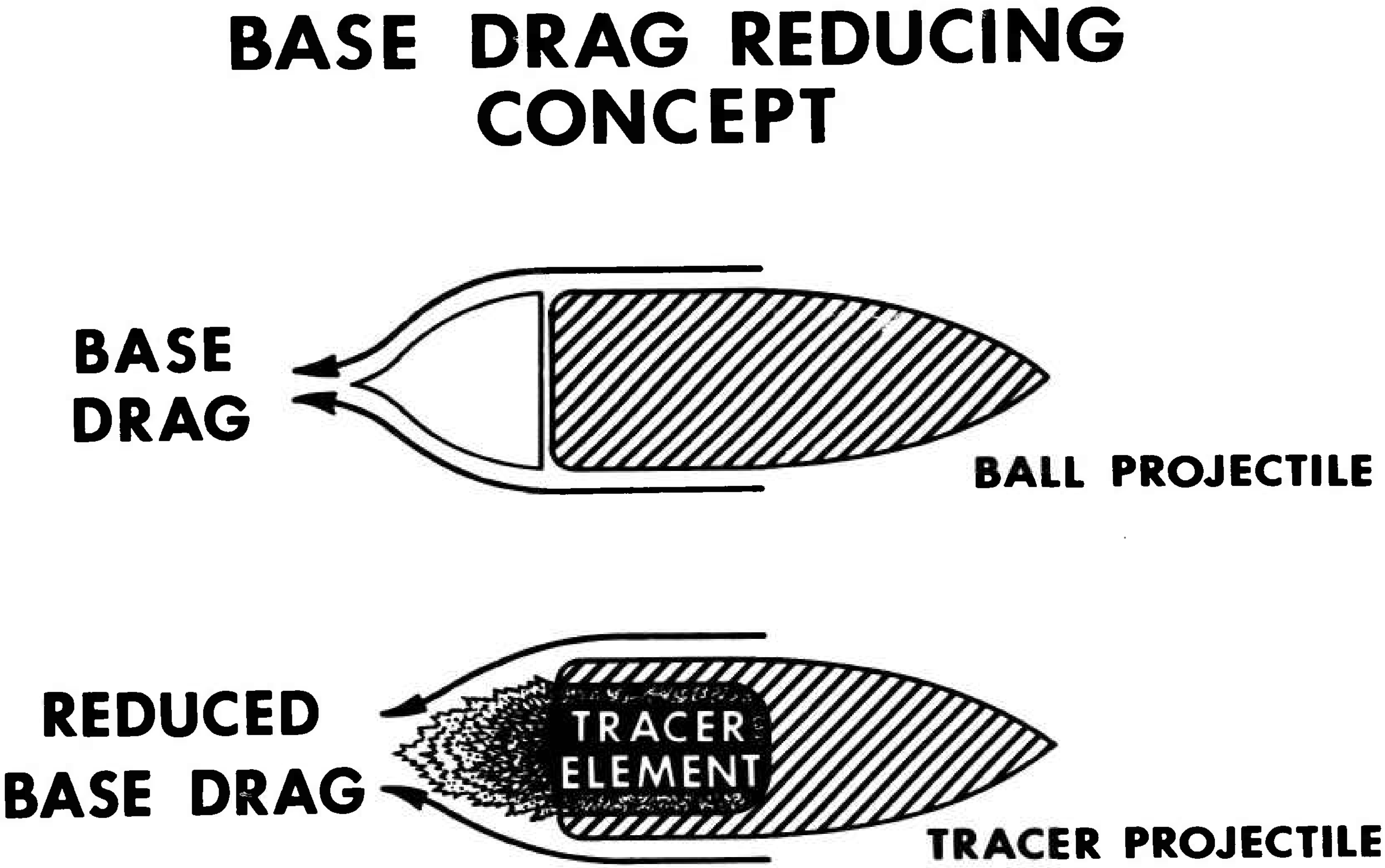


Figure 31. (U) Drag Reducing Tracer Concept

total drag. For the 7.62mm M62 bullet, the drag coefficient is plotted here as a function of Mach number. (See Figure 32.) Observe that the difference in drag between tracer and non-tracer bullets is as much as 30 percent. On the right of this figure actual measurements of drag coefficients are plotted as a function of position along the flight path from the ignition phase to the constant burning phase. For the first 20 meters, the tracer is not active and the drag is like that of the without-tracer projectile. As visual burning proceeds toward a constant burn, the drag decreases until it reaches a value appropriate to the tracer operation drag curve. The effect of the tracer operation on striking kinetic energy can be as large as 50 percent (see Figure 33), and thus the design of gas producers or base pressure modifying chemicals to improve striking energy is an important problem in bullet design.

The last objective is that of innovations, and several types of innovations are chosen for discussion. (See Figure 34.) These innovations are classified by categories of Flight Monitoring and Intelligent Projectiles.

The flight monitoring aspect is primarily directed toward eliminating registration of artillery fire. Registration is performed by firing 8 to 12 rounds at an observed point and adjusting fire until the point is hit. The necessary adjustment is then used to yield the weapon's effective muzzle velocity for later firing of that weapon. This registration suffers from inaccuracies due to the use of observers and, indeed, in some cases the observers' errors are as large as the velocity errors that the user attempts to measure. It also suffers from the tactical disadvantage of revealing the battery's location to the enemy.

The first suggested innovation is the use of a direct muzzle-velocity-measuring apparatus at the battery which would then allow a small number of shots fired at short range. This could be done with a Doppler radar (see Figure 35). A disadvantage of this technique is

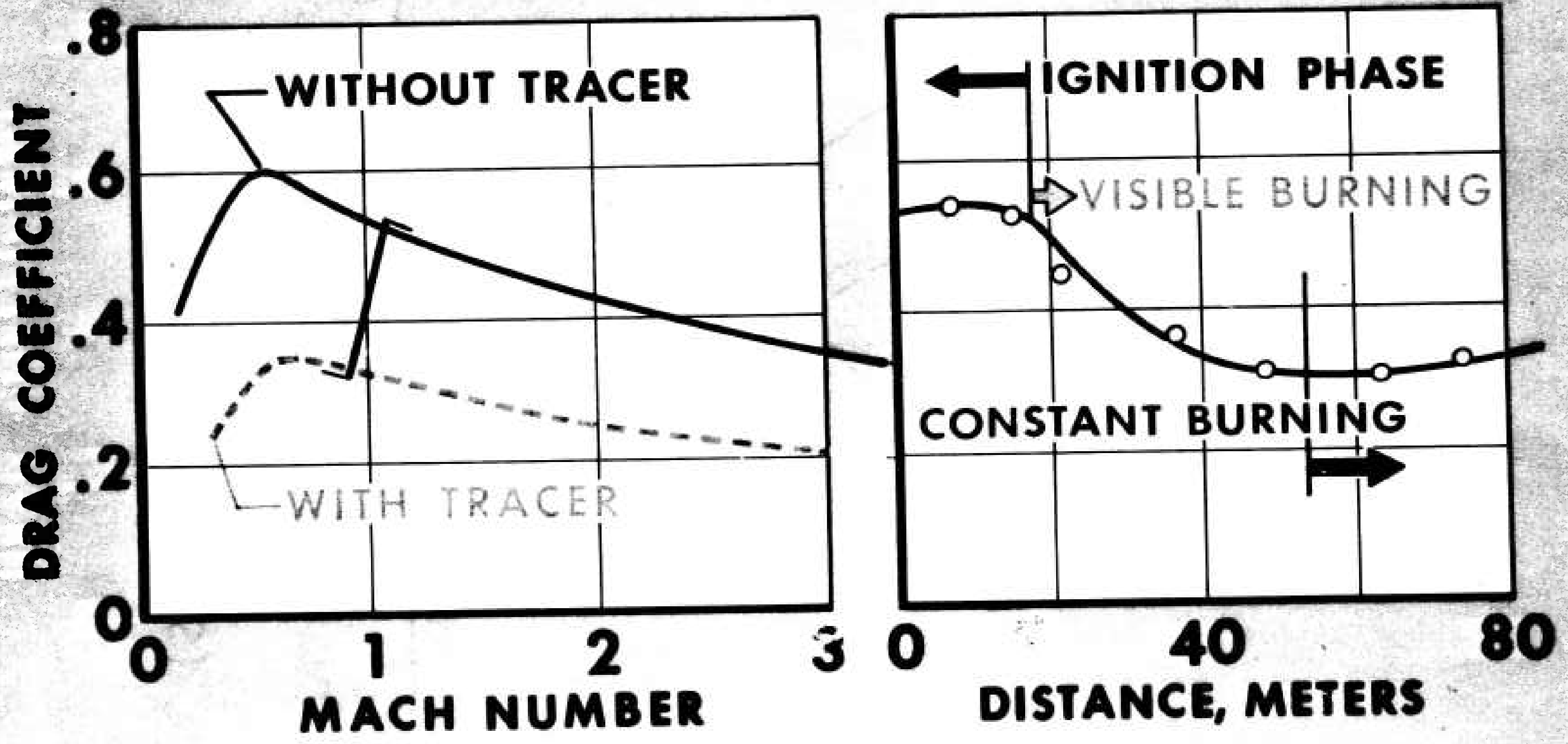


Figure 32. (U) Effects of Drag Reducing Tracer on 7.62mm M-62 Bullet

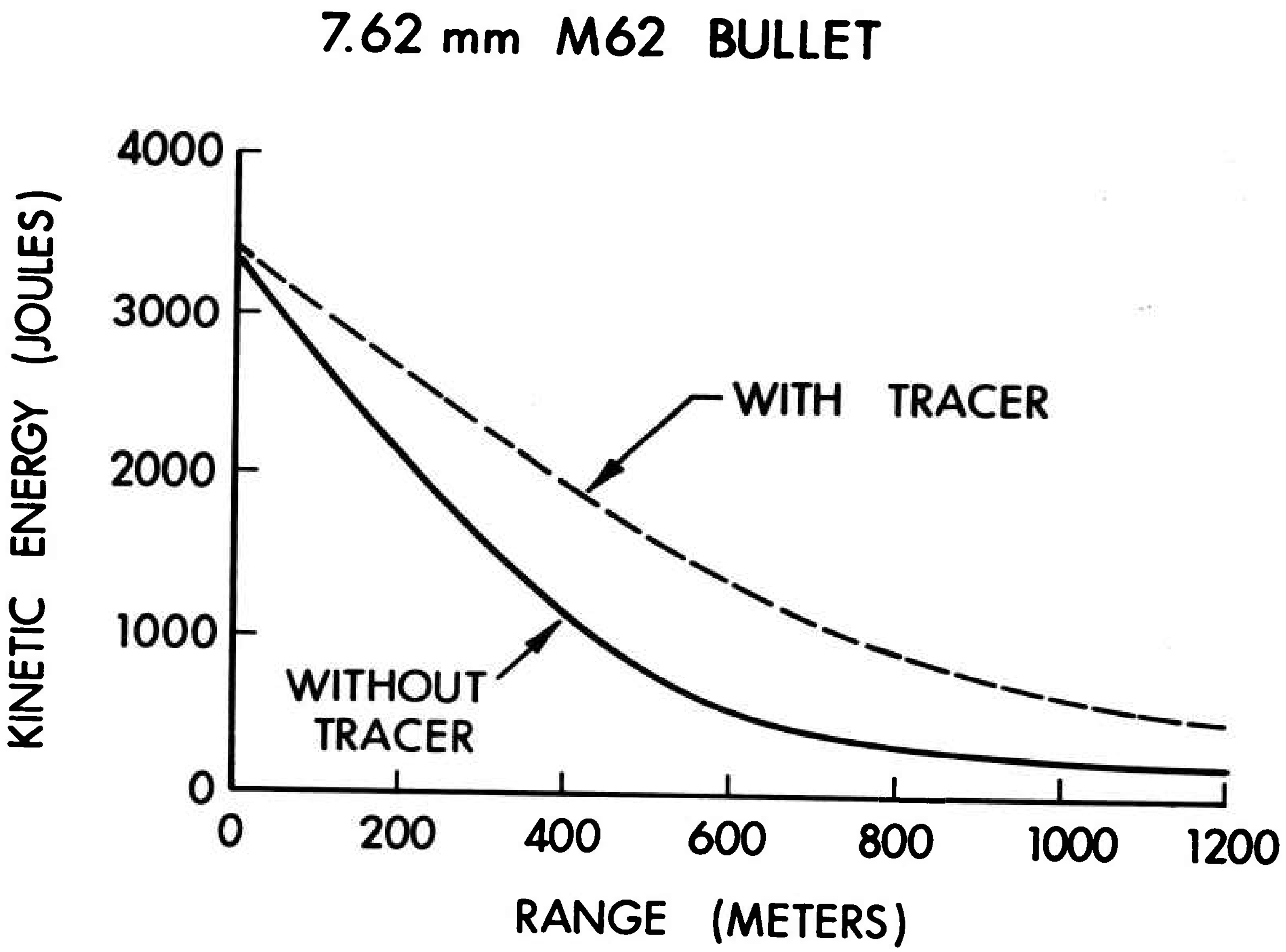


Figure 33. (U) Kinetic Energy vs Range for 7.62mm M-62 Bullet

INNOVATIONS

A. FLIGHT MONITORING

1. MUZZLE VELOCITY MEASUREMENT
2. TRAJECTORY MEASUREMENT

B. INTELLIGENT PROJECTILES

1. FORWARD LOOKING
2. BACKWARD LOOKING
3. PASSIVE

Figure 34. (U) Exterior Ballistics Innovations

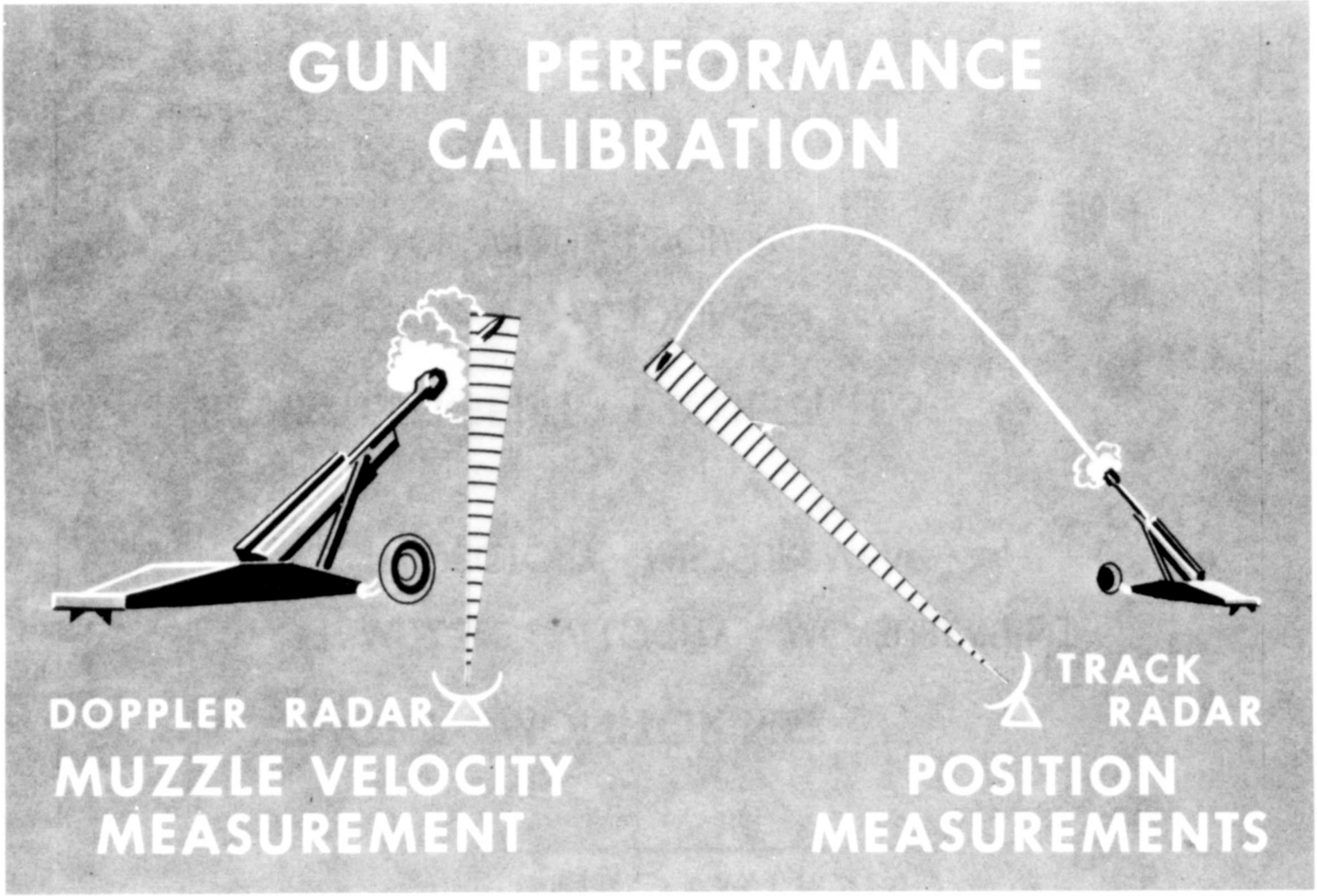


Figure 35. (U) Exterior Ballistics and Field Artillery

that it does not incorporate range wind or air density errors in the way that registration fire does. A second approach is to actually track the projectile over its trajectory with a radar and compare the radar track with the firing table predictions. By firing several rounds in two directions, it should be possible to separate range wind and muzzle velocity effects. If the coordinates of the target with respect to the radar are well known, then the radar could be used to adjust fire. Both of these applications improve the ability of the artilleryman to place the center of impact at a desired point.

The next two examples illustrate efforts to reduce the size of the impact area by utilizing intelligent shell. To improve the impact dispersion, a shell can either look forward to the target or back at its launcher disturbances. An example of a forward-looking shell would be the terminal homing projectile which is the objective of the CLGP program. The subject of terminal homing was covered in a recent technical review. The second concept, a rearward-looking shell, is a shell that could measure its velocity and make a small vernier adjustment by either a tracer, a small jet or a drag-producing device, with possibly four or five increments of control possible. The actual measuring device could be Doppler radar at the battery with a computer and transmitter. The shell would carry a fairly small, inexpensive receiver with a four or five-increment, low-impulse thruster or drag producer. Since the muzzle velocity in some cases causes as much as 50 percent of the total weapon dispersion, this device would be a substantial improvement in projectile dispersion with much cheaper projectiles than those required in the CLGP program. The lower cost is due to the fact that the expensive computers and velocimeters are reusable since they are located at the battery and not on board the projectile. A more sophisticated version would measure the deceleration close to the gun and infer from it the launch angular disturbances. This would allow the command from the battery to the projectile to incorporate the increased drag due to mal-launch.

The last example of an intelligent shell is that of a passive shell which lets nature take its course. (See Figure 36.) This is the ring airfoil grenade (RAG), developed at Edgewood Arsenal, which makes use of gravity and the memory of a gyroscope for its effect. The ring airfoil is designed to be extremely stable gyroscopically and, therefore, holds its orientation in space over its entire flight. The trajectory curves due to gravity and, therefore, the ring airfoil points at greater and greater angles over the trajectory. This upward angle of attack produces lift which can double the range of the projectile. This device, though ingenious, does, however, produce additional theoretical problems for the exterior ballistician.

In summary then, Exterior Ballistics is an old science with new ideas and new problems. The solution of these problems and the application of these ideas to Army weapons will be of great value to the Army in the future.

(CONFIDENTIAL) IV. INTERIOR BALLISTICS TECHNOLOGY REVIEW (U)

Interior ballisticians are concerned with the entire scope of events which take place inside a gun or rocket. In guns, Interior Ballistics deals with the combustion chamber, the igniter, bag charges (or packed bed propellant), the projectile, and the gun tube. In rockets, Interior Ballistics deals with the propellant, the igniter, and the nozzle (see Figure 37). The major portions of Interior Ballistics to be discussed are: ignition/combustion, gas dynamics, projectile-launcher interaction, and thrust alignment. Other major areas of concern which contribute to, and above all, utilize Interior Ballistics performance calculations are solid properties, propellant chemistry, weapon dynamics, and weapon-mount interactions. (See Figure 38.)

Recognizing that the status ignition/combustion of propellants is currently unsatisfactory, AMC has launched a cooperative, long-range program to take a somewhat more fundamental approach than has been

Figure 36. (U) Ring Airfoil Grenade

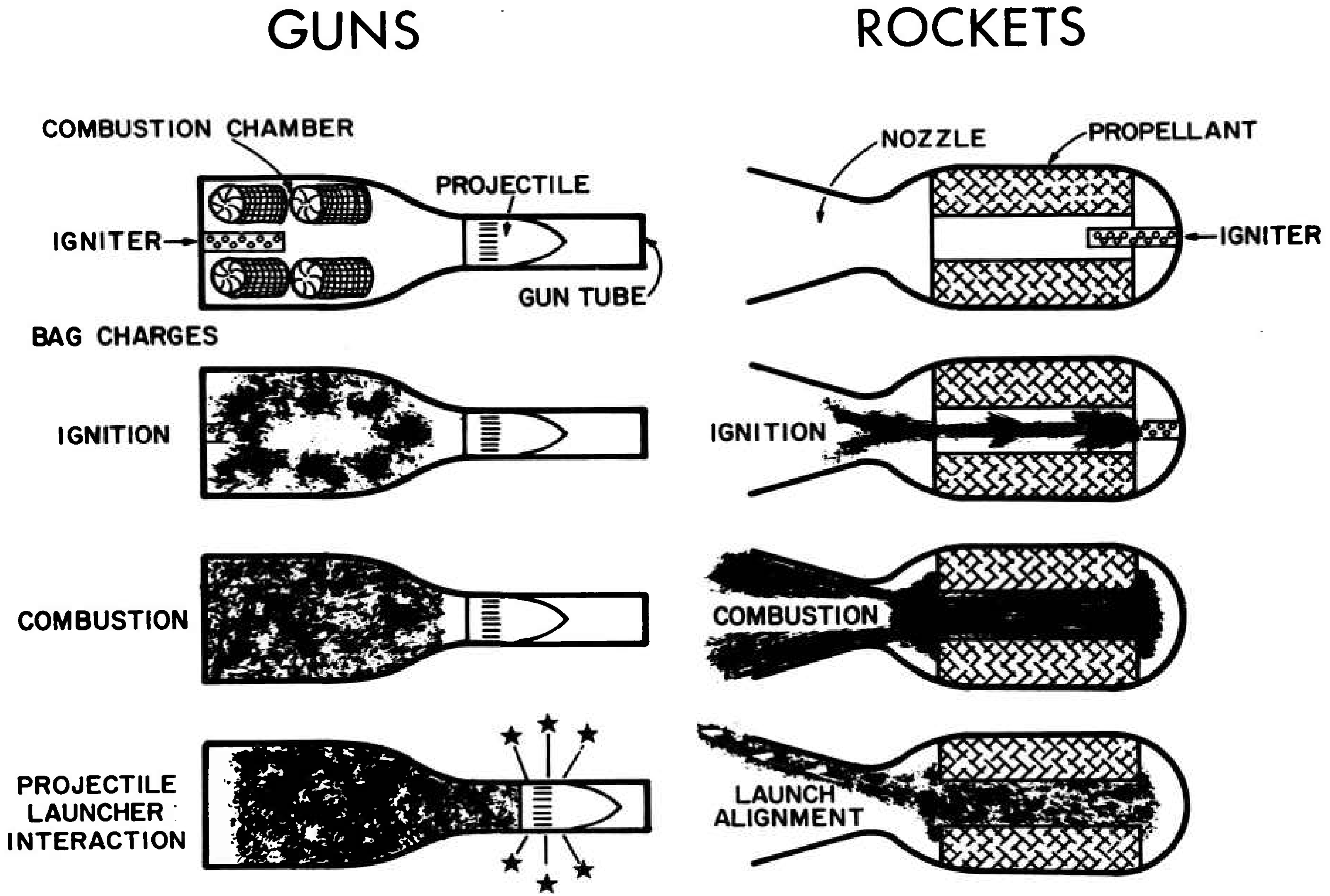


Figure 37. (U) Interior Ballistic Considerations in Guns and Rockets

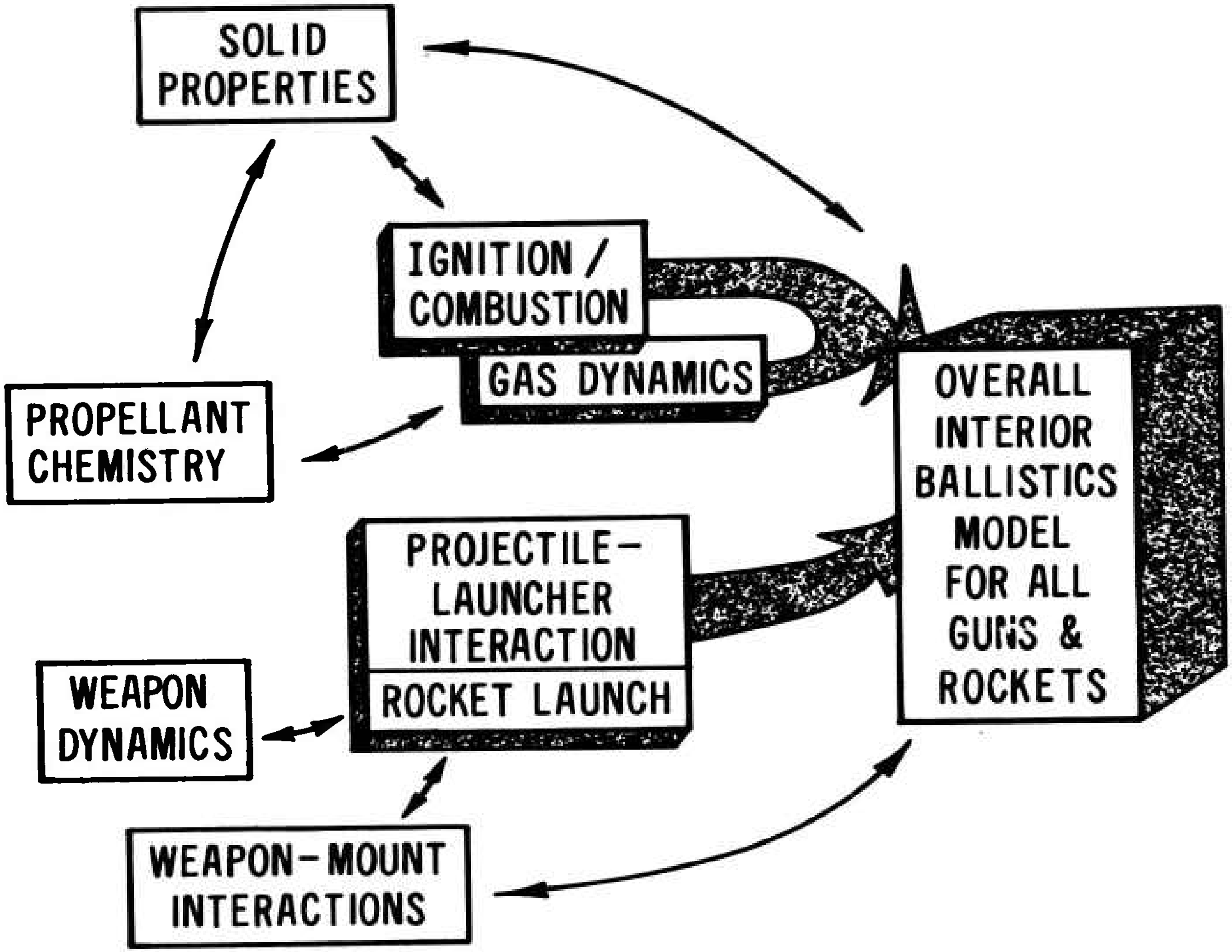


Figure 38. (U) Interior Ballistics Model Interface for Guns and Rockets

taken in the past. The aims of such a program are (1) to reduce the effort in terms of cost and time now being expended on quick engineering solutions required to solve problems as they arise in weapon systems, (2) to provide enough understanding of the basic ignition process to help minimize ignition problems before a new weapon system is fielded, and (3) to provide the model and understanding necessary to get tailored or programmed ignition and combustion.

In a large caliber gun having bag charges or in small arms cartridges where propellant packed beds must be ignited, normal ignition is presumed to occur as an instantaneous and all-grain-consuming event. But, of course, normal ignition is not ideal, and a typical pressure-time history is shown in Figure 39. Efforts to obtain uniform and complete ignition, oftentimes result in overdesign of the igniter which causes grain breakup and a pressure-time history as indicated. Along with all the other concerns, poor coupling of energy transfer can also be expected between the igniter and bag charge. A defective igniter train can be troublesome. One of the major goals of the AMC ignition/combustion program is to permit programmed or tailored ignition and combustion. Once this goal is achieved, a pressure-time history tailored to the requirements of a particular weapon system will be available.

Hangfire or delayed ignition is caused through generation of combustible gases from a fizz-type burning of the propellant. These products of incomplete combustion eventually attain ignition and explode. Although the coupling of this gas phase explosion with the propellant bed is not well understood, pressures well over the design limits of the chamber and gun or rocket are not difficult to rationalize.

In rocket motors, normal ignition takes place at the head end of the rocket. Hot particles and/or gases are then expected to spread the flame over the entire exposed propellant surface. A typical pressure-time history is shown in Figure 40, where an ignition spike occurs which

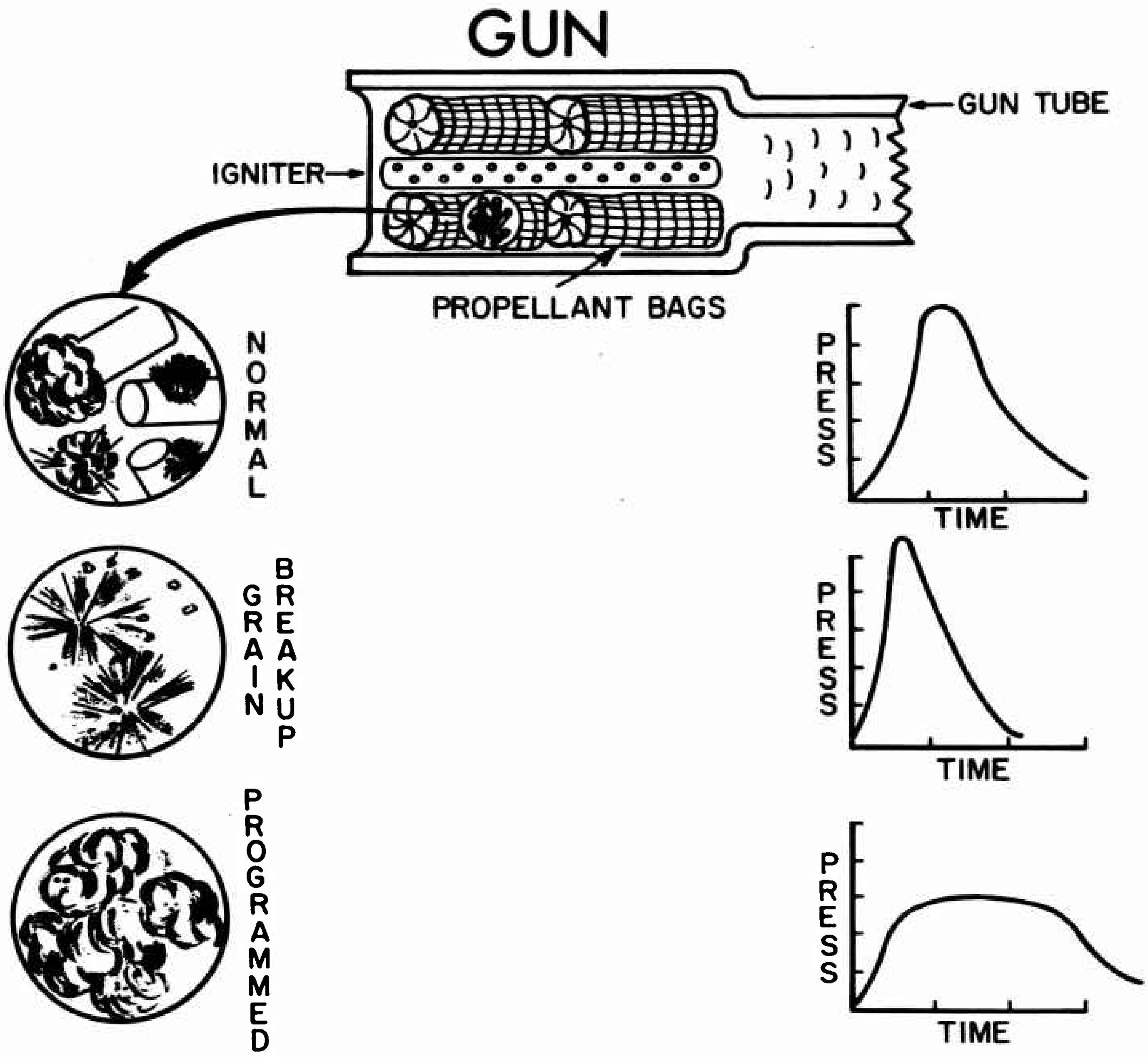


Figure 39. (U) Pressure/Time Curves for Guns

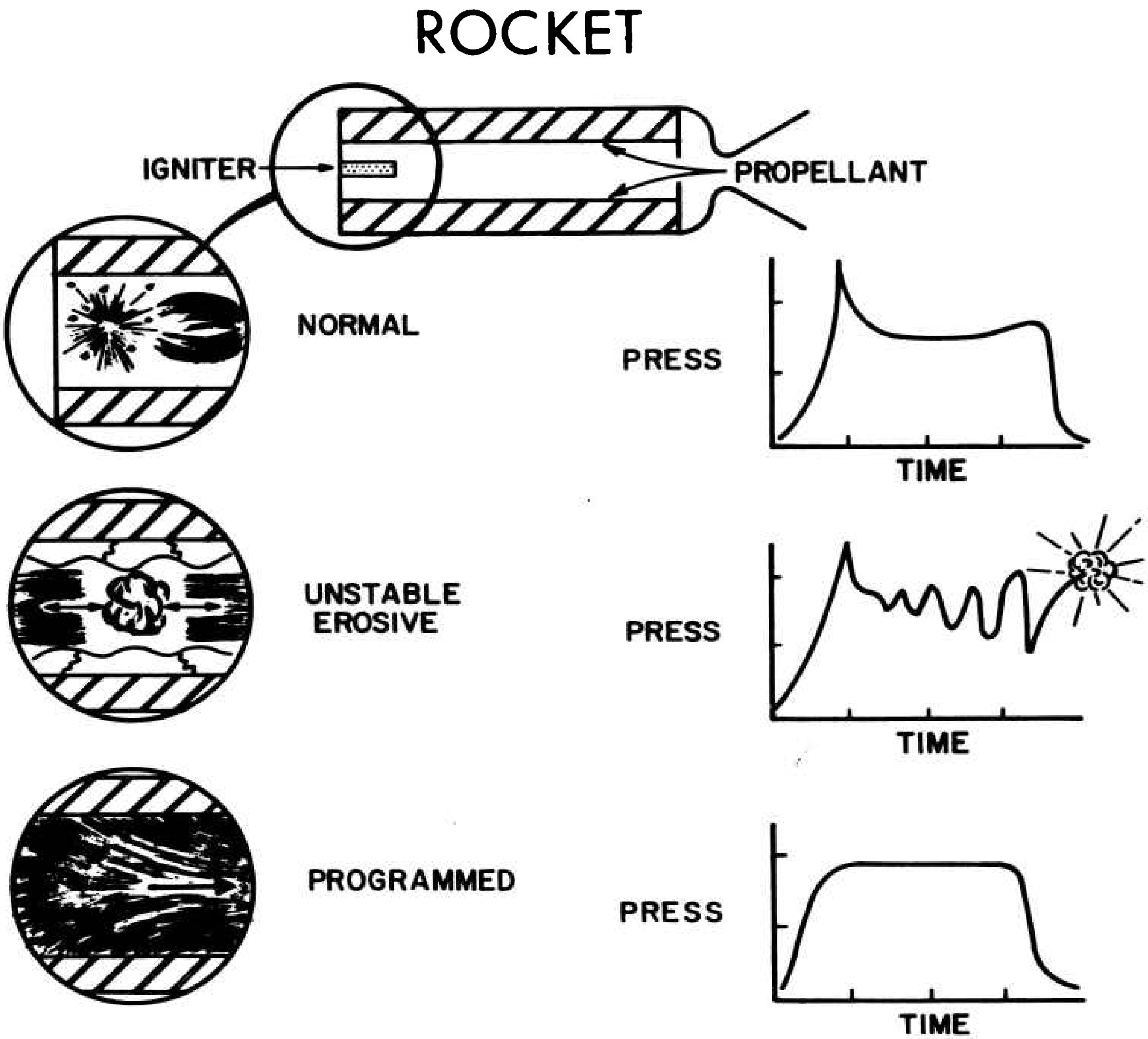


Figure 40. (U) Pressure/Time Curves for Rockets

can exceed the design strength of the rocket case. Hence, a rocket casing must be made stronger and heavier to withstand this pressure. On occasion, after ignition, pressure waves will build up inside a rocket motor which can lead to unstable burning and a catastrophic failure. Another critical concern, especially with higher energy propellants, is the possibility of deflagration to detonation transition.

Therefore, a major goal of the ignition/combustion program will be to develop a method of producing tailored, ignition-spike free processes in a rocket motor.

Gas dynamics plays an important role, indeed, in Interior Ballistics. For example, in small arms, such as the M-16 rifle, (see Figure 41) the gas feed system provides a source of great concern; as hot propellant gases pass through the many critical openings, heat loss occurs and particles of carbon or unburned propellant cause clogging.

In large caliber guns during ignition and early combustion, cycle pressure waves and expansion waves often pass back and forth in the gun tube. Pressure waves are probably due primarily to the ignition process and the expansion waves result from projectile motion. The flame front progression through the packed propellant bed is accelerated rapidly by the pressure waves and affects the overall burning. The 175mm gun provides a good current example of this typical gas dynamics problem.

Rockets are classic examples of gas flow with mass addition. Low subsonic velocities inside rocket motors are desirable for two reasons: (1) at higher velocities the nozzle has less pressure with which to operate, and the specific impulse goes down, (2) the increase in erosive burning at higher velocities causes difficulty with burn-thrust of the case, especially near the nozzle end of the rocket. Therefore, mathematical models and comprehensive combustion models that describe the Interior Ballistics of rockets must account for all of the conditions mentioned to be effective.

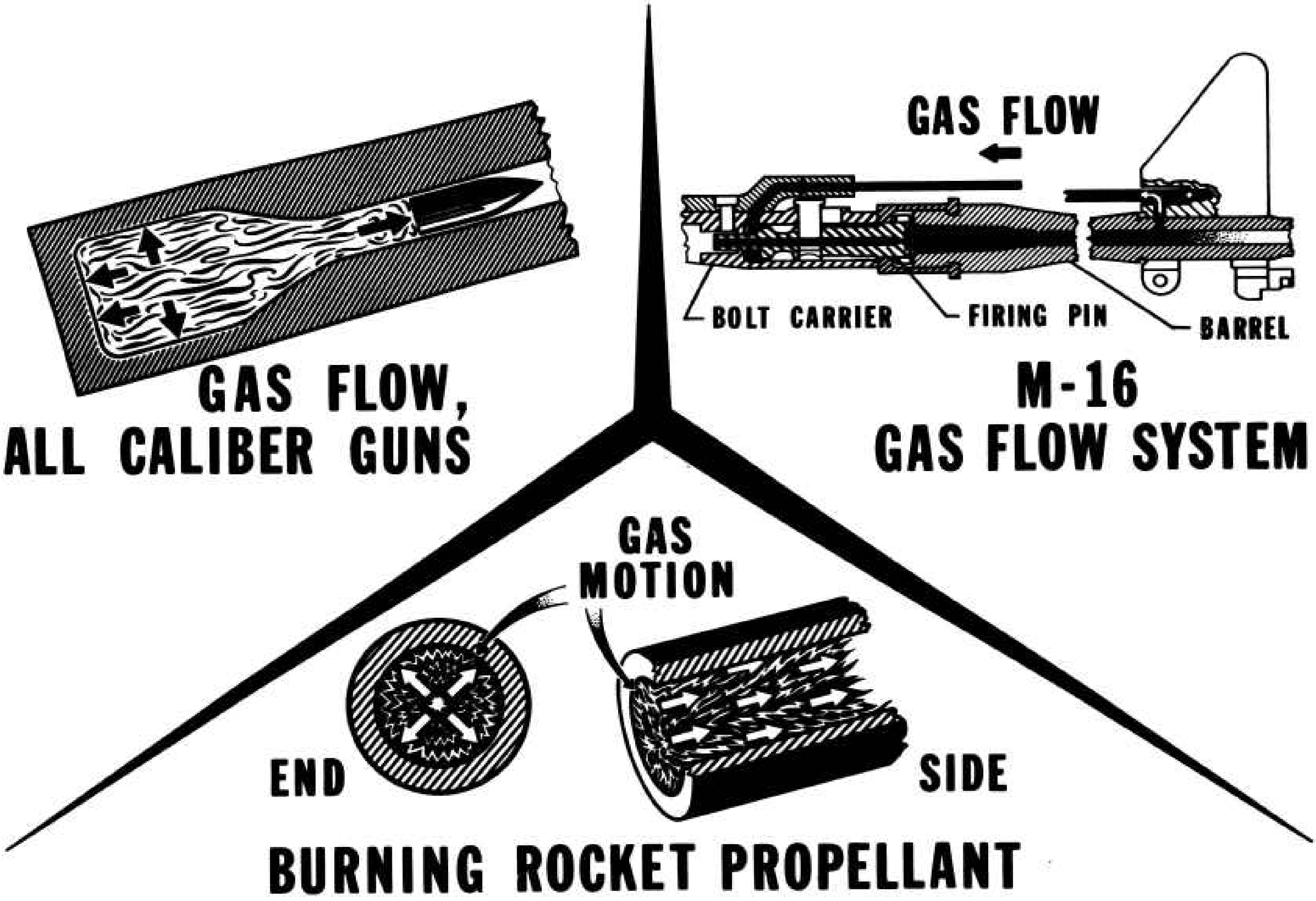


Figure 41. (U) Gas Dynamics in Guns and Rockets

Thrust mal-alignment in rocket motors may very well have its prime origin in asymmetric gas flow through the nozzle. The various physical and chemical aspects of thrust mal-alignment are of critical concern in the gas dynamics of rockets.

Combustion instability reactions in rockets have already been mentioned as shown by the pressure-time curves in Figures 39 and 40. A common means of combatting instability is to insert resonance rods having a variety of cross-sectional shapes. (See Figure 42.) This method is strictly "cut and try" and adds additional, and otherwise unneeded, weight to the system. The AMC combustion program will hopefully provide the understanding required to eliminate this instability without the added disadvantages.

Uneven burning just after ignition may play a key role in the difficulties still plaguing the 152mm KE round (see Figure 43). In studying the dynamics of the sabot we generally assume that the gas pressure is uniform over the exposed surfaces of the sabot and projectile. This assumption cannot be valid, however, in light of what has already been presented. This brings into focus the bigger problem that sophisticated systems with large but non-uniform cross-section may not continue to respond to such simplifying assumptions. Sabot technology, in general, needs a good, basic, concerted effort placed on it.

In approaching the overall objectives of the AMC ignition/combustion programs to reach tailored and programmed response, it is to be expected that significant contributions will be made in the improvement of current and future weapon systems. Consider lightweight, hand-held, infantry antitank weapons, such as the advanced LAW. One of the candidate systems is a recoilless rifle while the other is an in-tube burnt rocket. The design of the recoilless rifle system must take into account the variation in Interior Ballistic performance with initial propellant temperature. If the rifle is required to accelerate the projectile to a

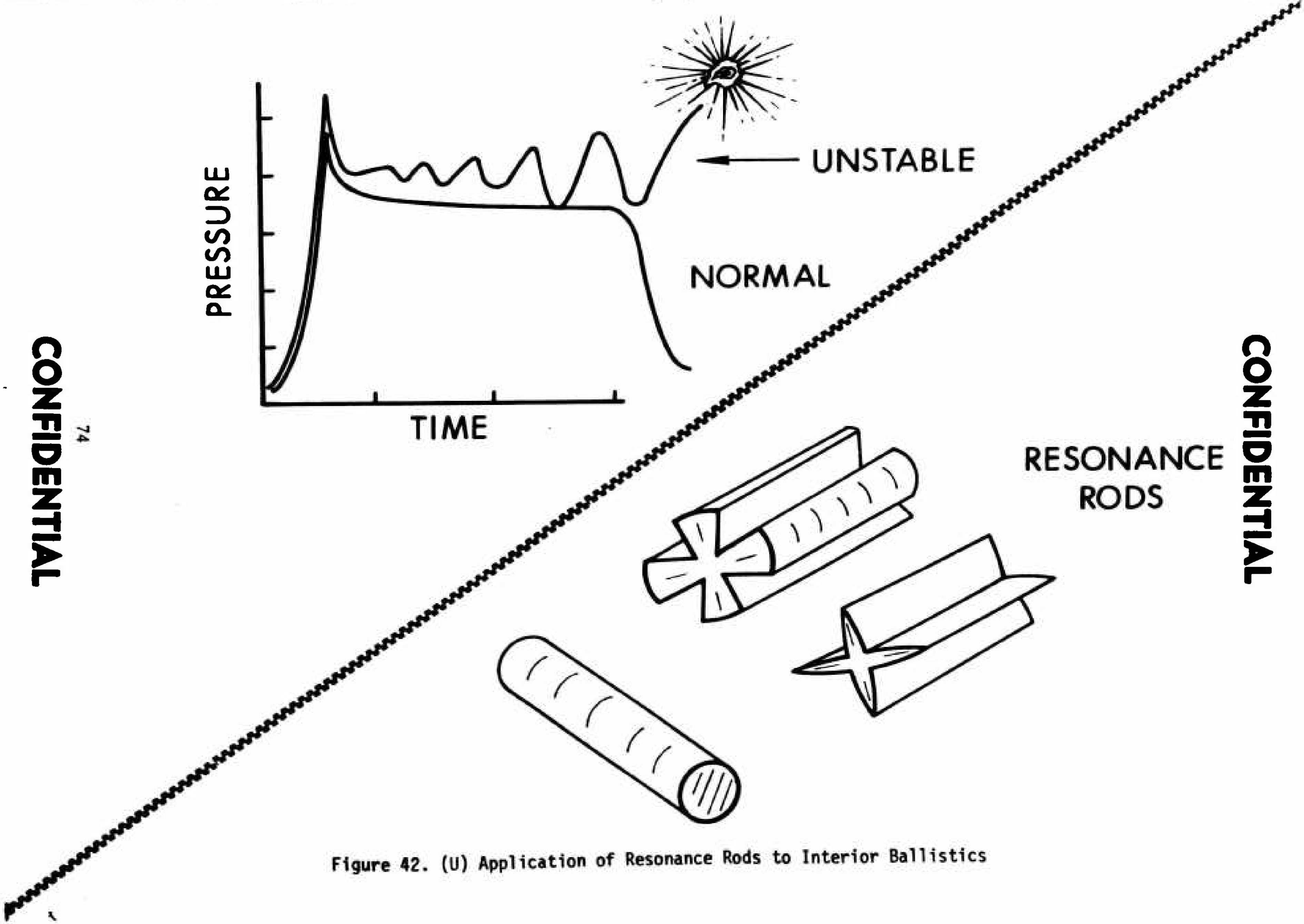


Figure 42. (U) Application of Resonance Rods to Interior Ballistics

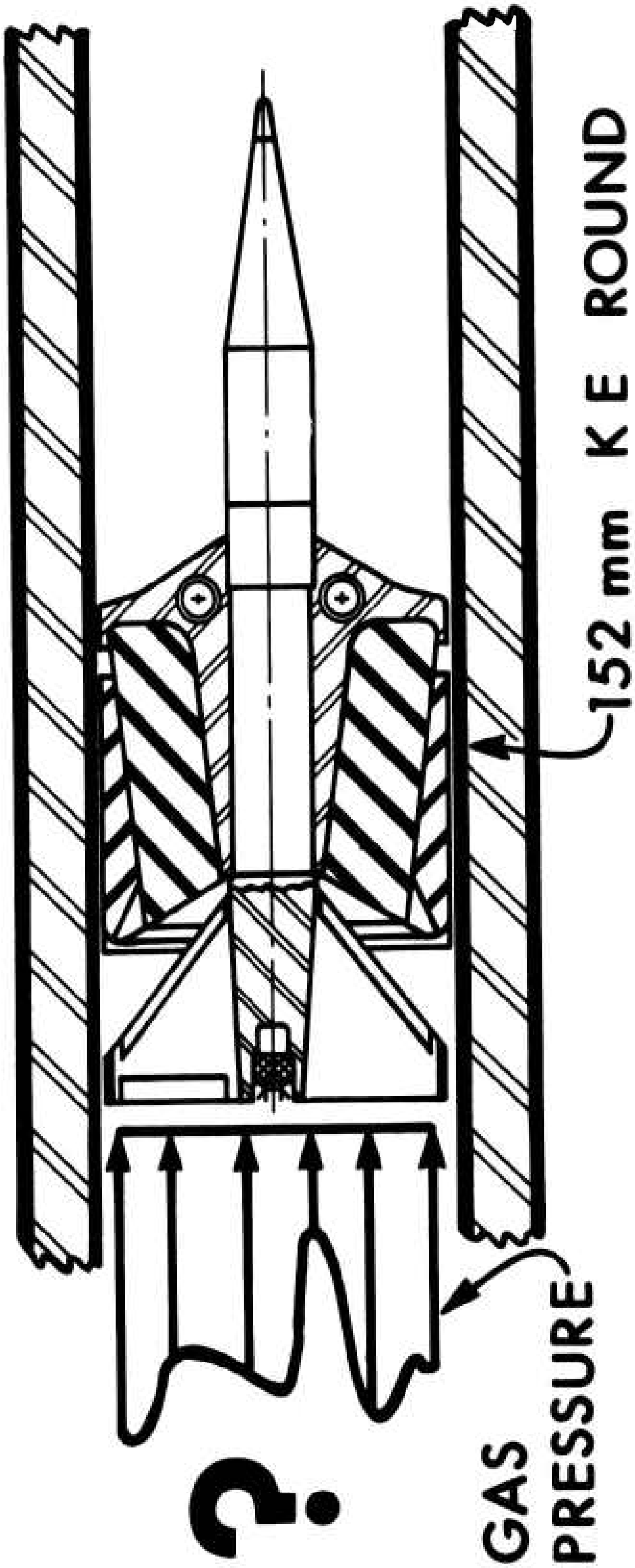


Figure 43. (U) Kinetic Energy Round, 152mm

specified minimum velocity, the tube must be longer (and heavier) than one designed for operation at 70°F. At lower temperatures, changes in propellant combustion, such as reduced burning rate, will result in lower pressures and lower muzzle velocities for a given tube length. Conversely, at higher temperatures, increased combustion rates will result in higher pressures with a resultant need for thicker (and heavier) tubes. From a different viewpoint, for fixed system weight, the specified velocity will be significantly lower than what we could achieve if there were no variation in performance with initial propellant temperature. Some actual values for the system under development are shown in Figure 44. Note that the velocity variation over this temperature range is approximately 11 percent, and that the pressure variation is approximately 16 percent.

In-tube, burnt-rocket design suffers from similar practical considerations. Because the rocket exhaust would be aimed directly at the firer as the rocket leaves the launch tube, the rocket must burn out in the tube. Therefore, in addition to the lower muzzle velocities at lower temperatures, an operational safety problem makes it necessary to make a tube longer than necessary for 70°F firing. This is the major problem with shoulder-fired weapons.

Artillery weapons systems, such as the 175mm gun (see Figure 45), are also adversely affected by variation in performance with initial propellant temperature. For the 175mm gun (M113) firing the HE M437 projectile, variations in initial propellant temperature produce the following variations in Interior Ballistic performance: 85 psi/degrees F at 50,000 psi (31%), and 0.75 fps/degree F at 3000 fps (5%). (See Figure 46.) Gun tubes must be heavier and less mobile in consideration of the temperature variation in the tube design.

ADVANCED LAW

TEMPERATURE DEPENDENCY

- **RECOILLESS RIFLE**
  - SPECIFIED VELOCITY
  - SPECIFIED SYSTEM WEIGHT
  - LONGER (HEAVIER) TUBE REQUIRED

INITIAL PROPELLANT TEMP. EFFECTS

TEMP RANGE: -40 TO +140 °F

VELOCITY: 150 FPS IN 1320 FPS

PRESSURE: 1250 PSI IN 7500 PSI

- **IN-TUBE BURNED ROCKET**
  - LONGER TUBE REQUIRED

Figure 44. (U) A Critical Parameter Associated with Advanced LAW

Figure 45. (U) M113 - 175mm Gun

M113 - 175MM GUN

M437 - H.E. PROJECTILE

85.0 PSI/°F VARIATIONS AT 50,000 PSI

0.75 FPS/°F VARIATIONS AT 3,000 FPS

Figure 46. (U) Variations in Interior Performance, M437, 175mm HE Projectile

With a better understanding of initial propellant temperature efforts, several other expected practical outcomes may be derived from the AMC ignition/combustion programs: (1) reduction of gun tube erosion, (2) reduction of heat transfer problems in rapid fire weapons and Gatling weapons, (3) reduction of signature effects, smoke and flash, and above all, (4) the expected ability to tailor or program the ignition/combustion process (see Figure 47).

Under certain battlefield conditions where zoned artillery is used, it is critically important that the battery commander be assured of a high first-round hit probability, or risk losing his target to cover. This applies whether the fire-mission is for close-in supporting fire for friendly troops or for counteracting infiltratration of perimeter defense. In these instances, he must rely on the predictability and reproducibility of his weapon to defeat the target without endangering friendly troops. Here, muzzle velocity reproducibility of his weapon becomes a major area of concern. Ballisticians have labeled a number of the velocity variations as: first-round, creep, crash, order-of-fire, and storage effects.

It is not the intent to imply that the effects cited are all, or in part, present in all artillery weapons, or, for that matter, that they even exist at all charge levels for the same weapon. They do exist in some instances, however, and, as such, can seriously affect the accuracy of the weapon and the intended field mission.

A nonmetallic rotating band program has been pursued on the 105mm Howitzer (M102) (see Figure 48), in a cooperative effort among AMC laboratories to alleviate some of these problems. Several materials, tried in lieu of copper or gilding metal, were carbon-fabric epoxy, carbon-yarn epoxy, asbestos-phenolic and Kraft paper epoxy (see Figure 49). Figure 50 shows the results of firings using gilding metal bands and sintered iron bands. Notice the pronounced first round effect and then the creep with the following rounds. Observe the results obtained with the paper-epoxy bands - quite an effective improvement!

▨ **REDUCTION OF:**

- GUN TUBE EROSION
- HEAT TRANSFER PROBLEMS
  (RAPID FIRE WEAPONS)
- SIGNATURE EFFECTS, SMOKE & FLASH
- UNSTABLE BURNING

▨ ▨ **PROGRAMMED IGNITION – COMBUSTION**

Figure 47. (U) Additional Practical Advantages to be Derived from AMC Ignition/Combustion Programs

Figure 48. (U) Lightweight Howitzer

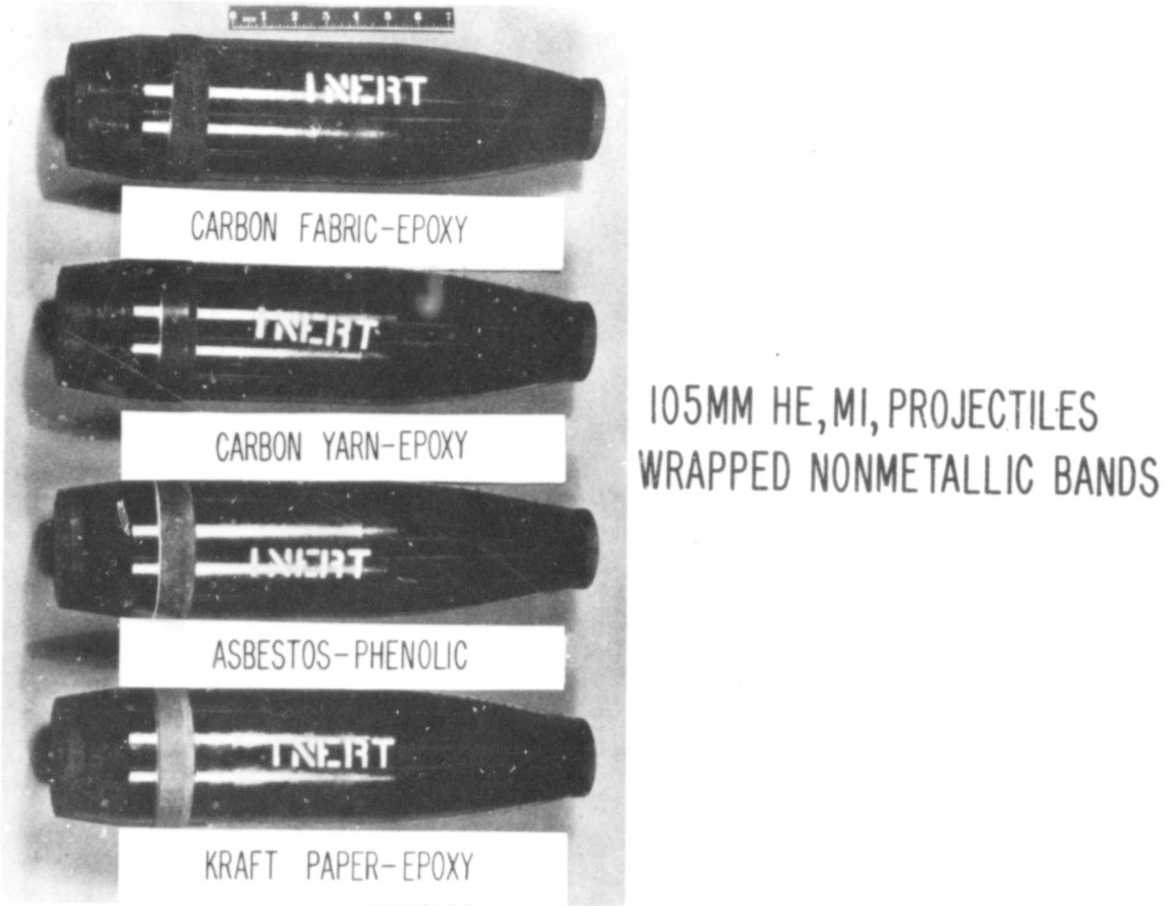


Figure 49. (U) Non-Metallic Rotating Band Configurations

In addition to Zone I effects already observed, recent tests have further confirmed the existence of muzzle velocity "first-round" and "creep" effects at the Zone II, III, and V levels for the 105mm Howitzer. Dramatic improvement in muzzle velocity variations was achieved at the Zone II level through the use of wrapped nonmetallic rotating bands. (See Figure 50.) Firing tests of molded polycarbonate bands, give additional credence to the position that a practical, nonmetallic rotating band for artillery is feasible. This technology has been passed along to the proper AMC command for incorporation into their plans for exploratory and engineering development of army munitions. Further studies will attempt to explain why the Interior Ballistics performance is affected by the nature of the shell banding material.

For example, it is known that engraving pressure and downbore friction are essential to the calculation of Interior Ballistic trajectories; both are affected by band material. The forces, induced by the rotating band becoming engraved at the origin of the rifling, produce tremendous stresses on the tube and the shell. Downbore friction affects many facets of the Interior Ballistics picture since it is influenced by barrel heating, condition of the lands and grooves, and barrel wear in general due to erosion and other factors. These forces are also affected by the specific design of the forcing cones, rifling, and radial stiffness of the band seat. In fact, the complete force system must be specified to determine most projectile-tube interactions, such as yaw-in-bore of the projectile. Balloting of the projectile in the bore, which occurs to some degree in many weapons, is of critical concern to Interior Ballistics. This unwanted motion can add greater loads to the shell, warhead, fuze, guidance packages, and the tube itself than are normally anticipated or incorporated into the design specifications. (See Figure 51.)

As future weapons systems tend toward higher velocities, better accuracies, less round-to-round dispersion, and greater ranges, these launch conditions (and many others not even covered in this review)

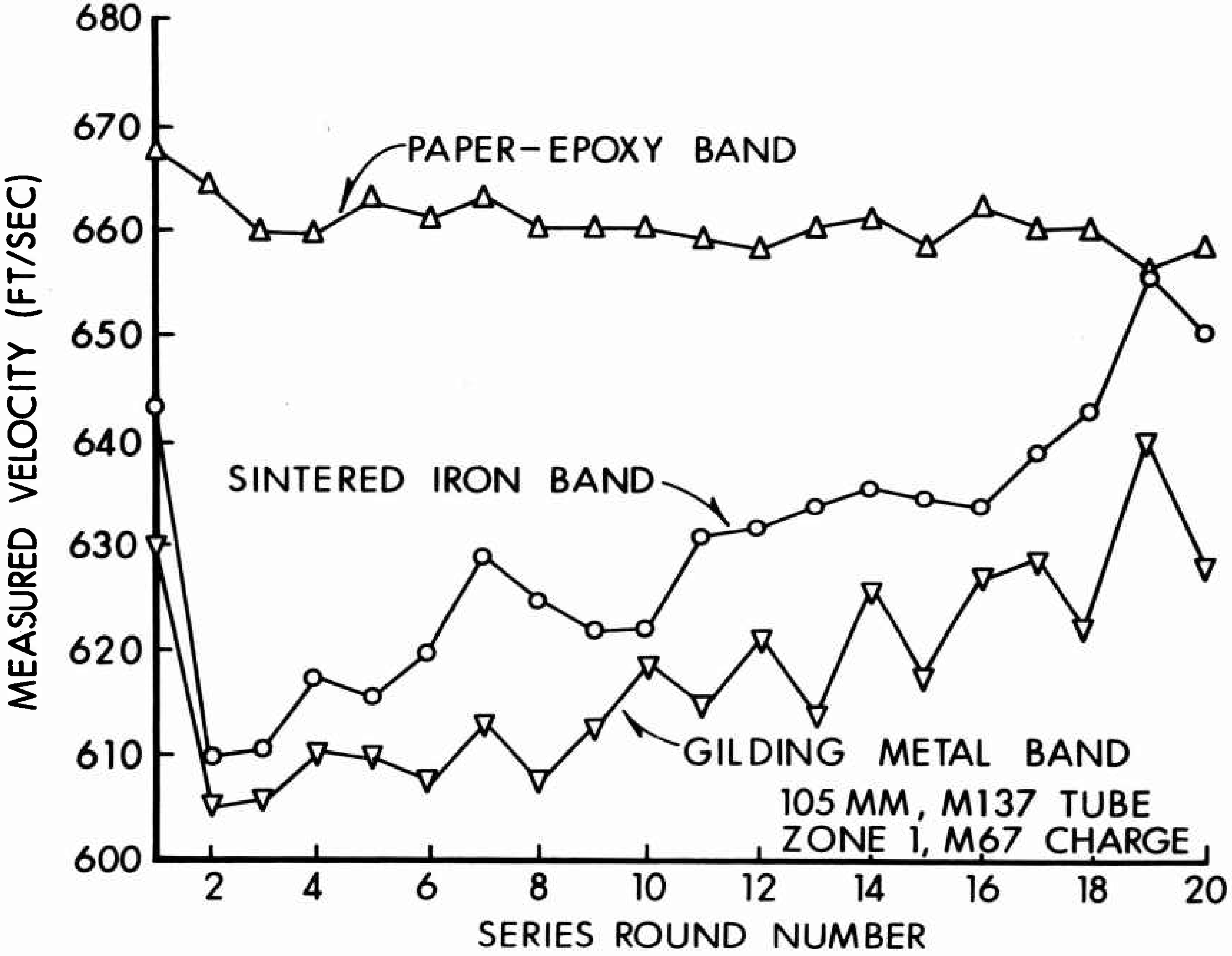


Figure 50. (U) Comparison of Velocity vs Round Number for Gilding Metal and Non-Metallic Rotating Bands

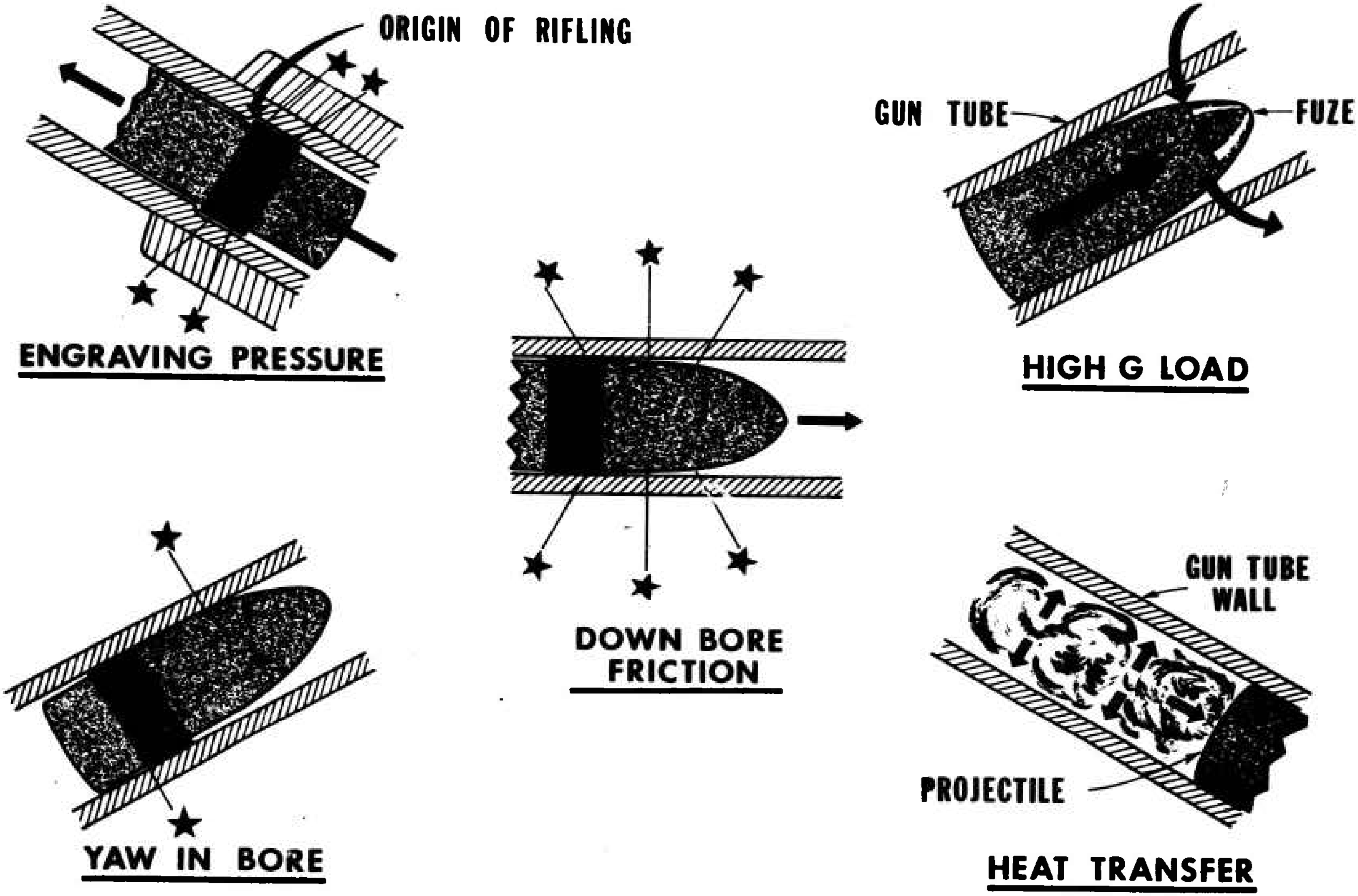


Figure 51. (U) Interior Ballistic Problem Areas

become crucial to the overall weapon performance. This statement is true even if the trend becomes one of strong consideration of smoothbore rather than rifled tubes, for each change brings with it peculiar Interior Ballistics problems. This is the reason for placing heavy emphasis on the mathematical modeling approach.

Much remains to be learned about the Interior Ballistics of weapons, especially, with regards to friction, heat transfer, in-bore behavior of projectiles, in-bore environment influence on fuzes and warheads, and sabot technology in order to more fully describe the complete Interior Ballistics cycle of guns and rockets and to increase their performance characteristics for the Army of the future.

(CONFIDENTIAL) V. SUMMARY (U)

Information has been presented on nearly a dozen facets of ballistics currently under study. The facets chosen constitute a sampling of current activities. The impact of the successful exploitation of advances in ballistic technology upon the performance of future weapon systems will be considerable. In many cases, the discussion touched upon subjects of current exploratory development; these subjects may appear in the next generation of systems.

The topics presented fall into two categories: four very general items, and a number of specific ones. The general items include the lethal effects of munitions, described as behind-armor effects in Terminal Ballistics; the work on stability of high l/d, spinning missiles; programmed ignition and combustion; and temperature-insensitive propulsion systems (see Figure 52). The studies of behind-armor effects are particularly critical at the present time because of the need for decisions on the warhead submissile design for systems such as LANCE, and for the selection of warhead characteristics for future automatic cannon ammunition and infantry antitank systems. The problem is particularly complicated by the unevaluated possibilities of follow-through incendiary devices.

- LETHAL EFFECTS (BEHIND ARMOR)
- STABLE, HIGH L/D, SPINNING MISSILES
- PROGRAMMED IGNITION/COMBUSTION
- TEMPERATURE INSENSITIVE PROPULSION

Figure 52. (U) General Applications of Ballistics Technology

Studies of Magnus moment and related effects upon the stability of slender aerodynamic shapes and fin-stabilized spinning missiles have a substantial impact upon efforts for improving the accuracy of rockets by means of spin and for extending the range of artillery projectiles. At the present time, a trial and error approach is necessary to the design of such missiles in order to assure their stability under all necessary flight conditions; this is a tedious, time-consuming, and expensive effort.

The potential contributions of programmed ignition and combustion and of temperature-insensitive propulsion systems for both rockets and guns will have far-reaching benefits in terms of reduced system weight and improved reliability. Such improvements will permit increased efficiency in the design of the rocket motor or gun, and substantial weight savings as a result of elimination of excursions in the combustion process. Parasitic weight of components added for the specific purpose of preventing excursions can be eliminated.

Some specific items addressed include improved kinetic energy penetrators, focused blast/fragment warheads, shaped charge warhead improvements in both penetrating ability and compensation for spin, base-drag reducing techniques, trajectory correction devices, and nonmetallic rotating bands. (See Figure 53.)

Kinetic energy penetrators, now in various stages of development, will offer substantial improvements in the terminal effectiveness of small arms, automatic cannon, and high acceleration rocket systems. (See Figure 54.) Probably the first effective exploitation of these improvements, however, will appear in rounds fired from tank guns. Specifically, effort is under way jointly by the BRL and AMMRC to provide better penetrators for 105mm guns. Small-scale tests that have been completed indicate that a round substantially better than those currently in use can be provided. It is confidently expected that the proposed new round will satisfy requirements for defeat of the medium triple Tripartite target.

- KE PENETRATORS
- FOCUSSED BLAST/FRAG
- SHAPED CHARGE
- DRAG REDUCING FUMERS
- TRAJECTORY CORRECTION DEVICES
- NON-METALLIC ROTATING BANDS

Figure 53. (U) Specific Applications of Ballistics Technology

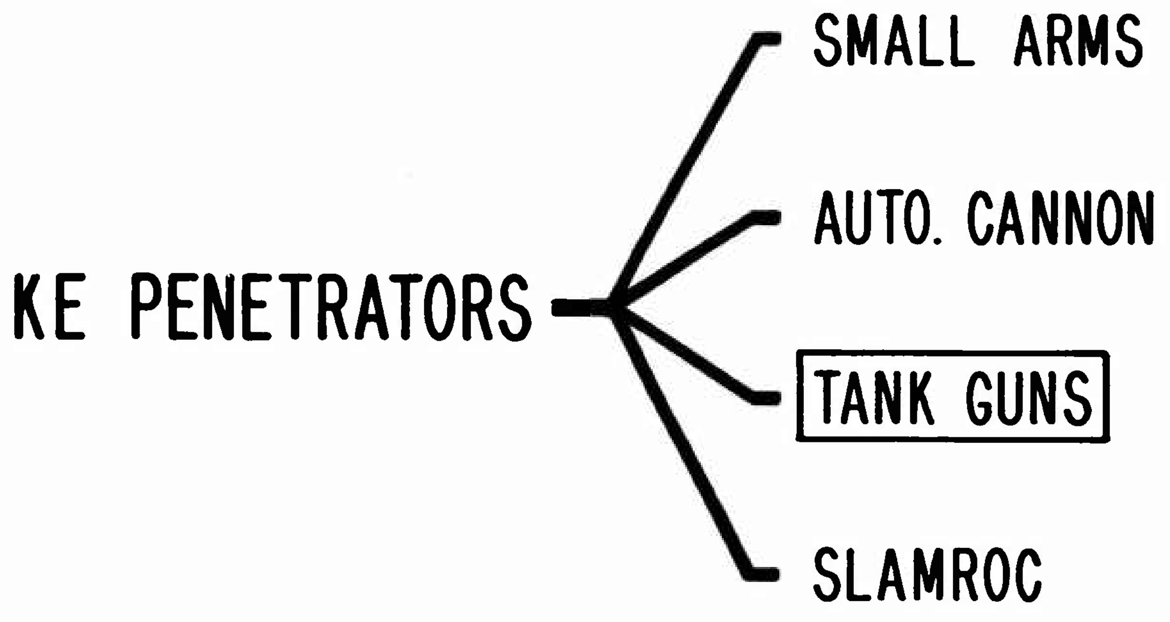


Figure 54. (U) KE Penetrator Applications

Focused blast/fragment warheads offer substantial improvements in antiaircraft missile warheads and long-term improvements in conceptual antimissile warheads and antimateriel submissiles (see Figure 55). In all cases, the key is to match the warhead design characteristics with fuze and terminal guidance. The most immediate and critical impact of focused blast/fragment warheads, however, will probably come in the cannon-launched guided projectile (CLGP) and terminal guided missile projects, in which the potential for near-miss kill of hard point targets should have an important impact on the requirements for precision in the terminal homing system.

The shaped charge warhead improvements described enter critically into plans for antiarmor sub-missiles, particularly for LANCE, and into the proposed utility weapon. (See Figure 56.) Their most dramatic contributions may appear, however, in the design of a future LAW system, wherein the improvements in penetrating ability offer reductions of as much as 50 percent in the necessary payload weight, and the work in spin-compensation areas will improve significantly the first round hit probability. Full realization of these potential benefits is contingent upon the behind-armor effects study, and to some extent, upon the development of fuzes matched to the warhead characteristics and of lighter weight.

Base-drag reduction techniques have been under consideration for some time in connection with rocket missiles, and have potentially important applications to tank gun projectiles, automatic cannon, and small arms (see Figure 57). The most dramatic benefit may well be derived in the case of automatic cannon, but the initial likely application will be in small arms as a result of current cooperative effort among the Small Arms Agency, Frankford Arsenal, and the Ballistics Research Laboratories.

The magnitude of the benefits obtainable, according to ballistic theory, is illustrated by the curves in Figure 58, wherein the residual kinetic energy of a round is plotted as a function of range. The projectiles considered are the M193 conventional round for the M16 rifle,

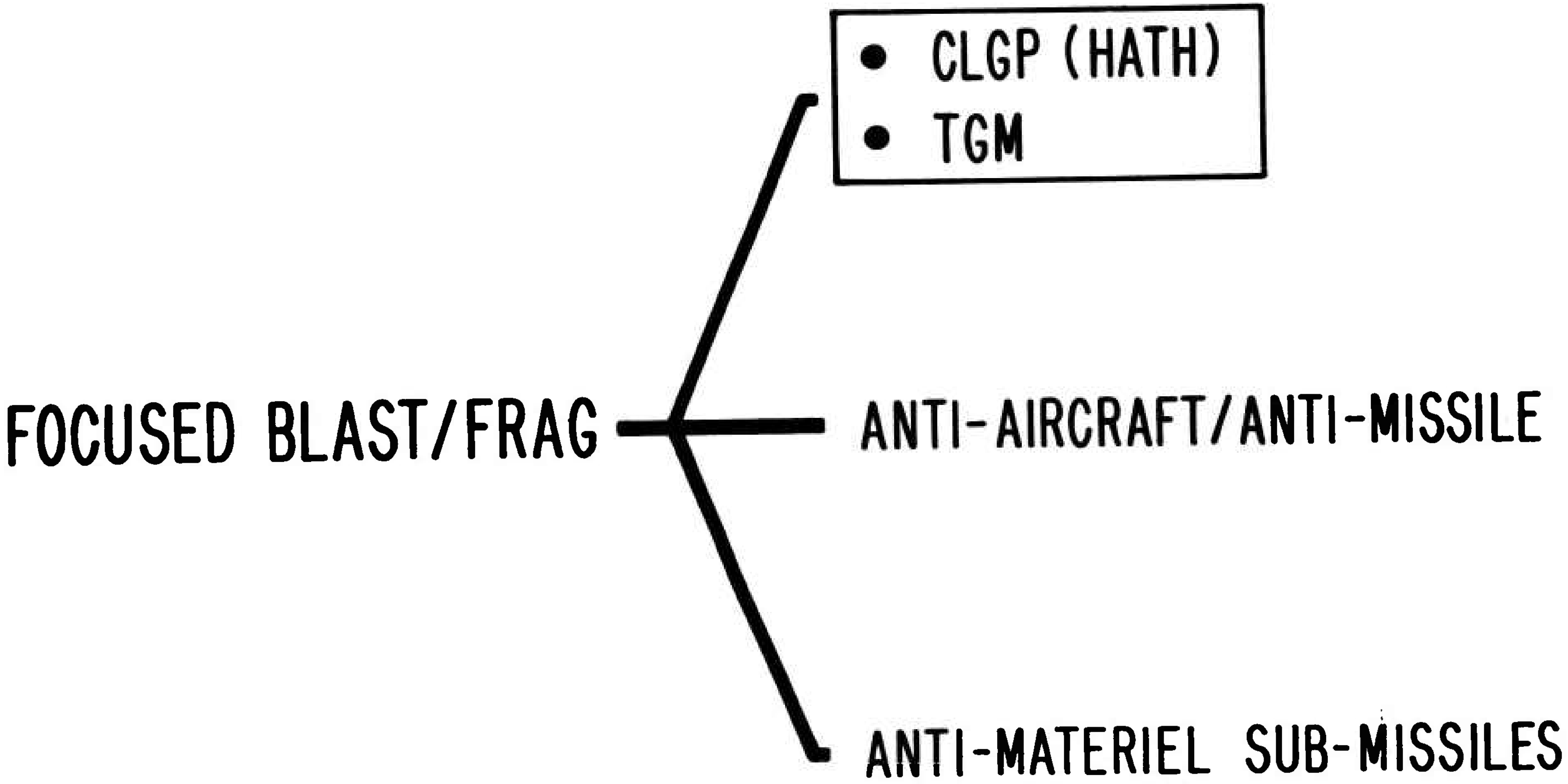


Figure 55. (U) Focused Blast/Fragmentation Warhead Applications

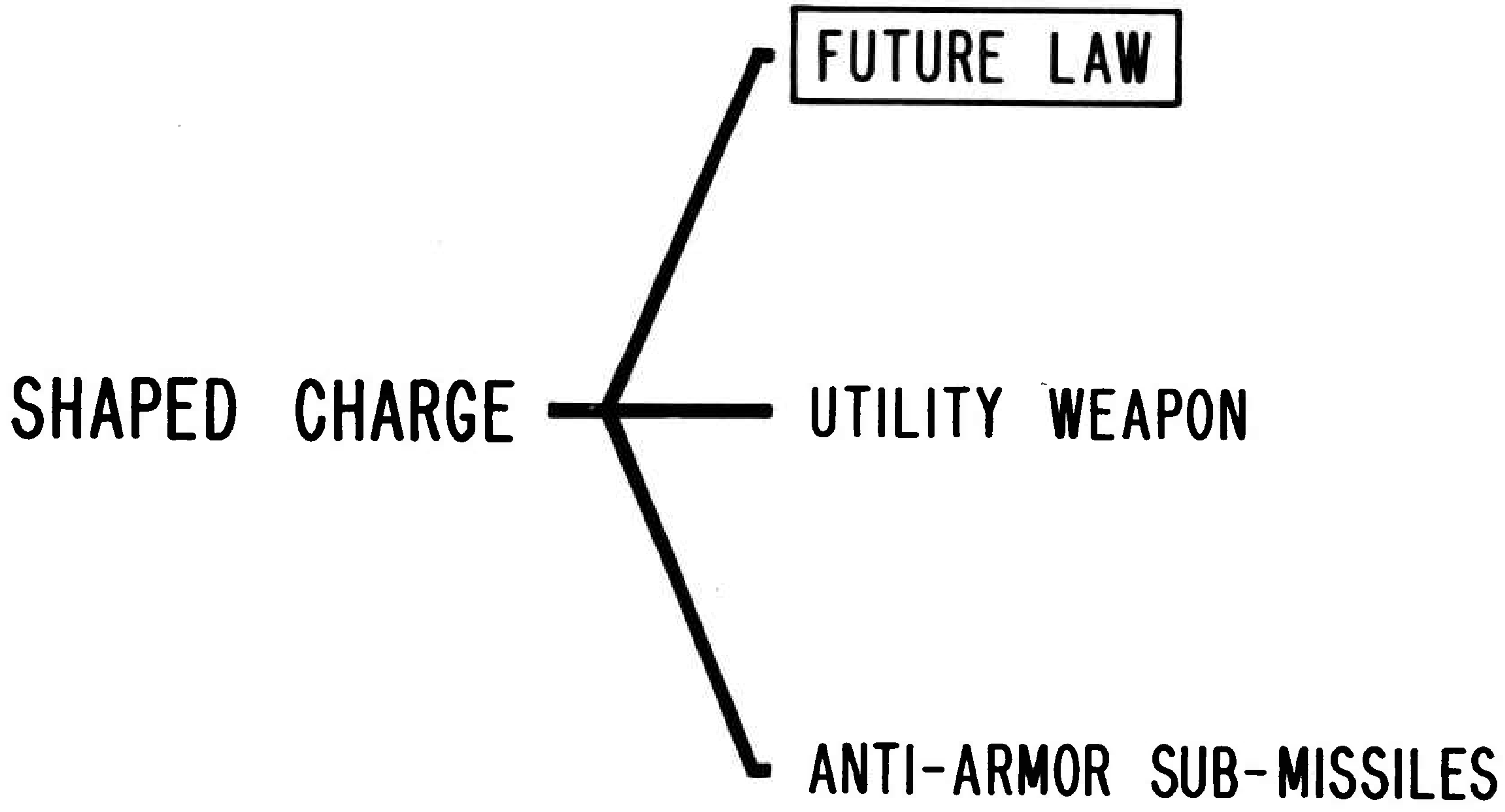


Figure 56. (U) Shaped Charge Applications

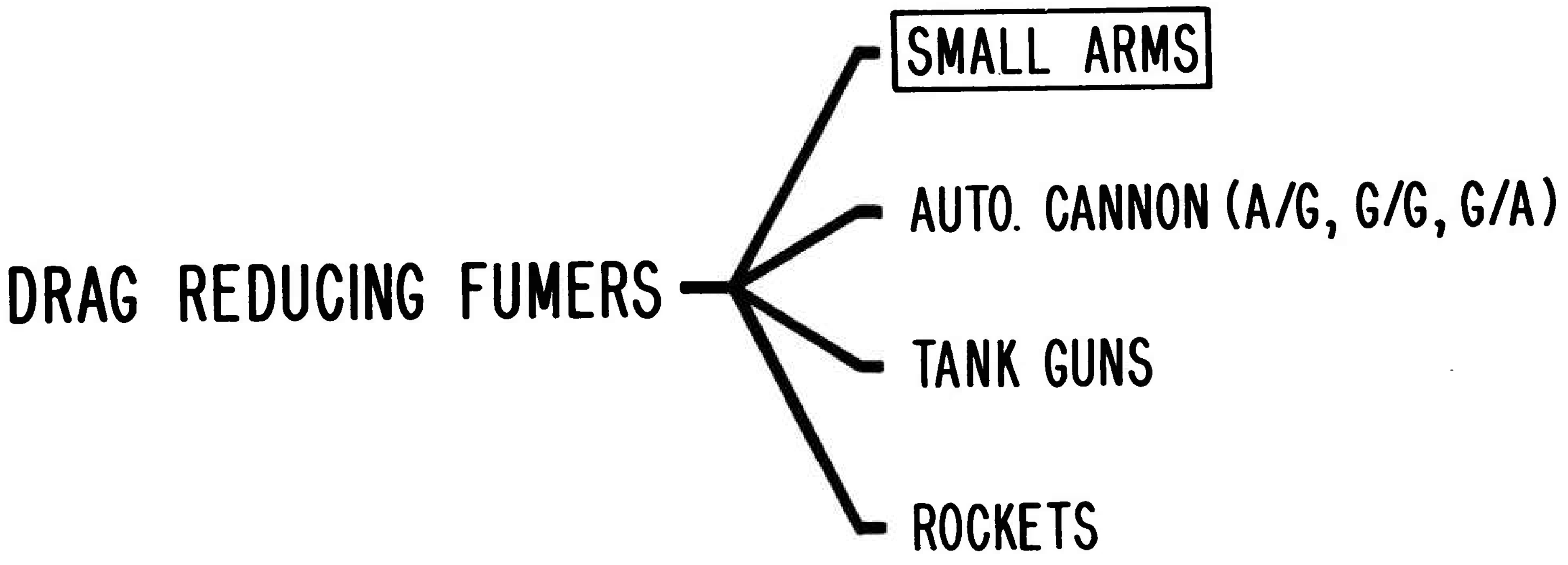


Figure 57. (U) Drag Reducing Fumer Application

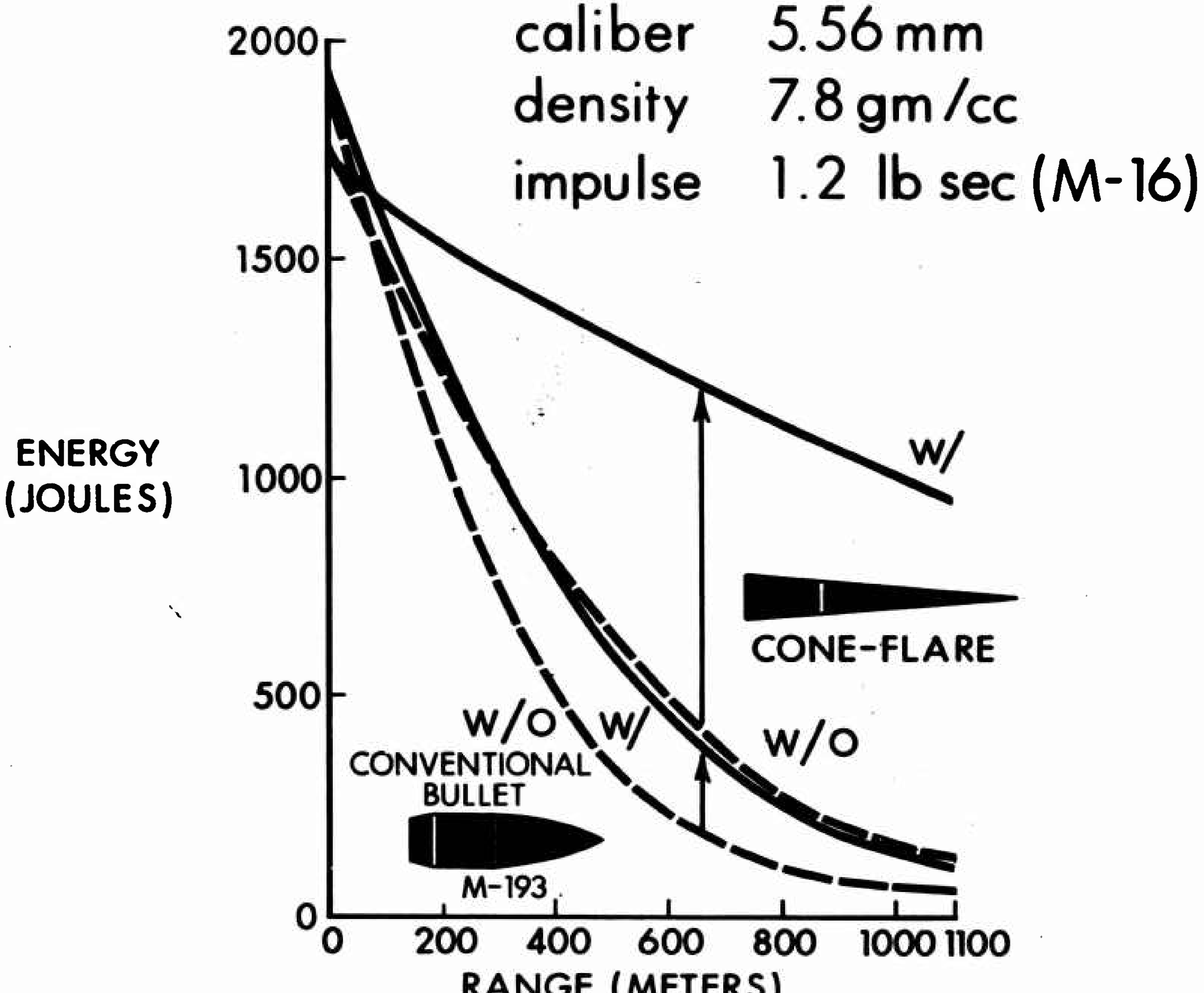


Figure 58. (U) Comparison of Bullet Shapes With and Without Fumers

with and without a tracer, and a proposed new bullet shape with a cone-flare configuration, with and without a base-drag-reducing fumer. The conditions under which the predictions were made are constant recoil impulse, equal to that of the M16, and a simple projectile of steel composition. The evidence indicates that the benefit of base-drag reduction in small arms is significant but not dramatic for the conventional bullet shape, but that the use of a better adapted shape permits a really significant improvement in energy delivered at long ranges. It is clear that the benefit for ranges of concern with rifles is relatively unimportant; but that at machine gun ranges, the benefit is spectacular. The enticing feature is that a single round can be used in both the rifle and machine gun without compromising the effectiveness of either weapon.

Trajectory correction devices can be considered to be a poor man's substitute for terminal homing. They could be applied to either artillery rockets, in lieu of guidance or terminal homing, or to tube artillery shell. (See Figure 59.) Consideration of these systems has not advanced to the point where their merit vis-a-vis terminal homing may be evaluated.

Nonmetallic rotating bands offer substantial advantages in automatic cannon, tank guns, and artillery in the way of reduced muzzle velocity, dispersion, and reduced stresses and heat transfer to the tube. (See Figure 60.) The greatest benefits can be obtained in the case of automatic cannon in the form of substantial improvement in the rate of fire and the burst length.

As a single example of the potential improvement resulting from combined Interior, Exterior, and Terminal Ballistics improvements and improved materials, consider the projected performance of a future LAW compared with the performance of the existing M72. As Table I indicates, the combined improvements result in an estimated increase by a factor of six for either a recoilless rifle or a rocket system in the single shot kill probability at 250 meters range with comparable weight and size of the system. Additional improvements not taken into account in the projected figures might also permit reduction in the blast pressure level.

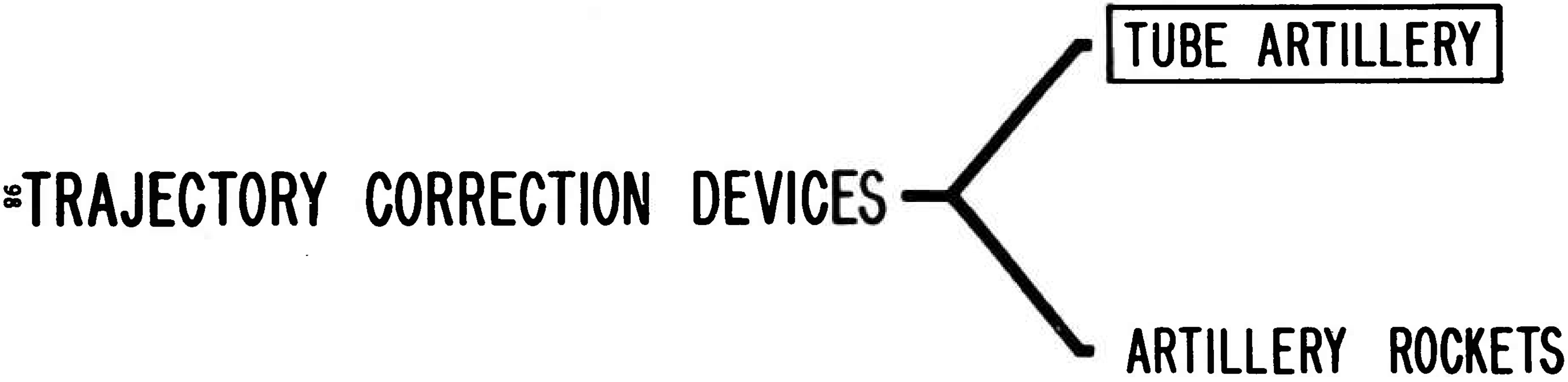


Figure 59. (U) Trajectory Correction Device Applications

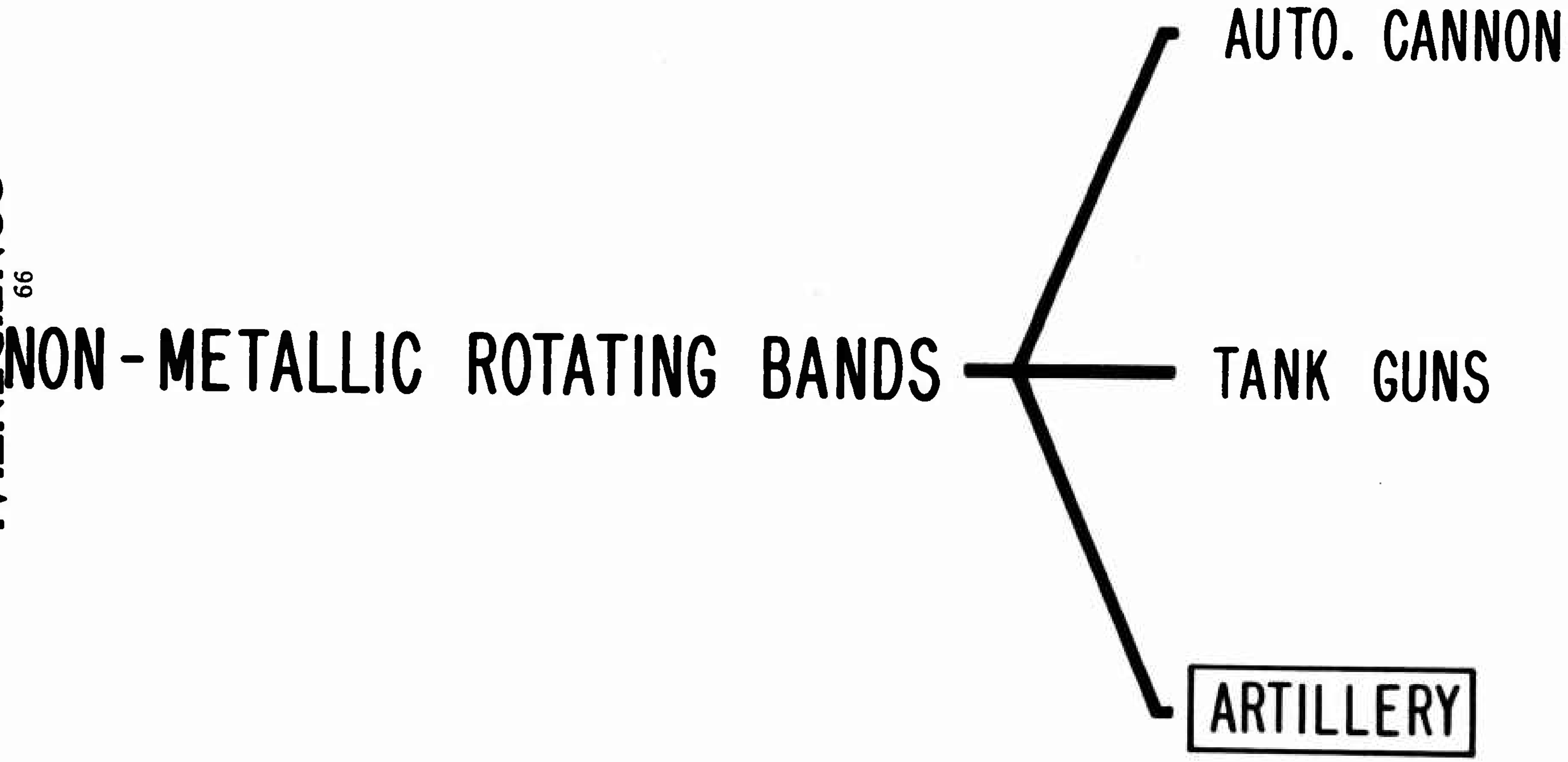


Figure 60. (U) Non-Metallic Rotating Band Applications

Table I. (C) Prospects for Future LAW (U)

	LAW M72A2	66mm RR Rigid Tube	66mm Rocket Telescopic
System Weight (lbs)	5.25	4.60	5.90
Launcher Length (in)	25/34	29	27/48
Muzzle Velocity (fps)	490	1200	1100
SSKP (250m)	.06	.36	.36

Now that some of the potential benefits from recent advances in ballistics technology have been described, it is time to consider some of the problems confronting the future progress of the technology. (See Figure 61.) Technology problems of a general nature are two-fold. First, in order to exploit the advances made in modeling of ballistics phenomena for computer-aided design and engineering, steps must be taken to assure that the AMC laboratories and commodity commands have access to the most advanced computing equipment available. At the present time, none of the installations have adequate computing facilities for handling full-scale models. (See Figure 62.) The relatively primitive models in current use for engineering purposes require that AMC people obtain time at more sophisticated facilities outside AMC.

Secondly, and also connected with the trend toward modeling and computer-aided design, is the lack of basic data to use in the computer models. These data fall into several categories: chemical reaction kinetics, dynamic materials response, fluid dynamics, and properties of materials. Because of the extreme conditions prevailing during most ballistic phenomena (reaction rates, pressures), it cannot be expected that the general scientific community will produce the necessary data, despite the popularity of the subject. Consequently, the in-house laboratories are forced to devote substantial parts of their resources to the determination of the essential input data.

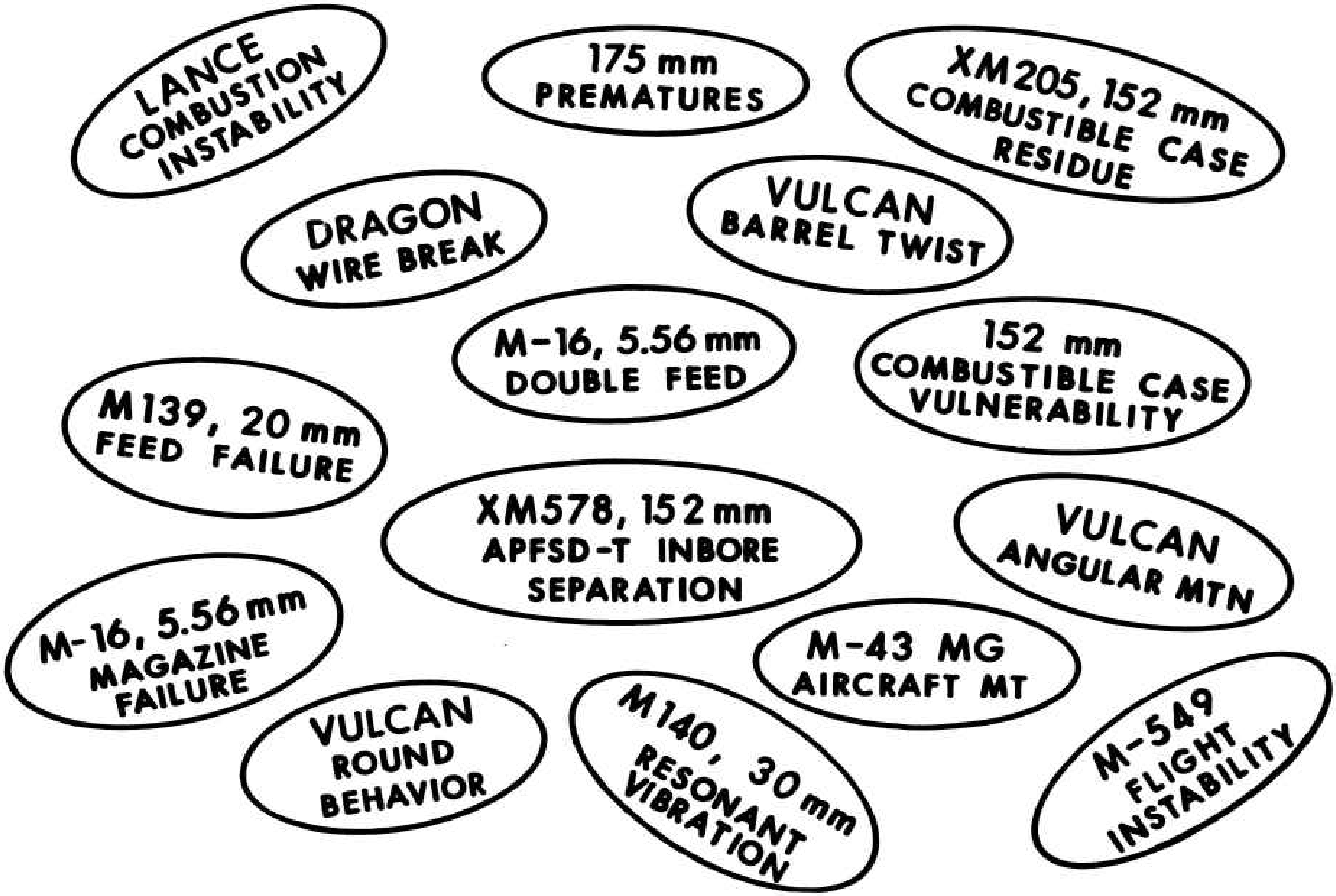


Figure 61. (U) Development Problems Requiring Ballistic Solutions

- **COMPUTER TECHNOLOGY FOR CAD-E**
- **BASIC SCIENCE**
  1. CHEMICAL REACTION KINETICS
  2. DYNAMIC MATERIALS RESPONSE
  3. FLUID DYNAMICS
  4. PROPERTIES OF MATERIALS

Figure 62. (U) Problems Facing Ballistics Technology

Finally, a problem that can be classified more as a policy matter than as a technical problem, is the failure of the system to assure that quality control in production is maintained at a level required to effectively use new ideas. (See Figure 63.) This problem impedes progress and exploitation of advances in ballistic technology. Significant improvements in weapons almost inevitably involve added complexity, closer tolerances, and/or exotic new materials and quality control is essential to their usefulness. The procurement system, on the other hand, has consistently demonstrated a tendency to favor slipshod workmanship, relaxation of tolerances, waivers on specifications, and absurdly simple acceptance tests in order to save small amounts of money regardless of the ultimate effect on system performance. Consequently, the design engineer, who is acquainted with this tendency, is driven to conservative design rather than to full utilization of the technology in order to avoid catastrophic failure of the system in the field. Closer inspection of production rifles, ammunition, shaped charge warheads, rocket motors, artillery tubes or any other piece of military hardware, except possibly the components of very sophisticated guidance and control equipment, will reveal the kind of variability that comes off the production line. To take maximum advantage from the technology efforts, some steps must be taken to assure that standards of manufacture will be maintained at an adequate level.

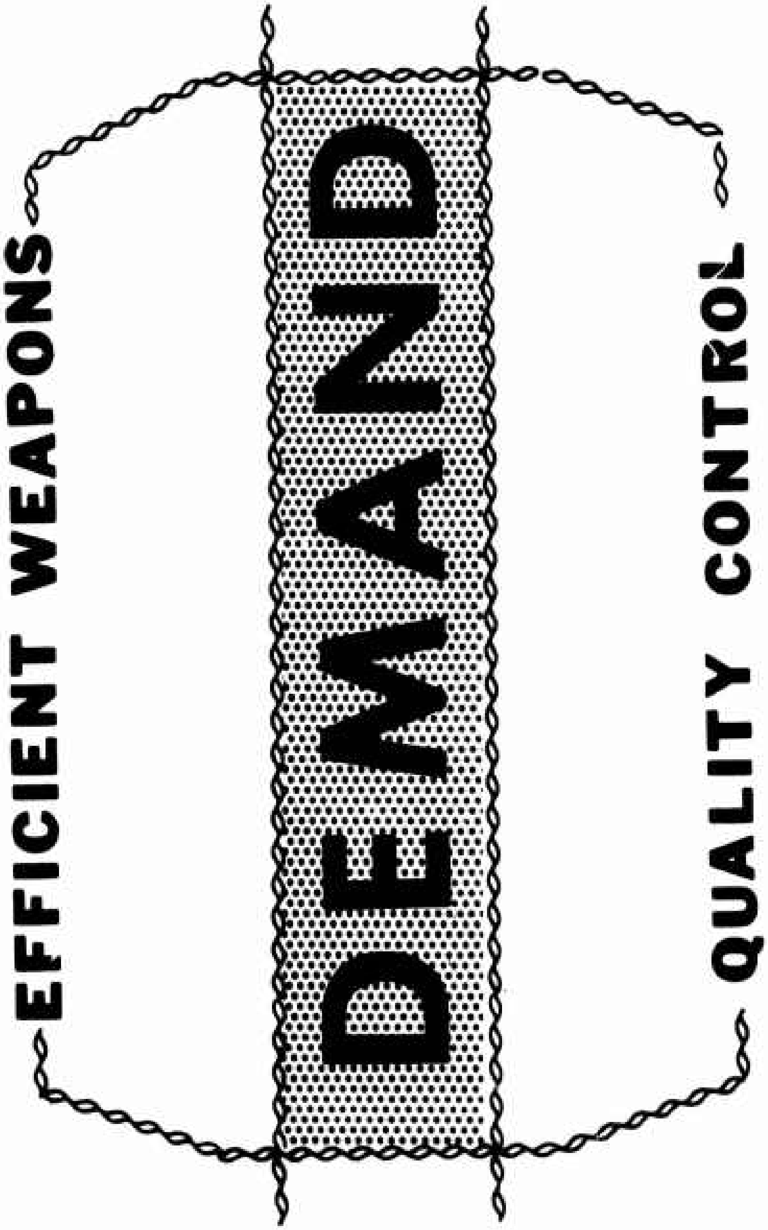


Figure 63. (U) Efficient Weapons Demand Quality Control

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11. SUPPLEMENTARY NOTES

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13. ABSTRACT

(U) This report documents a briefing by the chiefs of various laboratories within the Ballistic Research Laboratories at AMC Headquarters on 25 August 1971. The subject of the briefing was the status of ballistics technology. Selected topics covering developments in Terminal, Exterior, and Interior Ballistics were discussed.

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