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AFATL-TR-74-106

DEVELOPMENT OF A PLASTIC ROTATING BAND FOR HIGH PERFORMANCE PROJECTILES

DeBELL & RICHARDSON, INC.
AND AIR FORCE ARMAMENT LABORATORY

JULY 1974

FINAL REPORT FOR OCTOBER 1972–DECEMBER 1973

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied July 1974 . Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This project includes the investigation of plastic rotating bands fabricated directly to steel projectiles by laminating, casting, fluid bed coating, injection and transfer molding. The successful method was to injection mold nylon 12 over a clean and primed projectile seat and then to heat the primed interface to a melt temperature by induction heating the projectile. The use of angled leading and trailing edges was investigated. Projectiles banded by this method were successsfully tested at -65°F, ambient and +165°F at muzzle velocities up to 4400 feet per second.

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PREFACE

This program was conducted by DeBell & Richardson, Inc., Water Street, Enfield, Connecticut 06082, under Contract No. F08635-73-C-0030 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida. Major Stephen J. Bilsbury (DLDG) managed the program for the Armament Laboratory. The program was conducted during the period from October 1972 to June 1974.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

A. D. Brown Jr

ALFRED D. BROWN, JR., Colonel, USAF
Chief, Guns, Rockets and Explosives Division

SUMMARY

The objective of this investigation was to combine a choice of materials, process, and design to develop a plastic rotating band for high velocity projectiles. The 20mm was used as it provided an inexpensive yet realistic vehicle. During the program, the objective was modified to encompass projectiles in which the band seat depth was limited to 0.020 inch. A further objective was that the choice of material and process permit the shaping and anchorage of the plastic rotating band by a process suited to mass production and at a cost competitive with the existing metal rotating band. The study included all likely materials and processes, with design and tooling appropriate to each.

The objectives of the program were achieved by injection molding a rotating band directly on to a cleaned and primed 0.5 inch by 0.020 inch deep band seat on the steel projectile. The preferred molding material is nylon 12. After molding, the interface bond is consummated by induction heating the steel surface briefly to the melt temperature of the primer and nylon. After this is done, the band and projectile are quickly cooled to preserve the melt bond. Tapers on the fore and aft leading edges of the band were machined to various angles to find workable combinations; these tapered edges can be molded in place when the optimum combination of angles is determined.

The development work is reported herein, including the reports on screening and test firing of several hundred samples. A lot of 500 projectiles was molded composed equally of nylon 11 and nylon 12 bands; each of these lots was divided into equal numbers of samples of two combinations of fore and aft edge angles.

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SECTION I

INTRODUCTION

A plastic rotating band has been developed which has been shown to be superior to metal bands in performance, cost, and design. This band was developed in 20mm and appears to be adaptable to other calibers.

The rotating band is that part of a projectile which engages the lands and grooves on the interior of conventional gun barrels. Until now, the United States has routinely used copper or gilding metal for this purpose. European countries, on the other hand, use sintered iron as a band material. Under high-rate firing conditions, either material is a major contributor to erosion at the barrel throat due to cracking, and flaking of the chrome plate and subsequent gas erosion of the steel substrate. This erosion in turn causes a loss of both projectile velocity and accuracy.

These facts have long been recognized and much work has been done on the problem of gun barrel erosion.

The rapid development of increased aircraft performance, particularly speed and maneuverability, has also caused a requirement to develop for increased gun system performance. This performance is defined in terms of rate of fire, projectile velocity, and accuracy. Historically, this performance development has been hampered by projectile/barrel interactions which occur at high rates of fire. The most deleterious effect of high rate firing is on projectile accuracy and velocity due to rapid barrel deterioration. This effect was recognized shortly after the machine gun was invented; however, serious attempts to overcome the problem by this country were not started until early in 1942. One of the approaches taken was plastic or nonmetallic rotating bands. However, the only synthetic materials available at that time in any quantity were the phenolics. After a great many unsuccessful attempts, the effort was placed on a lower priority and other means of curing the erosion problem were taken up. Work continued sporadically until the early fifties when the Navy (NWL, Dahlgren) again took up the problem. In 1954 they came up with the world's first successful plastic rotating band. (The Air Force Armament Laboratory has recently fired some of these 19-year-old 20mm plastic banded projectiles. The nylon band obturated and remained intact at velocities of 4,000 ft/sec.) The early Navy data as well as experience on both the 25mm GAU-7/A and 30mm GAU-8/A substantiate this view. (See Figures 1, 2, 3 and 4.) In 1957, a DOD decision was made to use only missiles for aircraft weapons, and as a result all aircraft gun and ammunition development work ceased. The Vietnam war proved the fallacy of this decision. However, as a result of this course of action, the 20mm ammunition is still being fabricated with copper rotating bands.

Why plastic rotating bands? Aside from the obvious cost and production base advantages, there appear to be other more significant operational advantages which occur, thus:

An optimum high explosive projectile design requires a thin, uniform wall which assures a distribution of nearly constant size fragments. Thus, a configuration using a mechanically attached rotating band, with a deep machined band seat, is also a poor high explosive shell design which offers a relatively low charge-to-mass ratio and a skewed fragment size distribution.

The problem of attaching a plastic band to a thin-walled, high performance projectile was solved in an unconventional manner. A multisource statement of work was developed which was specifically designed to take advantage of the unique expertise of both U.S. industry and the Air Force Armament Laboratory (AFATL). The design criteria and testing were developed by AFATL. The polymer systems and modes of attachment were developed by the contractor. In this manner, the contractor was able to devote his entire energies to the sole problem of attaching a useable plastic band. This approach had the additional advantage of allowing a company not normally associated with ordnance work to participate.

This program has established successful plastic rotating band performance at velocities of 4400 ft/sec over the entire temperature spectrum (+165°F: -65°F). The 20mm test projectiles uses a band seat 0.020 inches deep by 0.500 inches long. There are no mechanical attachment devices.

SECTION II

BACKGROUND INFORMATION

The basic background information on the development of a plastic rotating band is contained in the contract. In addition, pertinent information was received from several sources:

a. Discussions with program manager and other personnel in both military and industrial capacities.

b. Reports of Government projects on previous experience with plastics in ordnance applications.

c. Reference material on plastics in ordnance applications and on high speed testing of plastics.

Several references have been summarized and are included in the Appendix. Information pertinent to the problem derived from discussions and reviews with the program manager are cited in sections following which deal with the design problems, methods of anchorage, mold design and molding, testing, and the selections of materials. The subsection on design review states the known design premises and our analysis of their relationship with the properties of plastic materials and the processing methods to be used.

Comments were received in telephone discussions with Mr. Frank Littleford at Lake City Ammunition Plant, Independence, Missouri, and Mr. Rex Butler at Naval Weapons Laboratory in Dahlgren, Virginia. Mr. Butler is the holder of patent 2,996,012 pertinent to the design of a projectile, specifically the anchoring of a plastic rotating band. The primary claim of the patent reads as follows:

2,996,012

ROTATING BAND AND SEAT THEREFOR

Rex B. Butler, Dahlgren, Va., assignor to the United States of America as represented by the Secretary of the Navy

Filed Nov. 17, 1955, Ser. No. 547,587

1 Claim. (Cl. 102—93)

(Granted under Title 35, U.S. Code (1952), sec. 266)

A projectile having an annular recessed portion disposed circumferentially thereof, an annular ring of polyamide material superimposed on said recessed portion, the recessed portion comprising a plurality of spaced ribs, said ribs having knurled outer bearing surfaces, said surfaces being formed of alternate crests and troughs in a thread-like arrangement, said crests being normal to the ribs and the depth of the troughs being substantially equal to but not more than the height of said ribs, each of said knurled ribs having a base portion and sides diverging from the outer limits of said base portion to thereby form locking grooves between successive ribs.

The telephone discussion with Mr. Butler developed the information that the 1956 project involved nylon, either 6 or 6/6 without glass reinforcement, as molded rotating bands for projectiles from 20mm up to 5 inches. The bands were quite successful, but still showed about 10 percent breakage and some melt smearing of the surfaces during the progress of the projectile through the barrel after continuous firing.

SUMMARY OF TECHNICAL REPORTS

Four interim reports dated April 30, 1954 from The Franklin Institute offers interesting sidelights on early R & D work on rotating bands. Report No. I-2358-1 is "Research and Development to Improve Artillery Ammunition" and surveys 40 moldable plastics for their suitability for use as rotating bands. Report No. I-2358-4 is "A General Discussion of Rotating Band Design"; it summarizes the design and function of a rotating band, discusses both plastics and metal powders, and cites inadequacy for designing and testing rotating bands. Report No. I-2358-5 is "Preliminary Development of Plastic Rotating Bands for the 27mm T142 Practice Projectile"; the abstract concluded that nylon bands satisfy the rotational requirements, but more work is needed on band retention. Report No. I-2358-9 is "Plastic Flow of Rotating Band during Static Engraving" and deals with a complex method of predicting the flow of the rotating band during engraving.

The Frankford Arsenal report A-532C (no date) relates an early experiment with plastic rotating bands for 20mm and 57mm projectiles using ethyl cellulose. The design of the rotating band is considerably different from present concepts and is comprised of several circumferential fins. Performance was at 2000 fps and 72,000 rpm.

NPG Report No. 1342 dated 10 March 1955 is entitled "Development and Test of Nylon Rotating Band for 20mm High Velocity Projectile" reports on excellent performance of nylon bands in slow fire from a Mk 12 gun at velocities up to 3500 ft/sec and temperatures from -65°F to +160°F. NPG Report No. 1357 dated 25 March 1955 is entitled "Development of Nylon Rotating Bands; Artificial Aging Tests" and reports on aging at high temperatures and humidities up to 16 weeks. The results indicated that the nylon bands would be serviceable after aging. Summaries of both of these reports are appended.

The Bureau of Ordnance, Dahlgren, Virginia offered a "First Partial Report on Nylon Rotating Band for 20mm High Velocity Projectile" on February 28, 1953 on Project NPGRe3b-225-1-53. This may have been work which preceded the two reports cited above. Details of mechanical anchorages used and the modification made in anchorages and leading and trailing angles are chronicled. A summary of this report is appended.

A group of miscellaneous reports covering rotating bands for ammunition ranging from 20mm to 5"/54 was reviewed; the dates range from 30 August 1954 to 4 March 1957.

The first reviews the status of 20mm nylon rotating bands as of 30 August 1954. At that time the nylon band was judged to have full and adequate retention except for a few instances when firing tests were conducted at extremely high or low temperature after extensive aging at high temperature and high humidity. A phenomenal improvement in gun life and velocity loss was noted compared to the performance of metal bands. Slightly greater dispersion of nylon banded projectiles was noted but not considered serious. Band growth of 0.010 inch in diameter was noted from humidity aging but this has not affected firing performance. Although specific tests on long time storage have not been performed, molded bands 4 years old have not shown any bad effects. In an update of this review to 22 June 1961, practically all of the performance factors noted previously were verified. An effort was made to mold bad bands by using hot molds, dirty molding powder, oily projectiles, and other abusive variables, but all bands made under those conditions continued to perform. The final summation of this report (identified as 8030, Serial 03451) gives an excellent commendation to nylon rotating bands:

> Under the difficult requirement of maintaining all but extremely minor gun, case, and projectile dimensional characteristics, a nylon band has been developed for 20mm projectiles. This band successfully imparts spin to the projectile at velocities up to 3420 ft/sec in rapid fire. Retention of the bands in flight is complete. Performance in rapid fire at temperature extremes has not yet been evaluated, and the long time storage life of the bands has not been established. However, accelerated aging tests and experience with nylon in other applications would indicate a reasonably long storage life. Under certain extremely severe temperature-humidity conditions a band diameter change of as much as +0.010 inch has occurred. Two rounds still chambered properly at 0.838 inch, however. It thus appears that no difficulty would arise from dimensional change especially in view of the possibility of using the 0.823 inch diameter as standard. Superior gun life has been demonstrated with either unplated or chrome-plated barrels. In a service test a new barrel would probably be required for the change over to nylon bands since the nylon is believed to be somewhat sensitive to origin wear. Because they are not standard and could be placed in service coincidentally with the introduction of a new type band, and because they would have an extremely long life, the chromium-plated barrels are recommended for service use.

With respect to this summation, additional information indicates that chrome plated barrels are much better than unplated.

A note dated 8 November 1955 indicated that 10,000 bands were molded in a 4 cavity mold. Dummy rings pulled in tension were considered brittle and unsuited to perform as a rotating band if they broke with less than 2 percent elongation. In a drop impact test, a 20mm barrel dropped 30 feet onto the banded projectile showed so little breakage that it was considered not probable that it would correlate with firing performance.

A note dated 4 March 1957 showed 4 of 10 projectiles fired at -65°F retained complete bands when recovered. The hardness was Rockwell R 102-105. The shooting trials were not well identified and the data was not considered conclusive.

Translations of three reports from the Japanese were reviewed. The first pertained to the 40mm shell; the report cited prior work with 90mm HEAT shell and 81mm mortar round and also the English 105mm sabot on the high velocity armor piercing projectile. The energy which moves the shell is less than 40 percent of the energy of the explosion. The energy lost in engraving and friction on the rotating band is from 4 to 7 percent. The velocity would increase 8.4 percent if the 7 percent could be reduced to 0 percent. In 1964, experimental work included bands of CTFE and TFE material. The TFE material fractured, but the CTFE did not at 80 percent charge; however, neither gave an additional velocity which apparently disappointed the investigators. In 1965 four additional materials were tried: (1) nylon 6/6 (2) Kynar (3) 85 percent CTFE: 15 percent TFE and (4) 80 percent CTFE + 20 percent molybdenum disulfide. None of these would withstand 100 percent charge; at 80 percent charge the durability was poor and at 70 percent charge the performance was satisfactory. The nylon gave the best overall result but gave a poorer velocity; the reasoning was that it engraved easily and hence did not permit a high bore pressure build-up.

In December 1969 a report was made on "Studies of High Velocity Armor Piercing Ammunition With Sabot (76mm)" and polyacetal copolymer and a blend of polycarbonate with a small amount of polyethylene were used. The latter had the better performance; this is a sabot application and not directly comparable to rotating band performance.

Also in December 1969 a report was issued on "Studies of Plastic Rotating Bands for 105mm Howitzers". The two materials cited above were used successfully. The lower velocity from plastic bands was again noted, and a computer program to study the effects of lowered bore pressure due to easier engraving of the plastic was presented.

A test report from Chemische Werke Huels detailed bonding trials of nylon 12 to itself and other materials, including sheet steel. The former can be accomplished by the use of phenol or cresol, but results of the latter were not markedly good. The best adhesion to steel was with the use of the adhesive WEVO-MK. The full designation is believed to be WEVO-MK A50 + hardener BX from Wevo-Chemie, 7 Stuttgart. Another report from Huels dated 5 March 1971 is a reprint from Kunststoff-Rundschau Vol. 17, No. 8, pages 378-380 on the use of nylon 12 for friction bearings.

Short notes on projectile performance pertinent to 20mm but not directly applicable are:

> A 6-page excerpt from a Philco Ford report on the GAU/7 program showing pressure/time/travel relationships for the 25mm projectiles using rotating band lengths of 1 inch for plastic and 0.36 inch for copper.
>
> Philco report DR 7/A 6055 compares the performance of nylon rotating bands in various barrel configurations and recommends the Philco-Ford gain twist design over the Avco design, with an entering twist of 3.1°.
>
> Philco report ARL-7/A-3000 similarly recommends the use of a gain twist barrel for caseless ammunition, and holds little hope for plastic rotating bands otherwise. This report is dated 3 February 1972.
>
> Section 6 of a report entitled "Plastic Rotating Band Development" (Task II), gives development data on bands for the GAU-7, A. The introduction confirms the conclusions of the previously mentioned report that the bearing stress on the plastic band from the rifling, as loaded by the 970 inch-pound torque, is the only significant force on the band, and in this case amounts to 8160 psi. Four methods of attaching the bands are pursued: bonding a pre-molded band (shrink fit); bonding a pre-molded split band; powder coating by means of fluidized bed; and heat shrinking the plastic onto the projectile. The following plastic materials were used for the molded types of bands: P1700 polysulfone; Cycolac GSM-1 ABS; Astrel 360 polyarylsulfone; Lexan 141, polycarbonate; Noryl SE-1; Zytel 158 nylon 6/12; Delrin 570 X acetal; and Diamond 8620 polypropylene. The heat shrink tubing was Kynar, polyethylene, polypropylene, and nylon 11.
>
> In work-to-break testing done at very high speeds (80-100 feet per second), the polysulfone and the polycarbonate show the

highest performance, almost double that of nylon 6/12. The performance of the split pre-molded band from P1700 polysulfone bonded with epoxy film adhesive EA 9614 was considered highly successful.

In the Philco-Ford report AFAL-TR-TBD of February 1972, a comparison is made of the performance of Delrin and copper used as rotating bands on the 25mm projectile GAU-7/A. Two bands were investigated: one of a total length of 1 inch and one of two sections 1/2 inch long separated by a gap of 0.1 inch. Anchorage depth was 0.034 inch, and the report states that a dovetail undercut would have to be about 0.040 inch to be effective. Feasibility tests performed by Philco-Ford demonstrated that a band could not be reliably retained on the projectile unless the band seat has a lesser diameter than the bourrelet. The calculations presented confirm that the fly-off stress is a low order stress, that the land shear stress is also a low order stress, and that the driving face bearing stress is the significant stress and does much to establish the length of the rotating band. The following materials were tested in sample bar form: ABS + 20 percent glass (AF 1004); polycarbonate + 20 percent glass (DF 1004); nylon 612 + 10 percent glass (IF 002); acetal (Delrin 150); acetal + 20 percent glass (Delrin 577); acetal + 25 percent glass (Celcon GC25); and polysulfone + 10% glass (GF 1002). Adhesives were also tested, and vinylphenolic was superior for polysulfone, acetal, and polycarbonate; and nylon-epoxy was superior for nylon 612 and other nylons. Work with polycarbonate and polysulfone bands was discontinued after it was found that the stress cracking could not be controlled. Adhesives selected for trial with glass-filled nylon 612 to bond to steel were: Narmco 332; RS5216/RM-60-M; Milvex 1235; BR-1009-49; and Stabond U-186. Narmco 332 was the best. In the actual firing trials, bands made from the following plastic materials were tried:

- Polyethylene, Marlex TR 880 HD
- Nylon RF 1006 (30 percent glass)
- Nylon 11, Fluidized
- Epoxy, Fluidized
- Polysulfone (unfilled), +10 percent, 20 percent, 30 percent and 40 percent glass
- Nylon +10 percent glass
- Lexan

- Delrin AF, 150, 577, +20 percent glass, +23 percent glass, +22 percent teflon
- Polycarbonate (unfilled), +20 percent glass
- Celcon Acetal +25 percent glass
- Adiprene
- Zytel 151 (unfilled)
- Nylon 7710 +43 percent glass
- Acetal GC +25 percent glass
- Polypropylene, Tenite 423AA

The best overall firing results were from the polysulfone +10 percent glass and the polycarbonate.

Five reports written by Philco-Ford in November 1972 carried the following designations:

725331	GAU-7/A Process Specification "Process Selection and Identification for Plastic Projectile Rotating Band"
725332	GAU-7/A Process Specification "Process Record for Plastic Projectile Rotating Band"
725333	GAU-7/A Process Specification "Application of Nylon 612 Rotating Band to GAU-7/A 25mm Projectile"
725334	GAU-7/A Process Specification "Adhesive, Nylon Epoxy-Film Phenolic Epoxy Primer"
725335	GAU-7/A Process Specification "Nylon Polymer"

Pertinent information from these reports are summarized in the Appendix.

Technical Report AFATL-TR-72-201 of the Air Force Armament Laboratory dated October 1972 was closely reviewed for its record of the application of plastics to 20 and 30mm plastic/aluminum cartridge cases. Although the end application is different, the plastic material still must withstand the explosive force of the firing but not the engraving impact and displacement. An abstract of this report is included in the Appendix.

The report "Field Evaluation of Plastic Rotating Band Materials: Artillery Applications (105mm Howitzer)," Project 1T161102A33C from Aberdeen Proving Ground, Maryland, dated January 1974 stated that epoxy impregnated paper bands showed good firing performance but poor retention, and unfilled polycarbonate and modified PPO gave good overall performance.

The report "Plastic Rotating Bands for High Performance Projectiles" issued by Avco Precision Products Division of Richmond, Indiana, reviews the development work on surface preparation and adhesive bonding of rotating bands separately molded and assembled to the 25 mm GAU-7/A projectile. The General Electric Company (Armament Systems Department) report PPS AW/AM 72-223 entitled "Plastic Rotating Band Munitions Technology" indicated good performance from plastic rotating bands for the GAU/8 system but gave no details on the material, construction or preparation procedure.

A report by Captain John Edgar of the AFATL Interior Ballistics Laboratory outlines in detail the facilities of the Laboratory and its abilities to test ammunition and rotating bands on projectiles. The sophisticated monitoring equipment is shown and described. Of special interest are graphs showing the lesser gun barrel wear of plastic rotating bands compared to metal, from two different studies.

The Materials Engineering Laboratory, FRL of Picatinny Arsenal, Dover, New Jersey, has issued a series of reports on "Evaluation of Nonmetallic Rotating Band Materials". Report No. 2, dated 15 March 1971, cites the efforts and problems on injection molding polycarbonate rotating bands directly on to the 105mm shell body. Designs for mechanical anchorages and problems of gating and filling the cavity uniformly are described. Report No. 3, dated 31 May 1971, expands the molding program to include five resins. Polycarbonate, nylon 6/12, acetal copolymer, X-917 and modified PPO were tried with varying amounts of glass reinforcement, and the polycarbonate and the modified PPO were also used without glass reinforcement. The mechanical testing of the molded ring sections in shear, tension and engraving is described. A partially related report from Picatinny Arsenal, designated as Technical Report 4358 of September 1972 is titled "Evaluation and Critique on Use of Polymeric Materials as Rotating Bands on 20mm Projectiles" and summarizes their experience with fourteen combinations of six basic plastic materials. Trials were made only with conventional metal band anchorages, and polycarbonate with 10 percent glass fiber reinforcement was capable of highest spin.

HIGH SPEED STRAINING AND TESTING OF PLASTICS

There is little published information on the high speed testing of plastics which is directly applicable to the impacting and displacement occurring in the rotating band. The following review summarizes some of the abstracts, references, and comments concerning the application of known techniques and data to the problem of testing the rotating band.

PLASTEC (Picatinny Technical Evaluation Center) has two separate bibliographies, dated September 1970, entitled "High Rate Loading Studies" and "Effect of High Loading Rate on Plastics". These have been received and studied but are not appended.

Probably the most applicable references are the series of symposia on high speed testing. They are covered in Volumes I through VI, published by Interscience Publishers. By way of introduction, Frederick E. Eirich, co-chairman of the symposia, cites that the basic reason for lack of information in the field of high speed testing is the difficulty and complexity of measuring the variables. He continues,"Furthermore, very few materials develop large strains at high speeds before they fail. Failure, in general, is always due to the growth of existing cracks and flaws in the test piece and is therefore statistical in nature and depends on specimen size. Inertia also depends on size, and there will be clear limitations of what accelerations can be obtained readily and measured precisely at high speeds. Again, in view of the small strains before break, most materials will fail by brittle fracture, a phenomenon which is very poorly understood and depends on the relative direction of flow at the apex of a crack and the amount of energy consumed during crack propagation. Such measurements present a formidable task under any conditions, and even more so at high speeds. A last complication to be considered when the rates of deformation become comparable to the rates of crack propagation is that failure will become less selective with regard to crack size. The smaller cracks might open up first when they are suitably oriented. On the other hand, larger cracks may not all have the time to develop in the energetic most favorable direction but may be literally opened at any direction so that components of straining speeds, rather than the rate in the main strain direction, may become effective. Finally, at high speeds no material structure will remain unaffected, and one has to expect all sorts of breakdown or, conversely, strain-hardening or entanglement processes which will materially influence the response of the specimen in a manner unknown at lower speeds."

Typical of the topics which are covered in the six volumes of the symposia are the following titles of articles:

Comparison of Impact Properties of Six Materials on Four Types of Tensile Machines. P. I. Donnelly and R. H. Ralston Hercules, Wilmington, Delaware

High Speed Puncture Testing of Thermoplastics. F. J. Furno, R. S. Webb and N. P. Cook, Marbon Chemical, Borg-Warner

Adaptation of a Ballistic Tool for Obtaining Strain Rates Above 20,000 Inch/Inch/Minute. D. A. D'Amato, Research, Winchester-Western, New Haven, Connecticut

Effect of Strain Rate on the Viscoelastic Properties of High Polymeric Fibrous Materials. Eugene C. Dogliotti and Wm. E. C. Yelland, U. S. Army R&D, Natick, Massachusetts

Basic Problems Involved in the Testing of Materials under Destructive Ultimate Loads at High Strain Rates. H. Grimminger, Fabwerke Hoechst, Frankfurt on Main, Germany

High Rate Tension Testing of Plastics. Stephen Strella R&D Monsanto, Boston, Massachusetts

Review of a High Speed Tensile Testing Program for Thermoplastics. Richard Ely, U. S. Army Ordnance Missile Command, Redstone Arsenal, Alabama

Tensile Testing of Elastomers at Ultra High Strain Rates. J. W. Jones, DuPont Explosives Department, Gibbstown, New Jersey

The Tensile Properties of Highly Filled Polymers. Effect of Filler Considerations. Kenneth Bills, Keith Sweeny, Frank Salcedo Aero Jet, Azusa, California

Characterizing Impact Behavior of Thermoplastics. W. E. Wolstenholme, U. S. Rubber Co., Wayne, New Jersey

Geometry Effects and High Speed Tensile Behavior in Styrene Polyblend Systems. J. Kenneth Lund, Monsanto Company, Springfield, Massachusetts

High Speed Tensile Testing as an Index of the Oxidative Degradation of Polyethylene Resins. Theo H. Meltzer and Ross H. Supnik

Detective Work with High Speed Testing: The Location of a Phase Change Area, K. B. Goldblum, General Electric, Pittsfield, Massachusetts

Factors Influencing Izod Impact Properties of Thermoplastics Measured with the Autographic Impact Test. W. E. Wolstenholme, S. E. Pregun and C. F. Stark, R&D U. S. Rubber, Wayne, New Jersey

A Medium Speed Tensile Testing Machine and Some Dynamic Data Produced Thereby. A. G. H. Andersen, U. S. Army Materials Research Agency, Watertown Arsenal, Watertown, Massachusetts

Of the Strength of Polymeric Materials at High Rates of Strain. F. R. Eirich, Polytechnic Institute of Brooklyn, New York

Static and High Rate Tensile Behavior of Various Resin-Reinforcement Combinations. E. McAbee and M. Chmura, Plastics Laboratory, Picatinny Arsenal, Dover, New Jersey

Time-Temperature-Strain Rate Equivalence for Various Engineering Thermoplastics, Jerome J. Lohr, NASA Ames Research Center, Moffett Field, California

Stress-Strain Properties of Textile Yarns Subjected to Rifle Bullet Impact. Carl A. Fenstermaker and Jack C. Smith, National Bureau of Standards, Washington, D. C.

Response of Several Materials at Intermediate Strain Rates. R. M. Lacey, Sandia Corporation, Sandia Base, Alburqurque, New Mexico

True Stress-Strain Properties for Filled and Unfilled Polymers and Elastomers as Functions of Strain Rate and Temperature. S. Saylak, Elkton Division, Thiokol Chemical, Elkton, Maryland

Some Aspects of Brittle Failure in Polymers. S. Matsuoka, C. J. Aloisio, J. H. Daane, Bell Laboratories, Murry Hill, New Jersey

Yield Stress Behaviour of Some Thermoplastic Polymers. J. A. Roetling Re-entry Systems, General Electric, Philadelphia, Pennsylvania

High Speed Puncture of ABS Plastics and Blends. V. E. Malpass, Marbon Chemical Division of Borg-Warner Corporation, Washington, West Virginia

It has also been noted that Dr. Nicholas at Air Force Materials Laboratory, Wright-Patterson Air Force Base has tested materials at high rates of stressing by a sonic technique and can test materials on a comparative basis with other materials, but not to absolute values. It is not likely that he can test adhesives by this method.

SECTION III

TECHNICAL DISCUSSION

DESIGN REVIEW

In this section the basic design premises and the rationale towards solutions based on the properties of plastics materials and their methods of processing are shown.

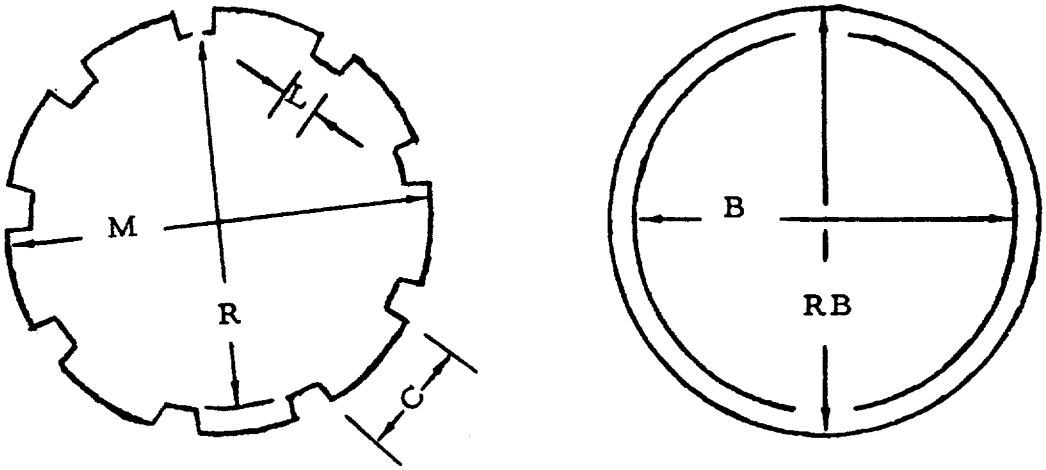
The performance forces and stresses which the 20mm rotating band is called on to meet are given in Table 1.

TABLE 1

PERFORMANCE DATA; 20mm PROJECTILE

Firing Velocity	4,400 ft/sec 52,800 in./sec 264,000 ft/min 3,000 MPH
Rate of Strain	10,000 in./in. sec 600,000 in./in./min
RPM	120,000 at 3380 ft/sec 157,000 at 4400 ft/sec
Barrel Twist	1 twist in 12 inches, twenty inches and 24 inches, constant twists
Engraving	9 grooves each 0.016 inch deep 0.075 inch wide
Internal Breech Pressure	> 65,000 psi
Acceleration	600 to 700 ft/sec in 1 inch
Barrel Length	108 inches
Weight of Projectile	99 grams 1575 grains

The stated dimensions of the projectile and associated hardware are given in Figure 1.



Gun Barrel

M. Major Diameter
0.817 + 0.004 inch
R. Rifling Land Diameter
0.786 + 0.003 inch
L. Width of Land
0.075 inch
C. Width of Clearance
0.200 inch
Number of Lands 9

Projectile Before Firing

B. Diameter of Body
0.786 maximum inch
RB. Diameter of Rotating Band
0.828 - 0.004 inch

Figure 1. Sizes of Gun Barrel and Projectile

Interference (or embossing) of rifling land diameter into rotating band:

0.035 to 0.042 inch on diameter
0.0175 to 0.021 inch per side

Interference (or obturation) of rotating band into major barrel diameter:

0.003 to 0.011 inch

Depth of embossing possible from gun barrel dimension:

0.014 to 0.0175 inch

A cast of the entry section of the gun barrel was provided and showed the entry angle of each individual rifling land to be approximately eight degrees to the axis of the barrel; the radius at the top corners of each rifling land is from 0.003 inch to 0.015 inch. The wedge-like ramp is 0.190 inch long.

The primary concerns of the design of the plastic rotating band relate to these performance requirements:

1. Ability to engrave without fracture and to displace or compress the engraved material.
2. Ability to bond or be anchored to the steel projectile.
3. Bearing and shear strength to transmit rifling force component to rotate the projectile.
4. Tensile strength to resist stress of the centrifugal force of high rate of spin.
5. Ability to resist impact blow of contact with rifling lands.
6. Need to resist the elevated temperature of storage and contact with hot gun barrel and perform at these temperatures.

7. Need to perform at low temperatures, and following storage at extremes of temperature and humidity.

8. Inert to effects of handling, humidity, proximity to propellant, grease, oil and other expected environments.

9. Material and process cost competitive with metal band.

ENGRAVING AND DISPLACEMENT

The problem of providing a rotating band which would emboss the pattern of the rifling land satisfactorily was discussed at length during the planning part of the program. In monthly report No. 2, covering the month of November 1972, the relatively shallow anchorage depth of 0.060 inch was still being projected. A 0.020 inch proud rotating band superposed on the 0.060 inch anchorage would thus be called on to take an embossing of 0.016 inch depth, or a compressive set of 20 percent. This requirement, of course, became much more demanding when, at a later date, it was required that the anchorage could not be deeper than 0.020 inch, thus raising the requirement for compressive set to that of 0.016 inch indent in 0.040 inch of plastic, or 40 percent compressive set.

As part of the consideration of engraving, it was also deemed acceptable that the engraving of the rotating band could be temporary, and that if a material were resilient and later regained its initial unengraved shape, fully or partially, the function would have been fulfilled. Thus, a live rubber material, if it were to meet other requirements, could be an acceptable material.

As the rotating band material is engraved, that amount of material must displace to somewhere else. In the metal bands, the displacement is partially forward and principally backward as an extension of the rifled groove. In the plastic design, the width of the rifled groove occupies 0.075 inch wide in an available width of 0.275 inch, or 27 percent of the material must be displaced. In considering the directions in which material can be displaced, the fact that the entire band is in interference with the major diameter of the gun barrel must be taken into account.

There are four potential answers to the problem of displacing the plastic material due to the engraving action:

1. As mentioned above, the material can displace momentarily and then rebound or recover its shape elastically.

2. The plastic material can have enough malleability to be displaced end-wise in the same manner as the metal bands now displace. It may be of some help to provide minimum distances for the material to have to travel, or relief grooves into which the material can be displaced.

3. The material can be compressible or have voids in its structure which permit it to be compressed without otherwise displacing itself. A plastic with a compressible void, such as those filled with compressible fillers or a foam structure, would permit this.

4. The material to be engraved can be sheared or scraped out of position and be displaced in this manner.

ROTATIONAL FORCES

Along with the requirement that the band material sustain the impact and displacement of firing, the next most demanding requirement is that the material have adequate shear and compressive (or bearing) strength to transmit the rotational force exerted by the sides of the rifling lands against the engraved grooves. This force is then transmitted in shear loading to the band material anchored to the projectile; the final requirement is that the anchorage then sustain the shear load imposed by the rotating band so that the projectile can be driven up to its flight speed of 157,000 rpm. Normally, most plastic materials have higher shear and bearing strengths at low temperatures and are also higher when stressed rapidly. However, they also lose strength at elevated temperatures, and many potential band materials probably will not be able to transmit rotational forces when tested at +165°F.

ANCHORAGE CONSIDERATIONS

This key consideration was initially toward a reliance on combined mechanical and adhesive anchorage derived, in part, from the anchorage configuration of the existing TP projectiles and related to the earlier trials of plastics for rotating bands. Those experiments, with nylon molded on to 20mm projectiles, were successful with the deep mechanical anchorage similar to that of the metal rotating band. As the anchorage depth became more limited, it became apparent that mechanical anchorage would be of little benefit. The sequence of development work on the problem of achieving shallow anchorage of plastic rotating bands to steel projectiles is detailed in a following section of this report.

TEMPERATURE AND ENVIRONMENT CONSIDERATIONS

The gun barrel will become very hot during continuous firing from the propellant gas temperature (as high as $2800^{\circ}F$) and may reach $500-600^{\circ}F$ or a dull red heat. The rotating band is not called on to be stored against hot metal, but only to survive the time of contact while moving down the barrel. This time will be in the order of 0.002 second. All indications from previous work is that this time in the barrel and the momentary contact with hot metal does not melt the plastic rotating band. This is not sufficient time to soften the plastic to lower its shear or bearing strength and weaken its ability to transmit the turning effect of the rifling to the projectile.

A different thermal consideration is that of the projectiles which are stored or reach a temperature of $160^{\circ}F$ just prior to firing. The plastic at this temperature will have a different stiffness and strength than at room temperature or sub-zero temperatures, and therefore the type of plastic must be chosen with this in mind. A reciprocal consideration is that the projectile should not be heated above $600^{\circ}F$ during processing so as not to disturb the heat treatment of the projectile.

Projectiles with rotating bands must withstand the usual range of gasoline, oil, and cleaning fluids such as those based on trichloroethylene. Especially pertinent will be resistance to acetone vapor which is used in the propellant formulation and permeates the sealed packaging boxes. The plastic rotating band material and its bond to steel must also withstand a full range of moisture and temperature exposures.

METHODS OF MANUFACTURE

In addition to the basic concern that the design and materials will meet the functional requirements for the rotating band, a second demanding consideration is that of how to manufacture the final part. The methods of shaping plastics which are most pertinent to this problem are:

a. Compression (transfer) or injection molding of the band onto the projectile.

b. Coating of the projectile for rotating bands by fluid bed powder process.

c. Casting of liquid resins.

d. Bands fabricated by machining or extrusion to be assembled to the projectile.

e. Bands generated by winding filaments or fabric laminate into place on the projectile.

The optimum design answer is to use the process most suited to manufacture which will still yield parts of optimum performance. In a general manner, the processes above are listed in the order of desirability of choice, and first consideration would be given to those first in the list if the attendant design and material were able to perform.

SOLUTION TO PROBLEMS

Considering both the aspects of the design problems and those of the methods of manufacture, Table 2 summarizes those approaches to solutions which appear to be solid premises. There are also, of course, unpredictable hurdles to some of the premises and also unpredictable mutations which could be quite successful. The exploration of these constitute the program.

TABLE 2.

DESIGN CHOICES

Requirement	Material Choices	Process
Impact resistance	Nylon, ABS, urethane	Injection molding
	UHMWPE	Machining
	2-part urethane	Casting
Ability to engrave; malleability	ABS, soft nylon	Injection molding
	Foam-like or compressible filler	Injection, compression molding
Ability to bond or be anchored to the steel projectile	Nylon, ABS urethane, epoxy	Mechanical engagement of undercuts with molding or casting Adhesive bonding between plastic and steel; with or without heat fusion
Tensile strength to resist stress of centrifugal force	Filament around or wrapped laminated reinforcement	Filament wound or laminated reinforced plastic
	High strength injection molding resins	Injection molding
Bearing strength to transmit rifling component force to rotate the projectile	Fiber-reinforced laminating resin	Filament wound or laminated reinforced plastic
	Reinforced injection molding resins	Injection or compression molds
Resistance to elevated storage and firing temperatures	Glass-reinforced plastic	Injection or compression mold
	Thermoset binders	Transfer, molding; winding or laminating
	2-part urethane	Casting

METHODS OF ANCHORAGE

MECHANICAL ANCHORAGE

The initial guidance on this program indicated that the existing TP projectile would be furnished and used for the experimental program. This indicated that mechanical anchorages up to 0.055 inch in depth could be considered and used; the contract did not indicate otherwise. Initial experiments therefore included anchorage depths of this magnitude and various experimental designs to utilize mechanical undercutting to provide physical anchorage.

Later in the program it became mandatory to work with an anchorage of 0.020 inch maximum depth. This dictated two changes in the program:

a. It became clearly unfeasible to include a significant mechanical anchorage in that restricted depth.

b. The stock of TP projectiles furnished by the Air Force under the terms of the contract became unusable, and a new supply of nongrooved projectiles had to be located and procured at contractor expense.

Because a significant amount of work was done on mechanical anchorage before the change-over to an anchorage of 0.020 inch maximum depth, a summary of the work is included in this report for record purposes. However, since the work is not applicable, lengthly detail will be omitted. The sequence described above is illustrated in Figure 2 showing the transition to projectiles with plain walls.

The basic program in establishing mechanical anchorages had these three objectives:

1. The anchorage would be capable of being machined in typical production operations.

2. The anchorage design lends itself to shallow anchorage depths.

3. The configuration can be adjusted to proportion the strength of the anchorage between the steel and the plastic.

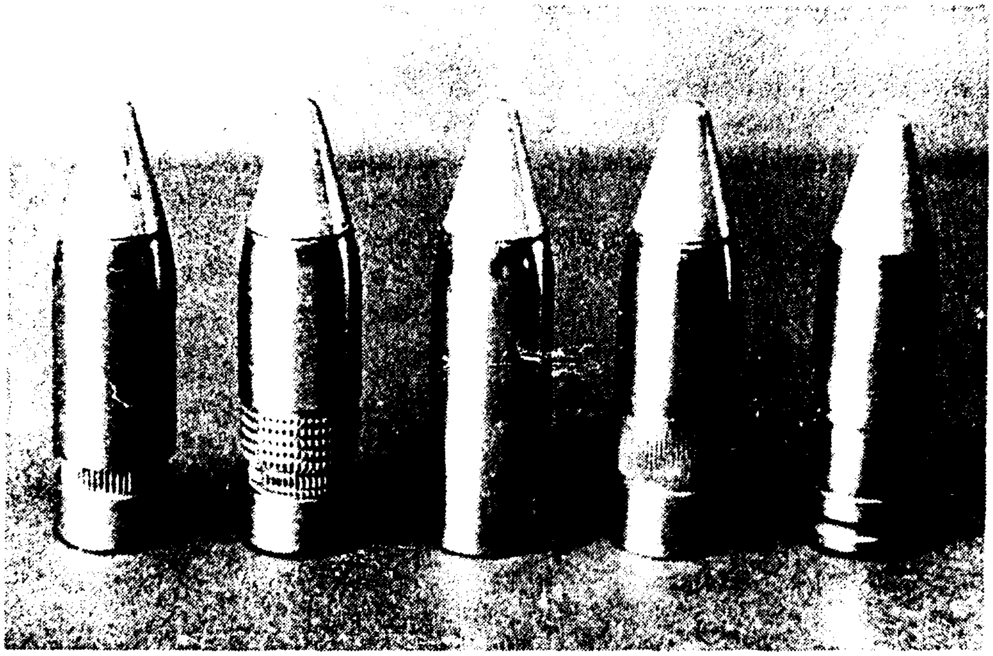


Figure 2. Evolution of Band Anchorage

1. Regular deep groove for copper band
2. Array of studs for mechanical anchorage
3. Grooveless blank
4. 0.020 inch x 0.50 inch lightly serrated groove
5. Final smooth groove and heel detail

Initial attempts on mechanical anchorage were in the order of those indicated by the anchorage patent 2,996,012, Navy Drawing, APL-355E and by prior work which had been done on other projectiles. These consisted primarily of multiple circumferential ridges with undercut walls to present an inverted V-shaped anchorage for the plastic material. Several variations of these were drawn and tried, but the primary objection to this approach was the added difficulty and expense of machining the undercut grooves and the need for having close spacing to make them effective.

The next series of mechanical anchorage are typified by the drawings EG-A1-A and EG-A2-A (Figures 4 and 5) which are copied on the two pages following, and by details from drawings EG-A3-C (Figure 6) and EG-A7-C (Figure 7) which illustrate further variations and are copied on following pages. This includes the anchorage EG-A4-C (Figure 25) devised for the over-the-end cap style rotating band. The anchorage design used for several hundred projectile blanks was patterned on the following machining concept (Figure 3).

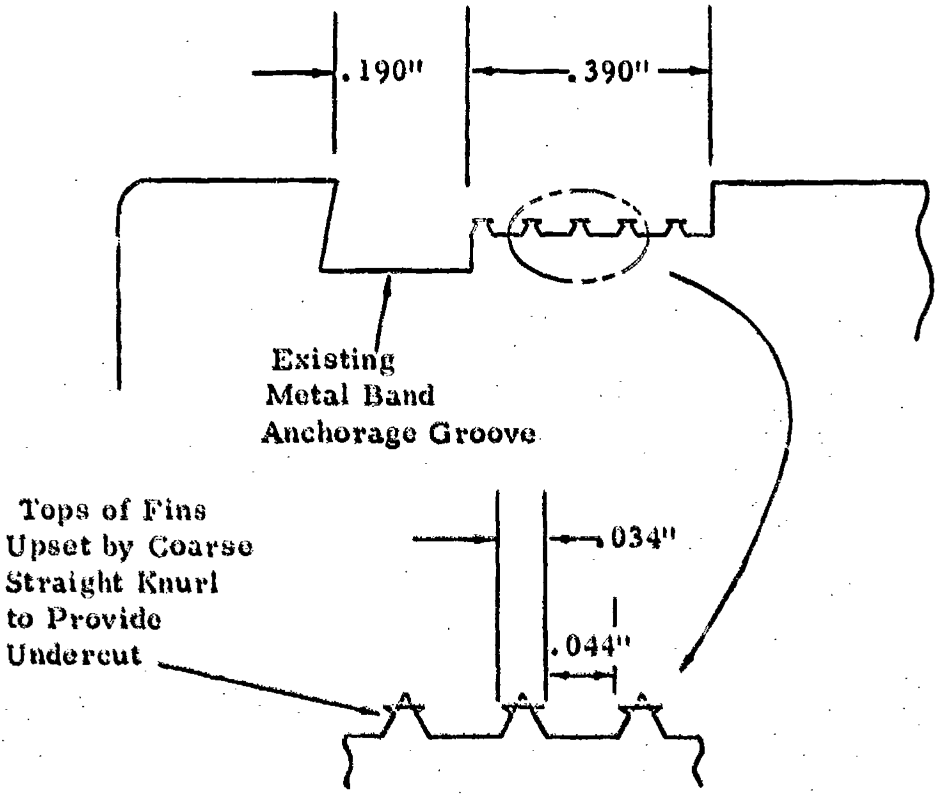
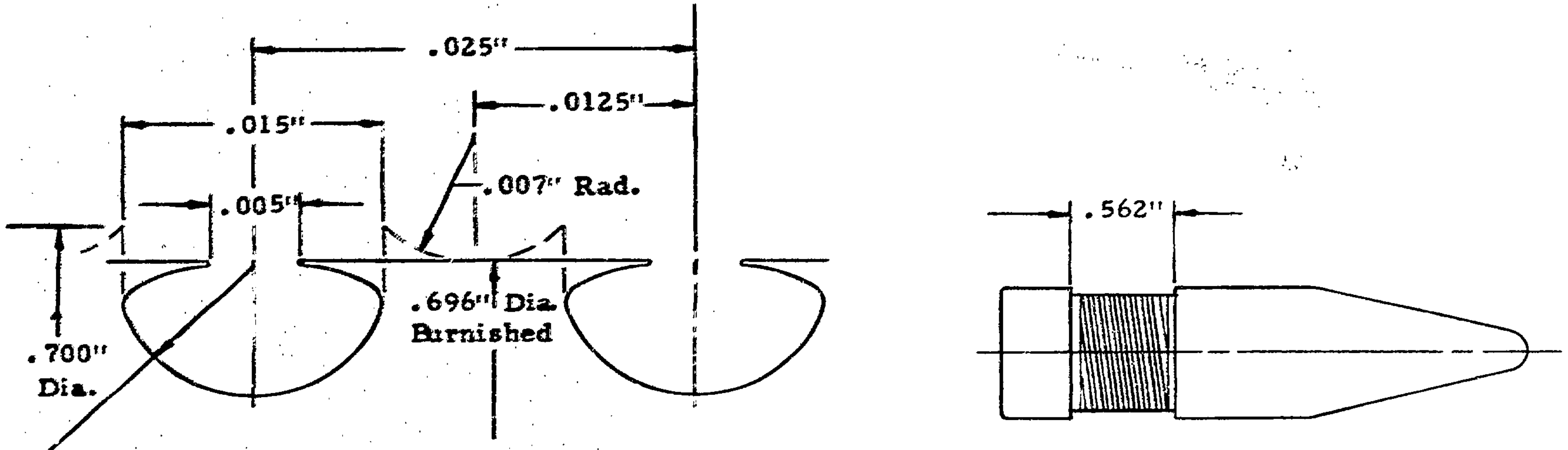
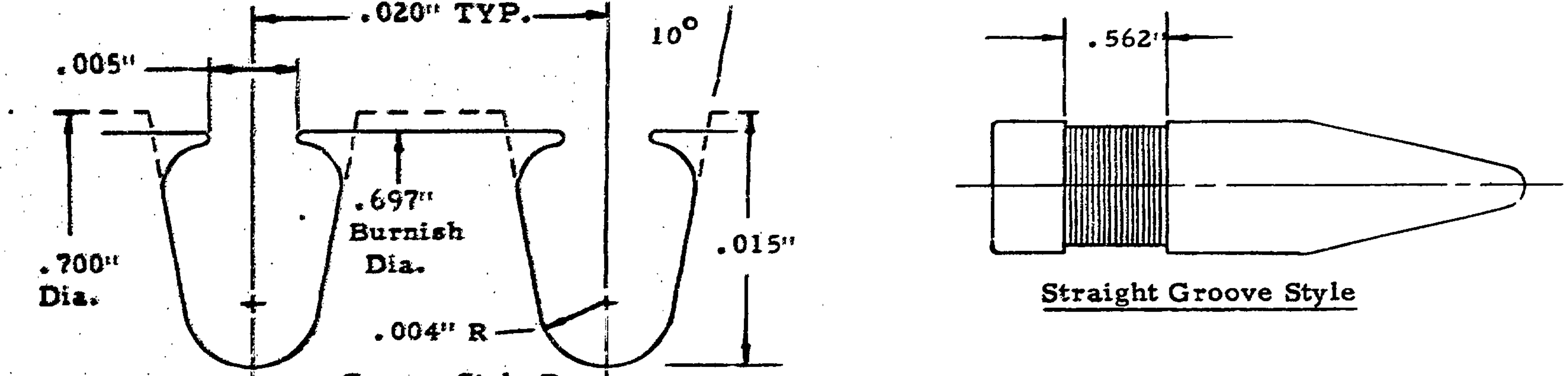


Figure 3. Mechanical Anchorage Detail



Groove Style A

Screw Thread Style



Straight Groove Style

Groove Style B

Figure 4. Mechanical Anchorage Detail

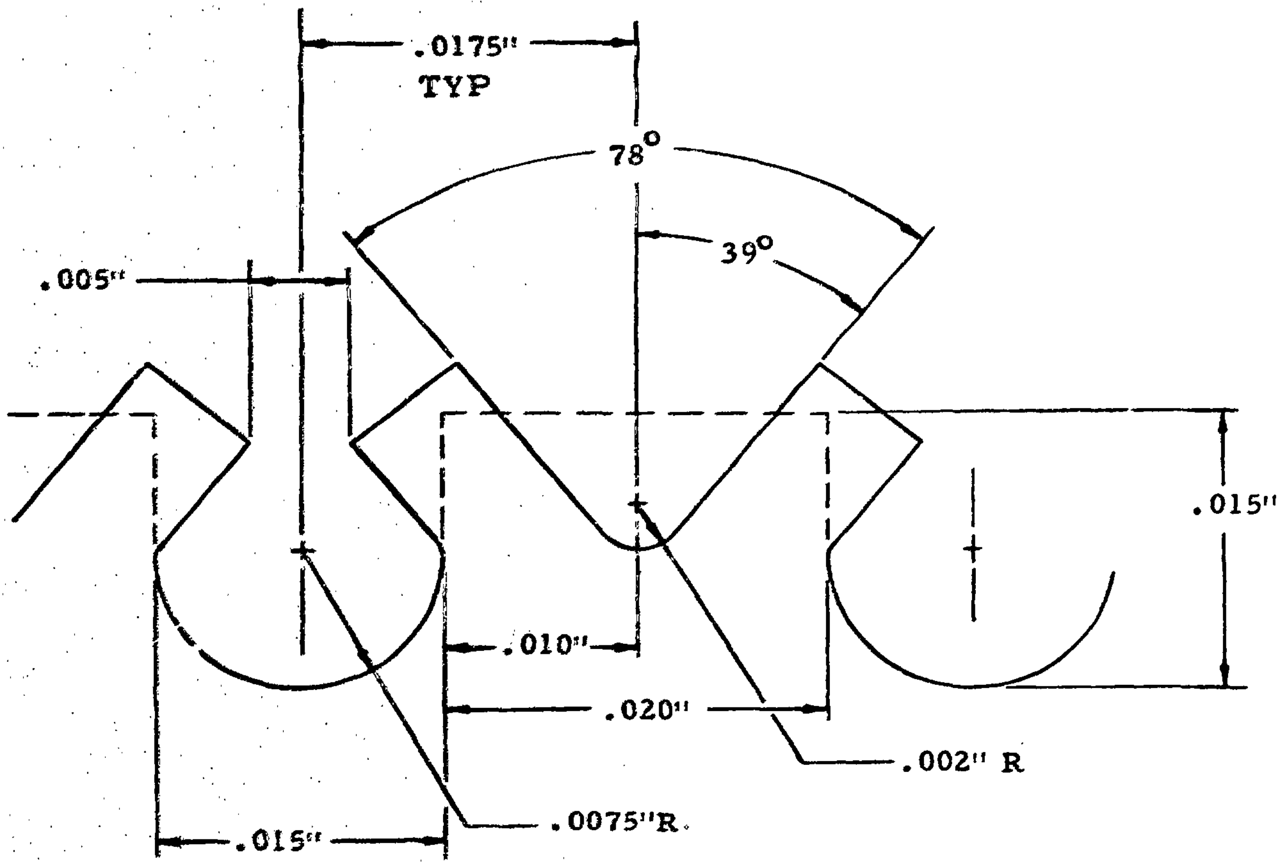


Figure 5. Anchorage Groove Detail

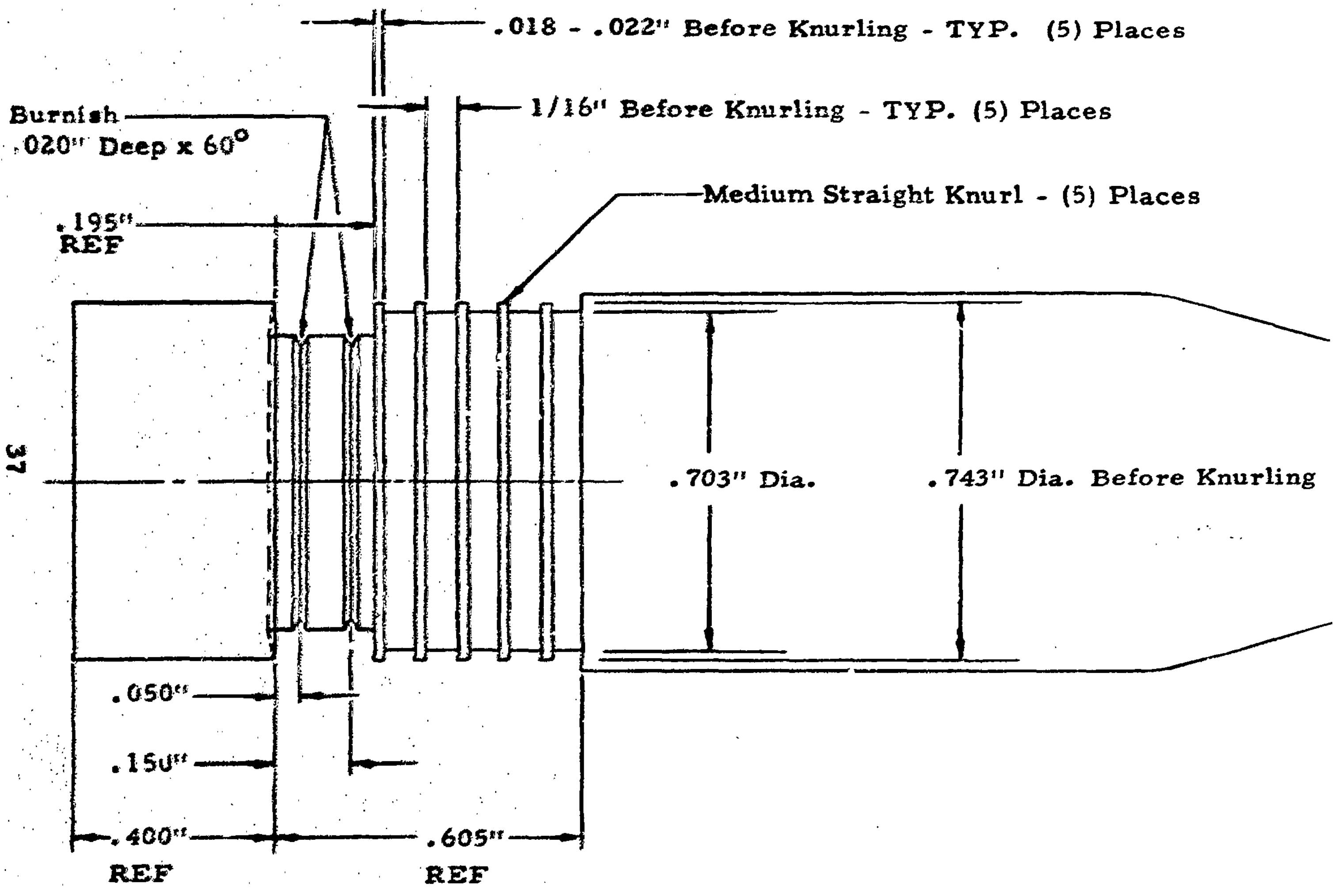


Figure 6. Anchorage Detail

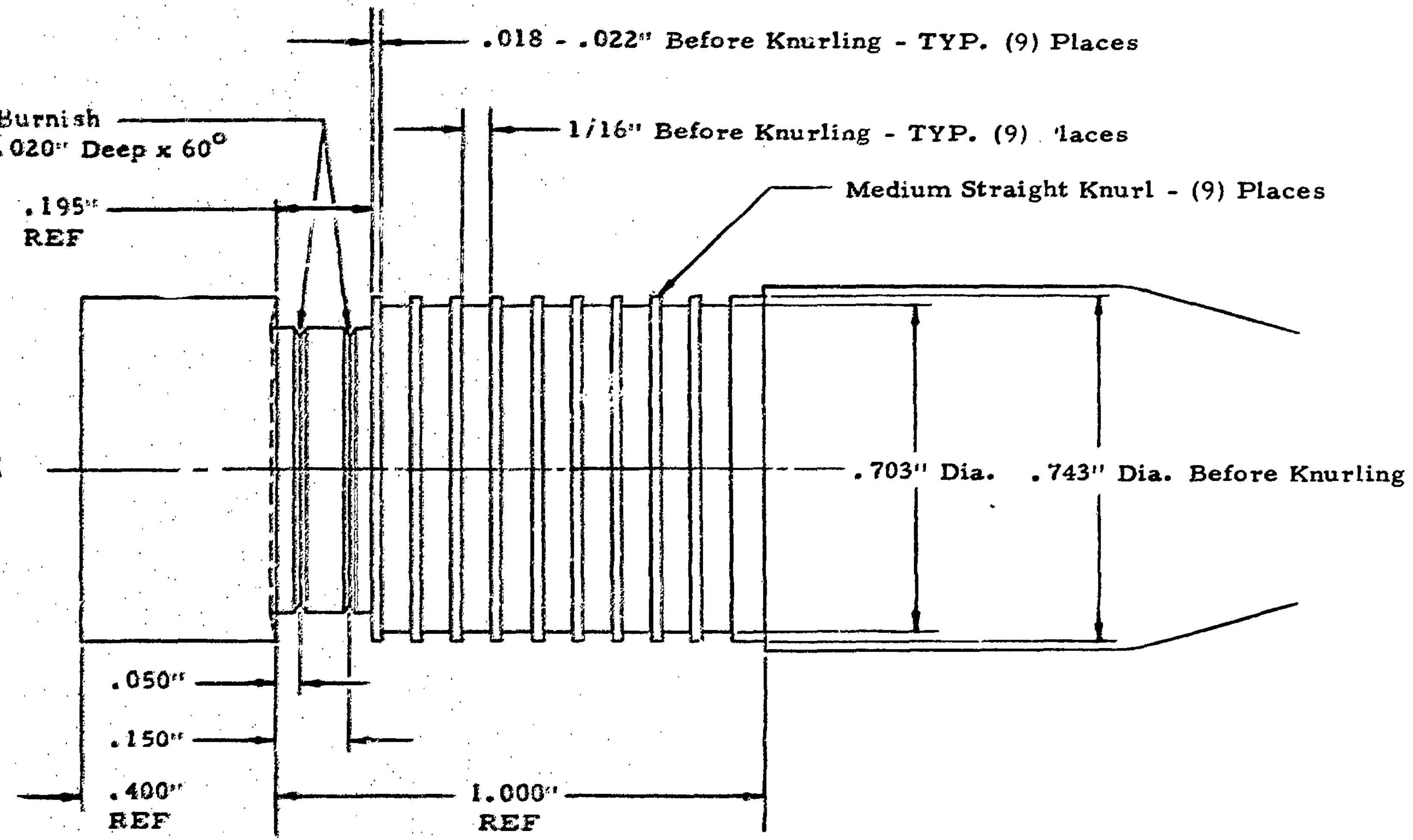


Figure 7. Anchorage Detail

CHEMICAL ANCHORAGE

As the work on mechanical anchorage evolved, it became apparent that any mechanical anchorage tried within the limitations of a 0.020 inch depth would be difficult to machine and highly questionable as to its effectiveness. All efforts therefore were transferred to an adhesion-type anchorage between the plastic rotating band material and the steel projectile.

One of the earliest references was that suggested by the Air Force program manager from Mr. E. T. Darden of duPont which consisted of a priming procedure for bonding Zytel 77 G-43 (nylon 6/12) to steel. It has also been noted that Phenoweld No. 7 from Hardman Co. has been found to give 1700 psi tensile shear strength in bonding steel to nylon. Good results were also had in a concurrent rotating band program in bonding nylon to steel with FM-1000 (3M Company) polyamide-epoxy tape. This procedure, however, requires an after-cure under pressure to consummate the bond.

A variety of primer materials based on past experience and on advice from suppliers of adhesives were studied, and several were procured for trial. The candidate materials, along with the rotating band material with which they may be useful, are depicted in Table 3.

TABLE 3.

PRIMER-BAND MATERIAL SYSTEMS TO BOND TO STEEL

Primer (adhesive) Systems	Nylon 6/12 43% glass	Nylon 12 50% glass	Absafil G1200/20	Epoxy ERL 2772 Compounds	Epoxy Type 105932 Compounds	Premix 1100-30 13 MC	Phenolic FM 1303	Phenolic FM-1132-P	Urefil	Polyurethane	Nylon 11	Nylon 12
General Mills Nylon Solution XX-1000	x	x									x	x
M&T Primer 253 P	x	x									x	x
Polysulfone Solution Primer	x	x					x	x			x	x
Flexible Epoxy 105934	x	x	x	x	x	x						
Thixon D12809	x	x										
Elvamide PB-8019	x	x										
Chemlok 607						x			x	x		
Thixon AB-1153									x	x		
Compo XL-901-1									x	x		
Phenolic Butyral 1P7	x	x					x	x				
Phenoweld No. 7	x	x					x	x				

TESTING OF PRIMERS

One of the important needs was to develop a method of testing the efficacy of various primer/resin combinations in their adherence to steel. The need is not only to simulate the type of adherence needed, but also to bond the test parts under conditions reasonably analagous to the manner in which the bond would be consummated in production.

The plan developed was to test the primer bond in direct tensile pull as opposed to a shear value as being more represe 'ive of the need to resist breakaway of the band. The test will be on the ends of 3/4 inch steel rods which have been sand blasted, cleaned, and appropriately primed and which can then be used as plungers in miniature mold to mold the resin directly against the primed surface. The simulation of compression molding is done readily, and the simulation of injection molding is accomplished cycle-wise by heating the resin to melt and then cooling in place under pressure.

A typical test specimen used for tensile tests of primer/plastic systems to steel is shown in Figure 8.

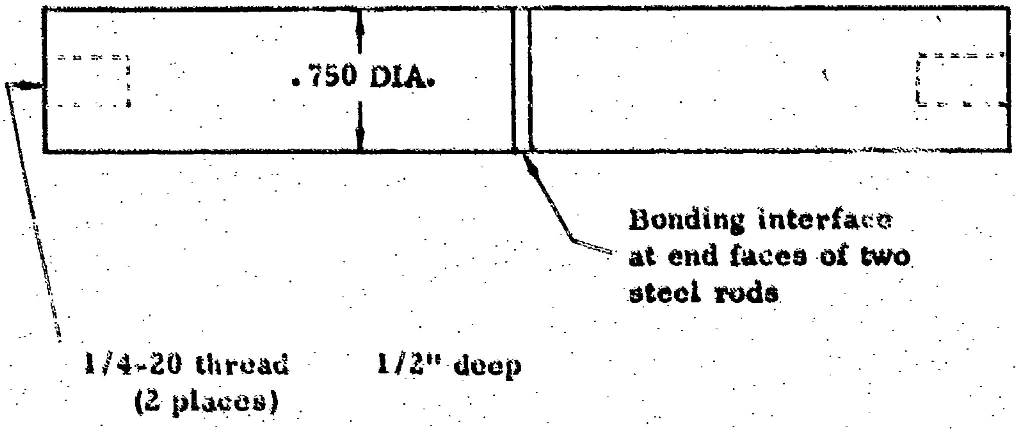


Figure 8. Test Specimen for Primer Trials

In a test for primers for use with cast 2-part urethane systems (Adiprene L-200/MOCA), the candidate primers were Chemlok 607, Thixon AB-1153, and Compo XL-901-1. In these trials it was found that the Chemlok 607 primed rods had a pull force approximately 150 percent that of the unprimed units, the Thixon AB-1153 were about 110 percent that of the unprimed units, and the Compo XL-901-1 were about the same as the nonprimed.

With the thermoplastic urethanes (CPR/Upjohn 2102-65DX and Estane 58111) the Thixon primer performed better with both materials, with adhesions as high as 200 percent that of unprimed surfaces.

Bonding trials were run with nylon 12 molding material and a series of seven primers. The listing of primers and a summary of the results are as follows:

1. "B" staged Epon 815/curing agent "Z" epoxy formulation.
2. "B" staged Epon 815/curing agent "Z"/LP-3 flexibilizer (30 phr) epoxy formulation.
3. M&T Chemical Co. Nylon dispersion No. 253-P, cut 2:1 with MEK and prebaked 30 minutes at 450°F.
4. DuPont's Elvamide PV-8019 nylon in 5 percent solution with ethyl cellosolve, prebaked 30 minutes at 450°F.
5. SeaGuard No. 1P7 phenolic butyral lacquer.
6. Hardman's Phenoweld No. 7 phenolic adhesive.
7. Whittaker's Thixon D-12809 nylon primer

Of these, the units molded using Thixon D-12809 fell apart after molding. The best pull test values were obtained on the M&T 253-P primed units and the SeaGuard 1P7 primed units. In these cases the values obtained were approximately 450 percent and 350 percent, respectively, of the unprimed units. Thus, considering ease of application and bond strength, these latter 2 primers were isolated as best choices for use with nylon 12.

A variation in the application of primer systems for nylon to steel was experienced in the bonding of nylon coatings applied by fluid bed powder fusion. On samples which were submitted of this type, the priming operation was done by the custom coating facility which did the coating. Their priming operations are proprietary, and the exact cleaning and priming operation used is not available. However, some informal comments indicate that the preferred cleaning may be chemical cleaning plus zinc phosphate. M&T Primer 253-P is specifically recommended as the primer coating for Nylon 12 fluid bed coating in literature obtained from M&T Chemical Co.

NYLON-STEEL BONDING

As the work progressed in the selection of the best material for the rotating band, more emphasis was placed on achieving a good bond between nylon and steel. The record of the primer trials cited showed that the M&T primer 253-P was a prime candidate. However, molding trials with this and other primers were not completely satisfactory. Trials were also made with the B-stage epoxy primer which were then post-cured, but firing trials on this showed they were not adequate. It was at this time that the combination of work with induction heating and the use of primers was combined to melt and activate the primer directly at the steel interface.

Because the heating action was by induction, the location and amount of heating could be closely controlled and could be directed to melt the primer interface first without any substantial deformation occurring in the molded-in-place nylon rotating band. By controlling the amount of heat so that it was just adequate to show a clear melt on the interface of the nylon rotating band, it was found that the primer was fully activated and that an exceptionally good bond was consummated. We believe that a primary benefit from this approach is that the interface of the rotating band can be brought to the activation temperature without fully expanding and loosening the tight shrink fit which the band had on the steel as a result of the shrinkage in the molding operation. Thus, it provides it own circumferential band clamp during the process. Water quenching is then used to quickly cool the band and steel after the primer has been melt activated.

Some of the history of this effort is depicted in Figures 9, 10 and 11.

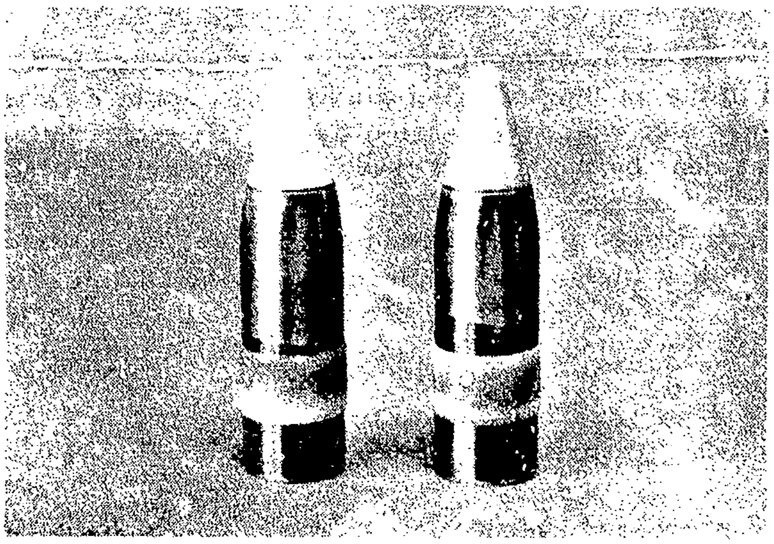


Figure 9.
Early attempts of molding and bonding, without success, nylon 12 rotation bands. Whitish areas indicate band to projectile separation.

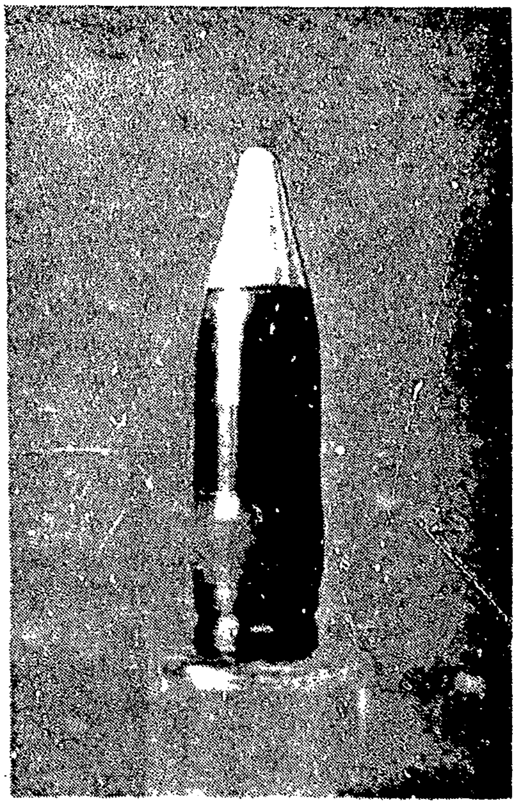


Figure 10.
First successful induction bonded nylon 12 rotation band, on lightly serrated band groove, 107671-1 series, June 21, 1973.

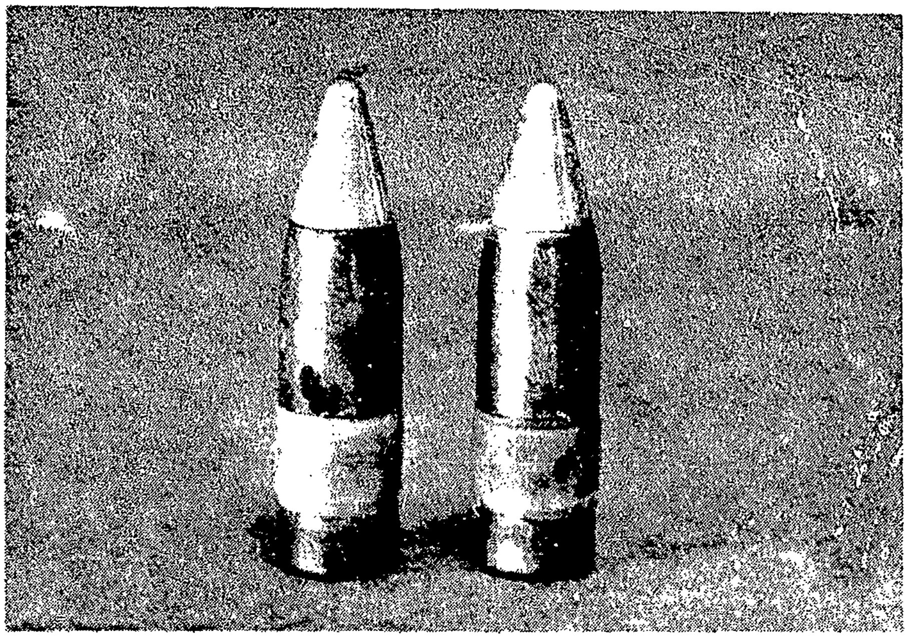


Figure 11. Tefzel Plastic Rotating Bands With Unsuccessful Bond

Unsuccessful attempt in banding with
Tefzel Fluoroplastic. Note corrosion.

MOLD DESIGN

Since the major development commitment is that of exploring a molded plastic rotating band, a very early step in the program was the planning and design of a mold for this purpose. The mold was planned to be versatile in its abilities and to be adaptable to changes as the development work progressed. The initial outline was for an injection mold with one cavity finished in a two-cavity frame, with the option of adding a second cavity when desired. In addition, the planning included:

a. Ability to mold the rotating band directly to the projectile.

b. Ability to mold thermosets by means of transfer molding or compression molding.

c. Ability to cast liquid resins.

d. Adjustment of the position of the projectile lengthwise in the mold cavity.

e. Provision for altering the length of the rotating band.

f. Provision for altering runner and gate configuration.

g. Provision for molding directly onto and over the end of the projectile for a cap-like rotating band.

h. Provision to heat or cool the mold.

The item of mold design encompasses the actual planning and design of the mold proper and the anticipation of the materials and molding methods with which the mold will be used. The various methods of manufacture of a rotating band have already been discussed in detail; in this section the considerations attendant to injection, transfer, or compression molding which affect the mold design and construction are shown.

INJECTION MOLDING

The most desirable method of producing projectiles with plastic rotating bands appears to be to mold them in place on the steel projectiles by injection molding. The same mold can generally be adapted to transfer molding, which is a variation in handling the material being injected into the mold. In these methods the material can be injected directly into place to produce a finished and accurate band shape, with superb conformance to the anchorage area regardless of its shape. Schematically the process is shown in Figure 12.

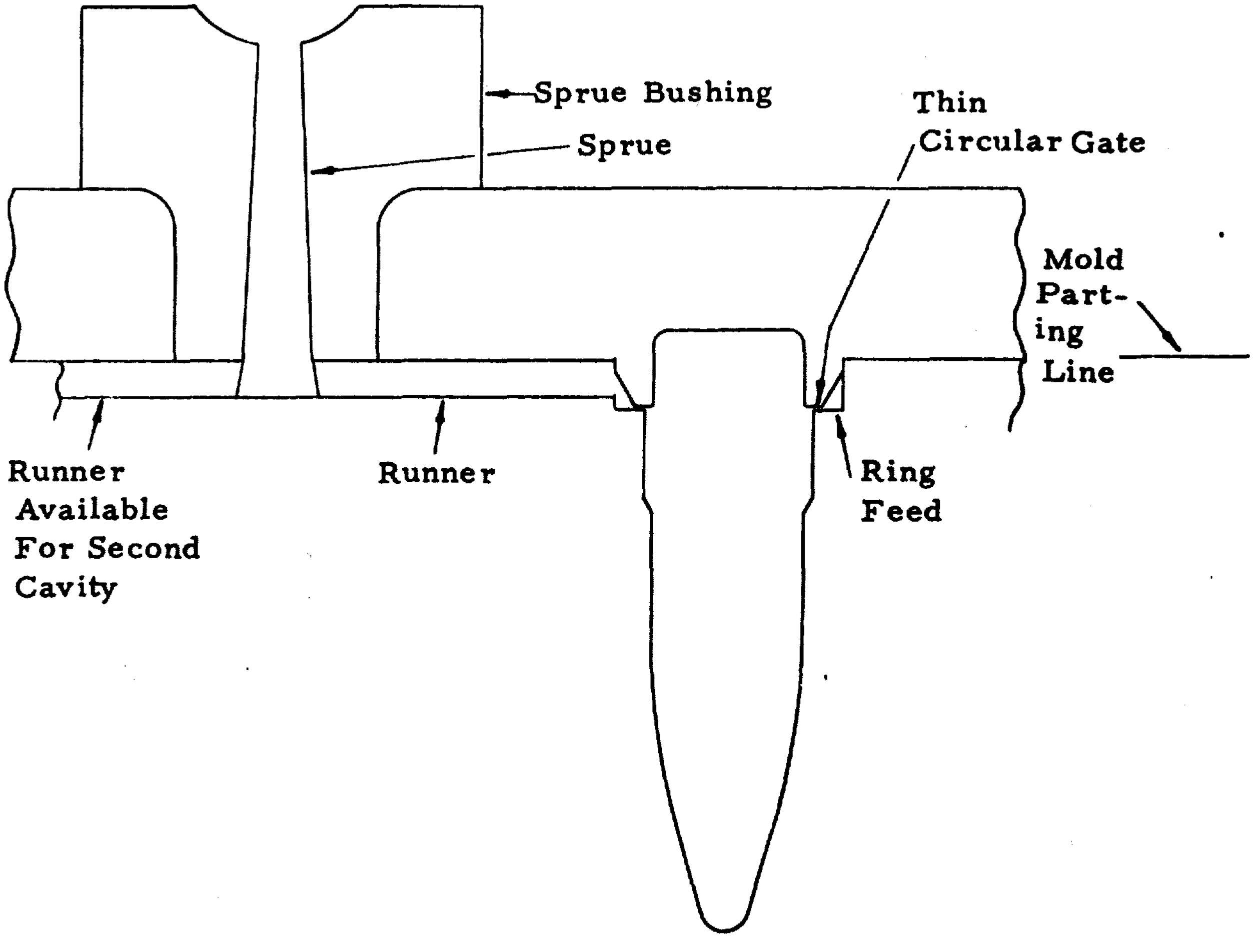


Figure 12. Schematic View of Injection Gating

Injection molding is generally done with thermoplastic materials, but can also be done with thermosets.

The mold design was made to accept the projectile shape and size delineated on drawing 7258812. The adaptation and use of the mold to make samples of over-the-end cap style rotating bands is described in Section III of this report under the heading Development Program.

The problem of establishing the optimum length of the rotating band was intimately tied to the choice of final materials and the performance of rotating bands at both low and high temperatures. Therefore, it was very late in the program before it was decided and approved that the length of the rotating band should be 0.5 inch. Additional refinements in the mold were also designed to accommodate variations in the length of projectiles. The mold revision is shown on drawing EG-A9-D and a component bushing detail on EG-A10-B.

GATING

In discussing molding and gating precedent on rotating band work, the Air Force program manager covered current and previous work. Bands which are premolded and then slit lengthwise are bonded to the projectile with adhesive which is cured under a holding pressure. Trials were also made with premolded bands not split lengthwise which were expanded and subsequently shrunk into place.

Molded-in-place bands have been made in a split mold with the parting line running axially along the length of the band; gating was on one side of the rotating band at the parting line, thus placing the knit line on the opposite side. Single-gate and three-gate patterns were used. A molded-on band gated from a circumferential disk feed has also been made: one sample of this type was found to vary in thickness from 32 to 46 mils, indicating poor concentricity. On a 25mm sample, a sleeve measured 27 to 31 mils in thickness indicating better concentricity. As Figure 12 shows, the rotating band is fed from a circumferential disk feed and circular runner. The possibilities of improving the circular orientation of the polymer by rotating the projectile during the injection of the plastic material were considered.

The mold was made with an initial gate thickness of 0.010 inch knowing that this would be the minimum ever needed, and that the ring gate could be increased in thickness by removing steel. The increase in thickness to 0.020 inch was required as soon as the molding of glass-filled materials was started.

TRANSFER MOLDING

The method of injection thermoset material into a closed cavity from an individual charge of material is called transfer molding. The cavity, gate, and runner system shown for injection molding is generally suitable for transfer molding, but a provision must be made to transfer the individual load of thermoset plastic from a pot into the sprue and runner system. Schematically, the change can be made by removing the sprue bushing from the diagram for the injection mold and substituting a plunger which can then pressure the material charge inside the cylindrical pot formed by the removal of the sprue bushing. (See Figure 13.)

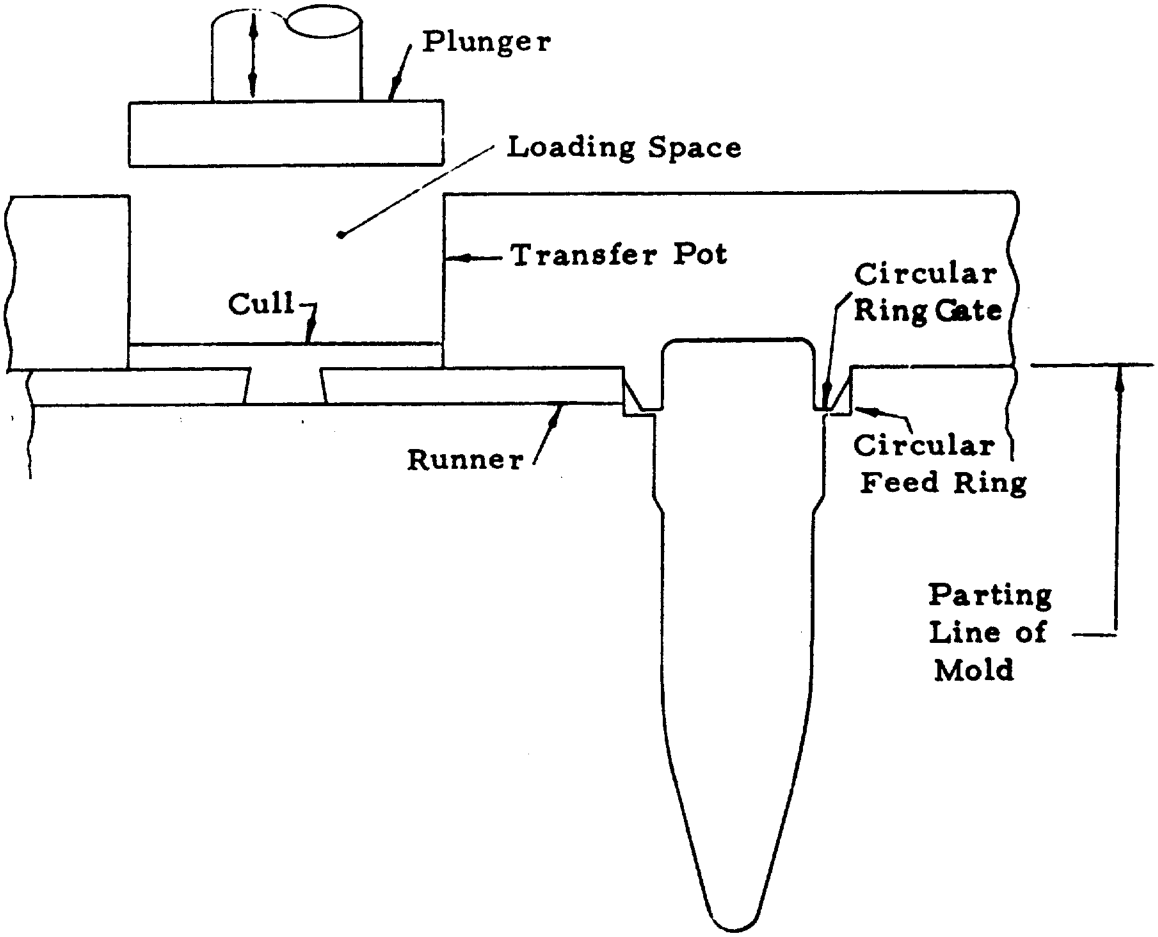


Figure 13. Schematic View of Transfer Mold Gating

COMPRESSION MOLDING

The cavity arrangement shown for injection molding can also be used for compression molding with a minor modification. In this process, plastic material is placed in the open mold cavity, usually in powder or granular form, and the mold is then closed under pressure, with the projectile in place in the cavity. The mold is then closed, and the plastic material, generally thermoset, is molded to the band shape. Excess material forces into the circular gate and runner system and is flashed out; the feed gate is blocked off. This method is also a convenient means of casting liquid urethane rotating bands to the projectile.

The primary problem with compression molding is to insure that the descending plunger does not strike the steel projectile insert which is already in place in the mold. However, the projectile does have good line-up and rigidity, and compression molding can be considered a viable process. Compression molding, perhaps with the parting line along the axis of the projectile, might be required to pressure a thermoset filament wound rotating band which could not be injected or transferred. Compression molding might also be necessary if the fibrous reinforcement of a thermoset molding material proved to be impossible to transfer mold satisfactorily.

METHODS OF MANUFACTURE

Some of the arguments for and against molding have been discussed in the previous section. Other methods of manufacture do not need the type of mold made for the injection process, and hence these approaches could be explored separately and ahead of molding. Section III, Design Review, has tabulated that, in addition to molding, these processes are of interest:

1. Wound filament structures and wound laminate structures.
2. Fluid bed coated projectiles.
3. Cast rotating bands from 2-part liquid plastics.
4. Fabrication and assembly of rotating bands from plastic sleeves.

FILAMENT WINDING AND WOUND LAMINATES

The process of filament or laminate winding has two excellent reasons for being considered:

a. The circumferentially reinforced structure can offer a maximum of tensile hoop strength.

b. The choice of filaments or laminate structures can be made on a basis of tensile strength and also the possibility of tailoring the laminate structure to adapt to engraving.

These types of laminates will generally involve resin impregnants of epoxy or polyester.

Because this part of the experimentation could be done without the completion of the injection mold, it was the first to be tried. Because of its early scheduling in the program, the depth of anchorage was still considered to be any level down to the depth of the grooving for the metal rotating band. The TP projectiles furnished were machined for laminate work. In some instances, the excessively deep anchorage groove was not desired, and required an extra filament wind in order to fill this added depth so that the surface of the wound laminate could be uniform. This hybrid structure was generally not successful and reflected the excessive amount of material at the trailing edge of the band. This appeared to be a point of weakness in firing trials, as might be reasoned due to the extra compressibility of the band at that point.

Practically all of the early trials at mechanical anchorage worked around the existing groove in the TP projectiles which were furnished to the contractor. Examples of this are the three anchorage systems detailed in Figures, 6, 7, and 25, with Figure 25 adapted for an over-the-end cap type rotating band. Three styles adapted to shallow anchorage were detailed in Figures 4 and 5.

The winding of fabric laminate offers an additional problem on anchorage--it is not possible to provide a mechanical undercut of any significance into which the laminate can be forced. Two examples are shown in Figures 14 and 15. The compromise answer is to provide an excess of the laminating resin which can find its way into the anchorage groove structure and thus provide a resin interface between the steel and the fabric laminate.

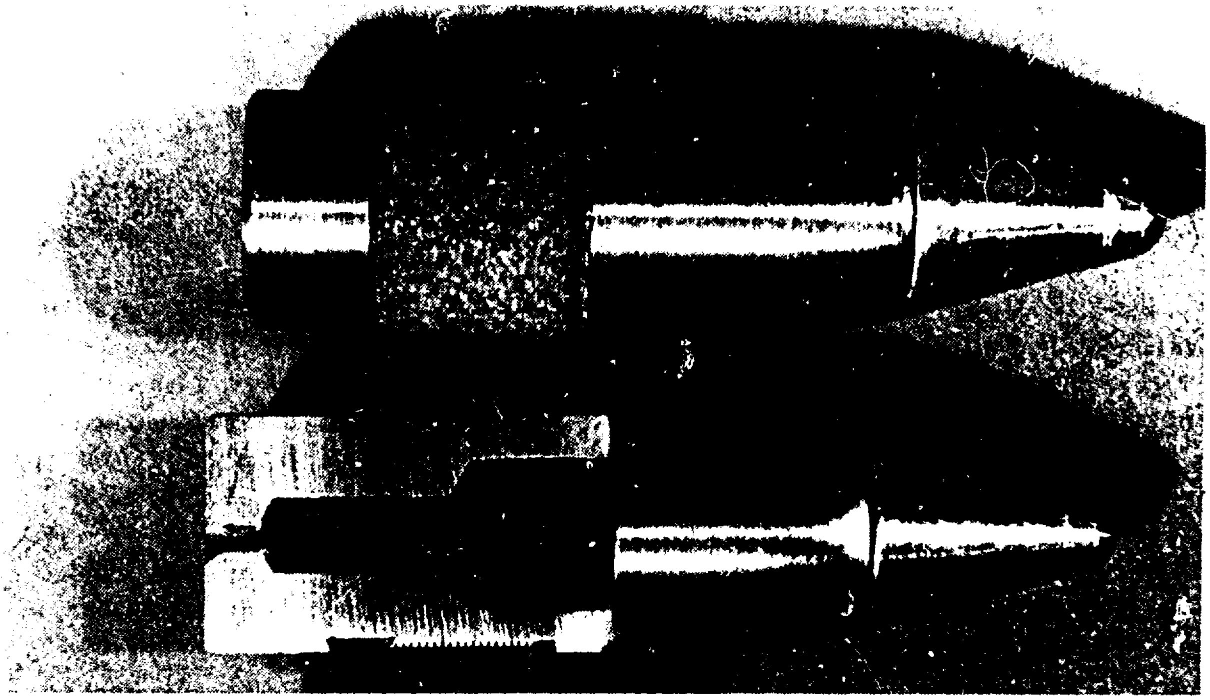


Figure 14. Laminated Rotating Band, Sample Type 105930

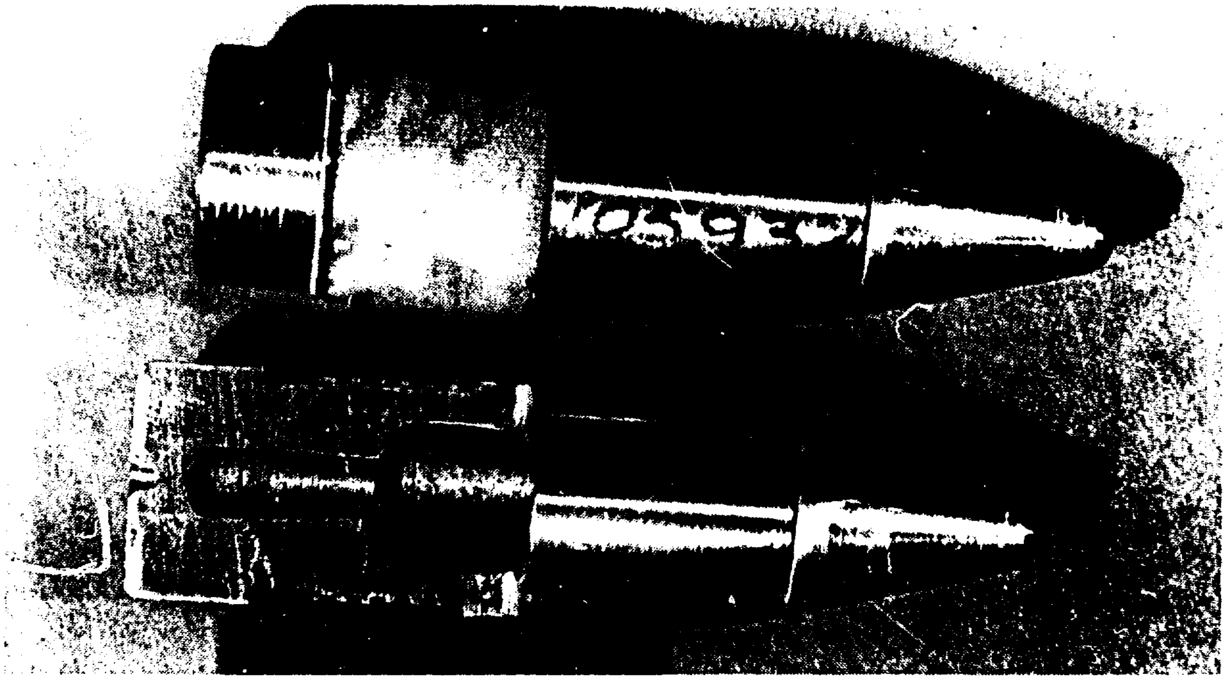


Figure 15. Laminated Rotating Band, Sample Type 105932

The performance photographs of the firing trials on samples of wound laminate projectiles were reviewed. Of most interest is the performance of construction 105934 wound with unidirectional glass tape. This band shape is 1 inch in length and 0.040 inch thick. The back end covers over the deep groove machined for the copper band: in order to fill this groove up to the winding level of the forward part, extra layers of narrow roving were impregnated and laid into the groove to fill it. Epoxy resin was used as the binder and adhesive resin.

Because of the need for compressibility for engraving, a woven laminate structure was sought which might offer that compressibility in the structure, with the knowledge that the impregnating resin generally will not impregnate into the cores of the individual threads. Fabric tapes of the following description were used:

Unidirectional glass nonwoven tape
Unidirectional nonwoven Fiber B roving
Woven nylon fabric tape
90 percent nylon/10 percent flax fabric tape
Polyester fabric tape
Linen fabric tape
Rayon fabric tape

The potential for void space as a means of absorbing the material displacement due to engraving shows clearly in this enlarged photograph (Figure 16) of a cross section from a fabric wound rotating band. The cut ends of the fabric threads which face out of the picture show the thread strands with open spaces which do not readily impregnate with resin. This is typical of many laminates — it can be controlled, and generally improves the toughness of the laminate as compared to a thread structure which is completely impregnated.

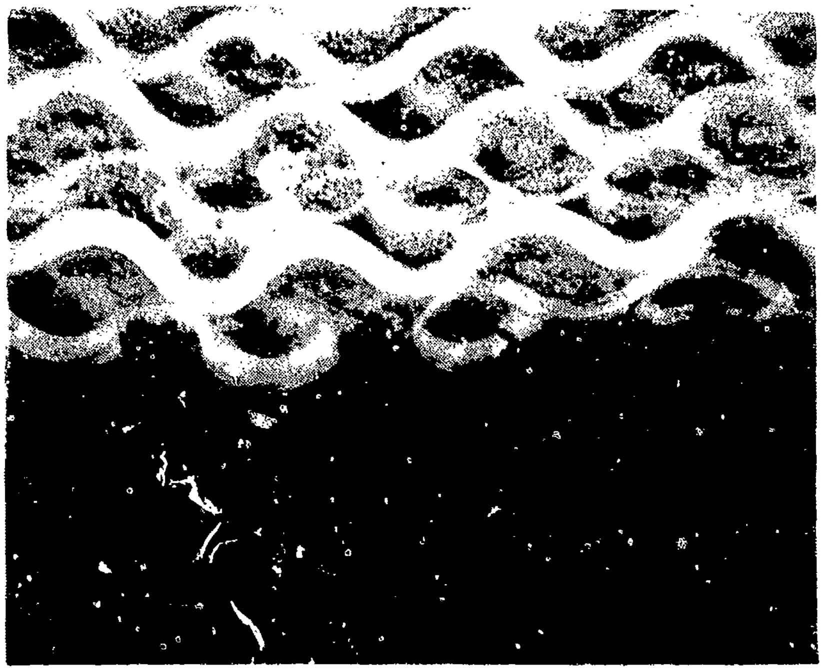


Figure 16. Enlarged View of Laminate Cross Section

Summary on Laminated Fabric and Filament Constructions. The time and effort spent on seeking good mechanical anchorages before the depth limitation of 20 mils was established was still productive in two ways:

a. Some of the anchorages, even at 0.020 inch depth, could be effective with a wound laminate structure where there is less need to accomplish very high anchorage due to the greatly improved hoop strength of the rotating band construction. It should be recalled that one series of laminated band firing trials, series 105934, showed good performance without necessarily reaching its top capability.

b. The early firing trials and direct contact with the problem which resulted from starting with laminated structures and existing TP projectiles was helpful in maintaining useful activity during the design and construction of the mold.

The consideration of wound laminate or filament wound rotating bands should not necessarily be faulted on the basis that they are impractical to manufacture in volume. Automatic winding equipment would be practical; preforms would then either be press cured to shape or pressureless cured oversize to be later machined to size and shape.

The trials that were made also indicate that a length of rotating band of 1 inch for this strong and solid construction is excessive and that viable trials could undoubtedly be had at band lengths of 1/2 inch and perhaps shorter. Lengths of 5/8 inch were tried enroute to shorter bands.

FLUID BED COATED PROJECTILES

Trials on fluid bed coating of projectiles were begun by welding metal into the machined grooves of TP projectile bodies and machining them to be smooth sided in that area. Thirty of these samples were fluid bed coated by Plastonics, Inc. of East Hartford, Connecticut, with nylon 11 and a thermoplastic polyester coating. Epoxy coating was considered but judged as being too hard. Nylon 11 is used because the history of this material in fluid bed coating is better known than that of nylon 12. A coating depth over the steel of 0.020 inch was requested, which is an approximate limit for this method of coating; no undercut or anchorage groove for the rotating band can be provided. After coating, the coated surface was machined to an O. D. of 0.825 inch and a 1/2 inch length. These were submitted as samples 105943-1 and 105943-2. Firing trials were not conclusive but were promising enough so that the approach to fluid bed coating was reviewed and additional samples were prepared.

The second lot of samples used projectiles which did not have the deep anchorage grooves of the TP projectiles. A study of the first round trials suggested that the lack of thickness and the greater rigidity of the coatings should be compensated by a shorter land length. This was most readily accomplished by establishing relief grooves between multiple short rotating bands. Three styles were prepared for the next sample series:

a. Four externally cut rings per pattern 107652.

b. Six externally cut rings per pattern 107653.

c. Plain sided, full diameter projectiles, without grooves, for control.

These were sent out for fluid bed coating with nylon 11 and with nylon 12, the latter being selected instead of the previously tried thermoplastic polyester coating. The nylon 12 gave trouble in this heavy coating, but the nylon 11 did coat to the necessary 0.020 inch + per side which was enough to provide for subsequent machining and clean-up. Measurements were made on the coating thicknesses, as affected by the grooving, and the tendency to coat heavier on one end of the projectile or the other depending on handling. After the unfavorable coating experience with nylon 12, a substitute series was then done with the thermoplastic polyester previously tried. These samples with the sidewall configurations noted, were identified in the series 107652, 107653, and 107654, and were all finish machined and submitted for firing trials. These samples, all fired at velocities of near 4200 feet per second, showed some cracking and feathering of the coating; the items are tabulated in the "Firing Trials" chapter of Section III of this report.

The machined projectiles before and after fluid bed coating are shown in Figures 17 and 18.

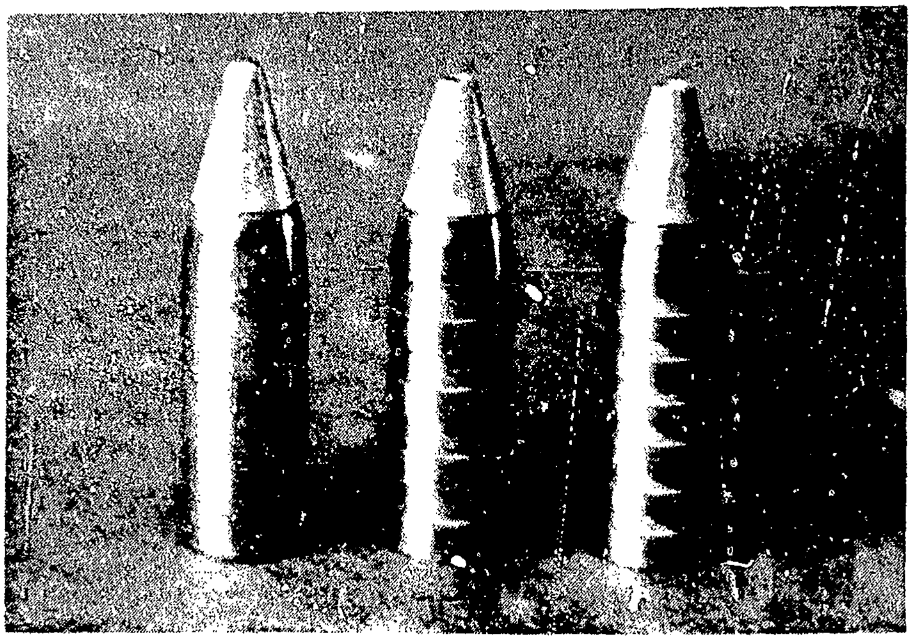


Figure 17. Projectile Shapes For Fluid Bed Coating

1. Smooth cylinder
2. Four wide grooves
3. Six narrow grooves

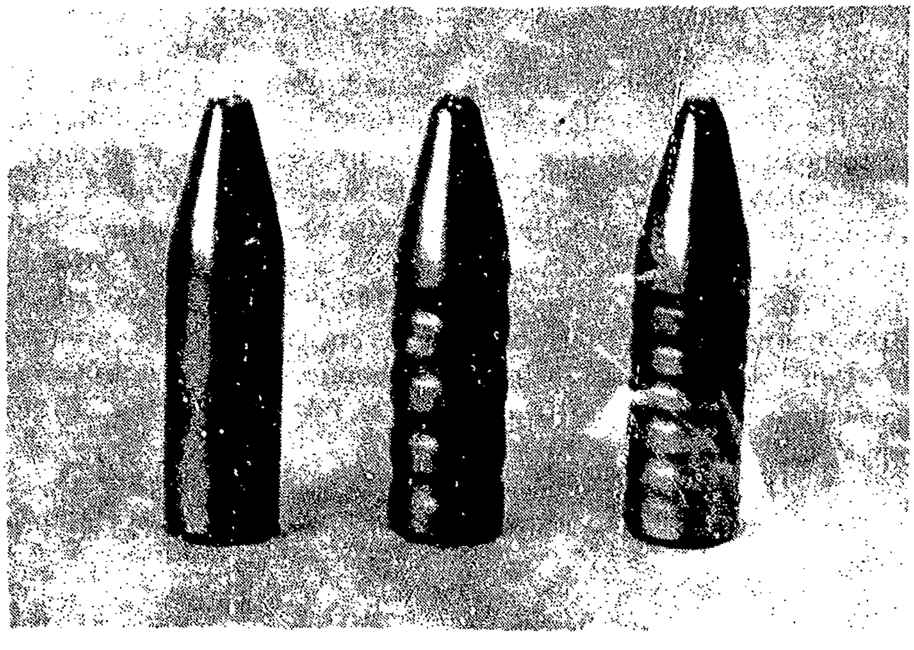


Figure 18. Projectile Shapes Fluid Bed Coated With Nylon 11
Nylon 11 fluidized bed coated specimen

CAST URETHANE

Cast urethane and thermoplastic injection moldable urethane have two distinguishing differences for application as a rotating band:

a. The two-part cross linking urethane system generally used as casting material has proved to have greatly improved properties compared to the thermoplastic urethane materials.

b. The casting of two-part urethane requires a different production approach in which multiple cavity, low cost molds can be filled under low pressure, but in which the cure time may be a matter of many minutes depending on how fast the cure reaction is planned.

A further side light on the difference in material is that the more effective catalyst for the two-part cure system called MOCA [4, 4^1 Methylene (bis)-2-chloroaniline] has, in the last year, been put on a list of materials which must be handled and used with extreme care due to its alleged carcinogenic qualities. This will additionally make production more difficult.

Before the ban on the handling of MOCA was instituted, samples were made for firing trials. The injection mold was used for the fabrication of the samples, and the two-part mixture was weighed and mixed by hand in small quantities, and poured into the mold cavity which, at the time, was holding the insert nose down. The mixture used was Adiprene L-200 with 23 parts MOCA per hundred parts resin. The mold cavity is such that there is a small annular space which can be used to hold the additional compound which is needed to fill the band when the mold closes. In this manner the cavity was filled with urethane mixture at 160°F and the mold closed. The cavity was held at approximately 200°F and the cure time was allowed to take 5 minutes. The parts were post-cured 5 hours at 250°F after removal from the mold and before machining.

A batch of 14 completed projectiles was shipped for evaluation and was comprised of three types: 107666-1 - without primer; 107666-2 - primed with Chemlok 607; and 107666-3 - primed with Thixon AB-1153. The anchorage used was a simple shallow grooved (0.020 inch deep) band seat, 0.5 inch long with the light shallow knurled band seat (107655). The performance was judged from the photographs of the firing trials and a record is tabulated in Section III, "Firing Trials". The performance was very encouraging and showed one of the candidate samples primed with Chemlok 607 as successfully withstanding a firing and flight at 4329 feet per second in addition to others performing at lower velocity firings.

FABRICATION AND ASSEMBLY OF ROTATING BANDS FROM PLASTIC SLEEVES

Some cursory trials were made in this direction with the hope of being able to evaluate the effectiveness of ultra high molecular weight polyethylene (UHMWPE) as a rotating band material. This material is famous for its ability to take high impacts and to show extreme toughness and wear resistance. The objective was to try the material rather than to plan how it might eventually be processed. One of the possibilities for the latter might be to mold the polyethylene as a lower molecular weight polymer and then to cross link it to a very high molecular weight after it has been formed.

MATERIALS

The materials which were investigated as candidates for plastic rotating bands fell into six classes:

1. Impregnant-type resins such as epoxy and polyester which could be used with filament wound or laminated construction bands.

2. Thermoset molding compounds with special features such as glass reinforcement, adhesiveness to metal, and compressibility by means of crushing; these nominally used phenolic, epoxy, or polyester binder resins. These compounds are generally transfer molded.

3. Two-component polyurethane resins which cross-link for maximum toughness; they are liquid resins and can be cast or molded under very low pressures.

4. Thermoplastic molding resins, either with or without glass fiber reinforcement, to offer a wide range of tough resins which can be injection molded directly on to the projectiles. Variations in this category are high density foam compounds which offer the potential of engraving without displacement of the material and tough elastomeric compounds which offer an elastic-type of displacement during engraving.

5. Thermoplastic resins adaptable to fluid bed coating.

6. Nonmoldable high performance resins such as ultra-high molecular weight polyethylene.

In addition to this classification of six types of materials on the basis of the methods of fabrication, there are also a number of performance criteria which serve to further screen the selection of candidate materials. Some of these requirements and their effect on the selections of materials are related in the following paragraphs.

RESISTANCE TO PROPELLANT. A primary consideration for this requirement is that the plastic material must resist the acetone vapors attendant to sealed ammunition. Although the magnitude of this exposure is not known, it has lessened interest in materials known to be solvent susceptible, including acrylics, cellulosics, polycarbonate, styrene-based plastics, and vinyl-based plastics. Relatively detailed but not specifically applicable information is offered in Plastec Report No. 40 entitled "Compatibility of Explosives with Polymers (III)", an addendum to Picatinny Arsenal Technical Report 2595 and Plastec Report No. 33; it is dated January 1971. The report offers 69 pages of tabulated data on the effect of solid explosives and associated chemicals on plastics and vice versa. Adhesives and elastomers are included. Most of the report information is on the effect of the plastics on the explosive, with information on the effect of the explosive on the plastics coming from the information from the Explosives Research and Development Establishment, Essex, England. This report is a supplement to information originally published as PATR 2595, March 1959, AD 714634 reissued as Plastec Note 22, October 1970, AD 716624 and its follow-on, Plastec Report No. 33, April 1968, AD 672061.

BRITTLENESS. Although some of the plastics judged inadequate in this category are not brittle per se, they have been shown in past trials to crack and shatter when used as a rotating band. Various data show that the acetal materials, such as Delrin, and the modified polyphenyloxide resins (Noryl) have shown this type of failure. The thermoplastic polyester molding materials, typified by General Electric's "Valox" resin, have also been found to be brittle.

COST. No plastic material was kept from consideration because of the cost of the material, and each was judged primarily on its potential for performance and processability. However, when there was a choice between pursuing the development of two materials with apparently equal potential, the lower cost material received preference.

TEMPERATURE PERFORMANCE. The material of choice for rotating bands must sustain good mechanical strength at the extremes of use at temperatures of -65°F and +160°F. This restricts the use of many formulations of cellulosics, ionomers, polyethylenes, and the vinyls.

ABILITY TO BOND. As it became apparent that the mechanical anchorage for the bond of the rotating band to the steel could not be relied on, the selection of a band material was tempered by consideration of the ability to bond the material to the steel. This poses a severe handicap in using materials known for their nonsticking qualities such as the fluorocarbons (including Teflon) and the olefin materials. A further consideration, however, is that some candidate materials, including nylon, are difficult to bond with an intermediate adhesive, but they have the ability to bond directly to steel from the melt.

The materials' groupings described at the beginning of this section are now discussed in detail with reference to materials used in the molding trials. The group numbering system of items 1 through 6 is carried through to delineate the following paragraphs.

(1) Impregnant Resins. The premise and achievement of laminating implies a filament type of reinforcement and requires a bonding resin to hold it together and give it substance. Thermoplastic resins are not generally used for this type of bonding; liquid resins which crosslink to a rigid structure are usually employed. The choice is generally between polyester, epoxy, and phenolic resins, although such resins as di-allyl phthalate, furane, and polyimide are sometimes used.

Epoxy resin appears to be a preferred choice for the bonding of laminated or reinforced rotating bands. It is a good structural resin capable of being modified for improved flexibility and will impregnate and bond many reinforcing filaments, including the filament Fiber B or PRD-49 (now called Kevlar by duPont). Epoxy is also known to be a good adhesive to steel. It also lends itself to "B" staging, at which time the coated laminate can be handled as a dry coated filament.

The preferred epoxy impregnant was a combination of a rigid and a flexible resin and a catalyst system which permits "B" staging and ultimate cure. The formulation is:

Dow Epoxy resin 331	70 parts/weight
Dow Epoxy resin 736	30
Shell curing agent Z	26

This impregnant resin was then used with various fabric weaves in tape form and with ribbon-type filaments. The materials comprising these reinforcements included glass, linen, rayon, cotton, PRD-49 Fiber B, and nylon. Some may have resisted actual bonding to the epoxy, but the impregnation and encapsulation of each layer and each filament was so complete as to make the bonding less significant.

The series of samples 105930 used the epoxy resin formulation to impregnate and laminate plies of nylon fabric, 90 percent nylon with 10 percent linen, and 90 percent nylon with 10 percent linen plus glass fibers at the interface. Woven rayon tape was also wound and impregnated with epoxy resin and wound into a rotating band; sample 105932 shows the band and a section of the projectile and band after curing. Photographs of the cross-sections of samples 105930 and 105932 were shown previously in Figures 14 and 15.

Additional trials were made with rayon tape with a bonding and impregnating resin of UCC epoxy ERL 2772 with a flexibilizing hardener ZZLA 0831. This approach illustrates that the hardness and resilience of the laminate can be varied, and that if compressible layers of laminate are used, the resin system can be flexibilized to accommodate the engraving displacement.

Several of the wound laminates showed relatively good performance when fired, particularly series 105930. The rotating band showed some chipping and loss of material, but the band stayed in place, was fully engraved, and appeared to have functioned. Velocities of the tests, however, were between 3200 and 3500 feet per second.

As the injection molding trials of rotating bands progressed and satisfactory results were achieved, the need for the circumferential reinforcement was disproved and this method of fabrication was shelved due to its inherently greater complexity.

(2) Thermoset Molding Compounds. Of the regular type thermoset molding compounds, the classes of materials listed below were considered to be of interest. One incentive toward a cursory examination of thermosets was the indication that they had never been given serious consideration in prior trials; more compelling reasons might be derived from the potential that epoxy materials would have for direct adhesion, the fact that all are chemically resistant and have high heat distortion points, and the final consideration that the cross-linked polyurethane material performed well. Although most of the materials tried were rigid materials with fibrous reinforcement, it should be remembered that many of the materials, such as rubber, offer an elasticity of the type which the polyurethane showed.

Each of these materials has the potential of being injection molded or transfer molded into a hot mold, thus posing a procedure which would apt to be helpful to a good bond to the primed steel. It should be considered that in the trials made in this series, practically all were done with the main emphasis on mechanical anchorage and very little work was directed toward adhesive type anchorages for the thermoset materials.

Epoxy. A special formulation of epoxy resin with a crushable filler is described separately in a following paragraph. The standard epoxy molding compound which was considered was Epiall 1288 by Mesa Plastics Company. The material was not available at the time that the molding trials with other thermosets were underway, and plans to mold were dropped following the thermoset trials and the advent of the nylon samples.

Phenolic. Two types of phenolic molding compound were tried, both incorporating flock filler designed to give toughness without sacrificing detail or uniformity of the thin rotating band. The materials were both from Fiberite Corporation, their compounds

FM-1303 and FM-1132-P. Both are two stage phenolic resins with filament reinforcement. The FM-1303 has a nylon flock reinforcement, and the FM-1132-P has a macerated fabric reinforcement. It was thought that this type of reinforcement would be more able to withstand the engraving by offering the compressibility and toughness conferred by the filament fillers. Both materials were molded onto projectiles prepared with a mechanical undercut and a B-staged epoxy primer. Firing trials were made as DLDL numbers 421 and 422. The photographs show a complete loss of the band material, indicating both fracture and poor bonding.

Polyester. Polyester thermoset bulk-type molding compound is available in many forms, including materials which can be fed into injection or transfer-type molding processes. The material selected from those available from Premix, Inc. was 1100-30 BMC, a formulation with 30 percent glass fiber reinforcement. The suffix BMC (Bulk Molding Compound), is descriptive of the long glass fiber and the relative coarseness of this material. Because of this, great difficulty was experienced in molding samples which were uniform in their glass content, with the indication being that the glass was not able to pass through the ring gate orifice despite the opening of the gate to 0.020 inch gap. Screening trials with the drop test confirmed both brittleness and poor adhesion, and these samples were not submitted for firing trials.

Epoxy Compressible Molding Compound. It was necessary to specially compound the type of epoxy molding compound which could be used as an example of a rigid molding compound which had the ability to be indented without displacement of the material except inwardly. This is to be done by using hollow glass beads which will collapse into their void space when subjected to the high compressive loading of the engraving of the rifling. The formulation 105933 was made and transfer molded on to steel projectiles with mechanical anchorage and a pre-prime of epoxy resin. The formulation of the compound is:

100 parts by weight	ERL 2772 epoxy resin
20 parts by weight	Catalyst Z
35 parts by weight	B-25 glass beads
26 parts by weight	Glass fiber, 1/8 inch cut
4 parts by weight	Cab-O-Sil

The firing performance of these parts was poor, undoubtedly because of the combination of low strength, rigidity, and lack of adhesion. Samples were such that the theory of compressibility of material could not be verified. However, molded material samples which were struck with an edge in the manner of engraving did show an inward crush which supported the premise of compressibility.

(3) Two-component Polyurethane Resin. An early trial with a two-part casting polyurethane produced a rotating band with very promising performance and furthered the interest both in two-part materials and in thermoplastic moldable compounds.

The initial sample was made by casting L-200 Adiprene polyurethane from duPont. The cross-linking agent used was 4, 4' methylene (bis)-2-chloroaniline, commonly called MOCA. Tests showed that the Chemlok 607 and the Thixon AB-1153 were the preferred primer systems, and they were used in the preparation of the sample series 107666. The firing trials on these samples showed excellent performance and a distinct improvement over cast urethane samples previously made on a mechanical anchorage without primer and on a mechanical anchorage with Chemlok 607 (samples 107656-1 and 107656-2).

Work on the cast urethane/MOCA compound then had to be suspended because of a directive from the Office of the Occupational Safety and Health Administration as to possible toxicity associated with the handling of MOCA. A search for an adequate substitute polyurethane has centered around a catalyst recommended as safe for the two-component casting mixture and a thermoplastic injection-molding grade of polyurethane. For the former, a recommendation from E. I. du Pont Co., the suppliers of MOCA, indicates that their CAYTUR-21 is the best substitute. Physical properties for this combination, however, are approximately 1/3 lower for properties such as tensile strength. Although published values for injection moldable, thermoplastic polyurethanes also indicate mechanical values much lower than those published for the L 200/MOCA combination, samples were molded for evaluation; these materials are reported in the discussion that follows as a thermoplastic molding compound.

(4) Thermoplastic Injection Molding Compounds. Because of the indicated superior performance of nylon resins, this category of

injection molding materials represents the process and materials of most interest in this development. The earliest trials were made with mechanical anchorage configurations and without the benefit of good chemical primer bonds. Included in this first set of trials were the glass-filled thermoplastic materials.

Absafil G 1200/20	Fiberfil ABS with 20% glass
Urefil TF-1004	Fiberfil urethane resin with 20% glass
Thermofil N9-5000-FG	Huels Nylon 12 with 50% glass
duPont 77G/43	duPont Nylon 6/12 with 43% glass

Each of these materials molded well, but the combination of inadequate anchorage and the decreased ductility of the highly filled glass formulations caused breakage and separation of the rotating band elements.

Thermoplastic Polyurethanes. After working successfully with two-part liquid urethane casting resins employing MOCA as the curing agent, it appeared desirable to find either a curing agent which could be used in place of MOCA or else enjoy the convenience and ability to injection mold which the thermoplastic urethane materials offered. However, in a tabulation of some of the properties of interest, it will be seen that the MOCA cured L-200 polymer has some very obvious mechanical superiorities over both other curing agents and the injection molding grades of polyurethane. Of the many available urethane grades, two were selected for molding trials: Pellethane 2102-65DX (from CPR Division, Upjohn) and Estane 58111-021 (from B. F. Goodrich). These samples were molded and shipped under the designations 107667-2 and 107667-3, respectively. The primer used was Thixon B-1153 and was given a 4-hour post cure at 250°F to improve adhesion. The banded projectiles are shown in Figure 19.

Olefin Types of Rotating Band Materials. It would be highly desirable from a cost and availability viewpoint to be able to use a domestic olefin plastic as the material for the rotating band. High density polyethylene has a good history of performance for shot gun shell casings which are required to withstand the explosion of that firing. The toughness and ductility of polyethylene might serve adequately as a rotating band; the property most in question would very probably be the ability of the material to transmit the rotational torque at 165°F without smearing.

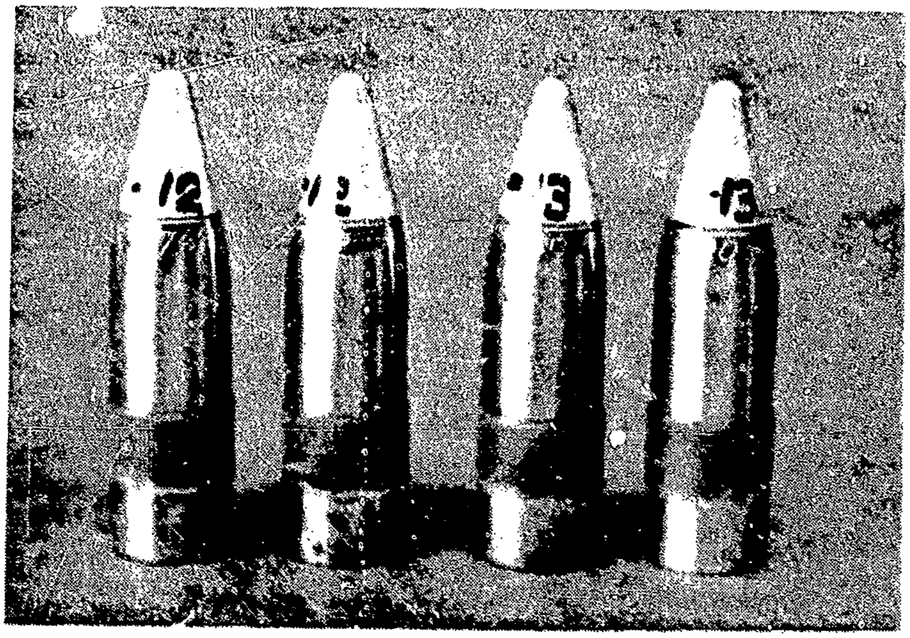


Figure 19. Injection Molded Polyurethane Rotating Bands

107667 series projectiles having thermoplastic polyurethane rotation bands

The primary process problem would undoubtedly be to secure the plastic to the steel with an adequate anchorage. Bonds to polyethylene are notoriously difficult and will undoubtedly require steps not usually employed in capturing a steel insert in molded polyethylene.

Sealectro Corporation, Mamaroneck, New York, has advertised its ability to bond polyethylene to a variety of substrates. A letter from Mr. Stand, dated 28 August 1973, includes a sample of ultra-high density polyethylene (Allied Chemical's AC-1221) sprayed to steel and various advice on the design of the composite and the ability to control coating thickness. The fact that the coating is sprayed on is normally less helpful than when applied by fluid bed coating because the metal is cold when it receives the polyethylene. The sample was cut and subjected to a peel test and an impact test, and it does not appear that this type of coating operation or adhesion could meet the requirements for adhesion for a rotating band.

In a previous trial reported verbally, Eglin has made firing trials on projectiles which were fluid bed coated with polypropylene in which the engraving during firing was accomplished largely by a scraping action. In this firing trial, the polypropylene showed evidence of being brittle.

In the late part of the development schedule, information and sample material were received from Exxon Corporation on Dexon XPA-3 material. This is described as a polyolefin terpolymer which has usually good adhesion to steel and other substrates. The material, being essentially a polyethylene/polypropylene has a low stiffness flexural modulus of approximately 120,000 psi), and a very low heat deflection temperature. This combination would make the material suspect in its ability to successfully engrave at elevated temperatures without smearing. One typical approach to solve this problem is the addition of glass fiber, and Mr. D. W. Miller of Exxon writes as follows concerning this:

> "The XPA-3 material will not have the 200,000 psi flexural modulus of nylon. However, as the data attached will show, we have the ability to compound our materials where in some cases they reach moduli of near 1,000,000 psi. There are other recommendations that we can make if impact properties are not of extreme importance."

The data referred are summarized in Table 4.

TABLE 4

DEXON XPA-3 FORMULATIONS WITH GLASS FIBERS

	D-561		D-563	
	20% glass	30% glass	20% glass	30% glass
Melt flow	5.5	4.5	8.0	6.0
Tensile yield, psi	7900	8800	10,000	13,300
Izod impact (notched)	1.0	1.1	1.2	1.7
Flexural modulus, psi	470,000	645,000	480,000	660,000
HDT, 264 psi, °F	284	293	288	300

A comparable Izod impact strength for the material without glass reinforcement would be 3.3 or higher. It is questionable as to whether the lowered impact strength will be adequate for engraving, but this factor, together with the known problems of adhering polyethylene to steel, make the use of this material for rotating bands marginal.

Another series of trials representative of typical development sequence was the investigation of Tefzel and as potential band material. Our report of this as an investigated material is very brief, in that there appears to be no way to make the Tefzel adhere to the steel, and the incentive to solve that problem is dimmed by the high cost of the material. However, the investigation of Tefzel material led to the investigation of induction heating as the means of consummating the bond between the plastic molding material and the steel. It was initially tried as a means of raising the surface temperature of the steel to a temperature which would remelt the Tefzel and create a bond. This was not effective and, in contrast, actually appeared to create a corrosive breakdown at the melt face. However, the technique was later found useful for selectively heating the nylon primer bond placed on the surface of the steel and needing a melt temperature to activate it.

Nylons. Nylon is a generic term for a family of plastic materials, with many variations in the types of nylons and their properties. They derive primarily from two categories:

1. Polymers from a diamine and a diacid. Examples are nylon 6/6 (hexamethylenediamine - 6 carbons with adipic acid - 6 carbons), nylon 6/10 (hexamethylenediamine - 6 carbons with sebacic acid- 10 carbons), and nylon 6/12 (hexamethylenediamine - 6 carbons with dodecanedioic acid - 12 carbons).

2. Polymers from amino acid or amino acid derivative. Examples are nylon 6 (0-caprolactam - 6 carbons), nylon 11 (amino undecaoic acid), and nylon 12 (laurolactam).

Early work in the 1950's in rotating band development favored the nylon 6/6 which was the leading commercially available nylon at the time. A comparison of the properties of nylon 6/6 with some of the presently available nylons of interest is shown in Table 6.

Development Work with Nylon Materials. In this project. nylon materials were used both for injection molding of rotating bands and for fluid bed coating of projectiles. These were among the most successful trials of any material, and the injection molding of nylon 12 was the final selection for the rotating band.

Nylon 6 and 6/6 were molded into rotating bands in one exploratory series and nylon 6 in the form of high-density foam Nylafil F 3/15 by Fiberfil was considered. Despite the qualified successes of the early rotating bands molded from nylon 6/6, it should be recognized that they were very much thicker in proportion to the engraved depth and that their firing velocities were lower. Nylon 6/12 represents an intermediate hardness, softer than nylons such as 6 and 6/6,because nylon 6/12 showed impact brittleness; therefore, trials of nylon 6 or 6/6 were not repeated.

One of the earliest series of molding trials included molding of nylons 6, 6/6, 11, and 12. Primers for each were chosen from primer adhesion trials run as laboratory tests, but the adhesion resulting from the injection molding operation was poor. Trials were repeated using B-stage epoxy as the primer and then post-curing the epoxy with the application of heat. This latter approach, tried with nylon 12 nonfilled resin, resulted in the completion and submission of 5 projectiles designated 107667-4. The firing trials were made, and the resultant photographs indicate a tearing of the rotating band in what appears to be a skinning action.

Nylon 6/6 in the form of a glass-reinforced high density foam was also considered on the basis that it offered a compressible band which would engrave with a minimum problem of material displacement. The void spaces in the foam could be expected to collapse whereas the reinforced foam structure has good mechanical strength. This material is one of a series in the category of high-density structural foams recently available from several suppliers; the Fiberfil material has the advantage of having glass reinforcement and therefore better mechanical properties. The specific formulation of most interest is their F-3/15 Nylafil/Foam:

TABLE 5

PROPERTIES OF NYLAFIL/FOAM F-3/15

Tensile strength, psi	10,000
Flexural modulus, psi	650,000
Flexural strength, psi	16,000
Izod impact, notched	1.0
Izod impact, unnotched	3.2
Deflection temperature, 264 psi, °F	390
Density	0.87
Mold Shrinkage, in./in.	0.006-0.007

Because the nylon 12 has played such an important part in the development of the rotating band, selected descriptive information on the material is copied into the following pages as Tables 7, 8, 9 and 10. These tabulations will also detail the comparative properties of L-1801 and L-2101. Not shown in the tabulations is the impressive chemical resistance of nylon 12. A list of exposure performance indicates complete resistance to acetone among other chemicals and solvents.

Glass-Reinforced Nylon. At the start of the materials trials nylon resins were used either without glass reinforcement or with the commercially available loadings of 33, 43, or 50% glass fiber. Other commercial compounds offered lower glass contents but generally only in nylon 6/6, whereas the higher glass loadings were available in nylon 6/12 and nylon 12. These high glass contents did not test well, and no more trials were scheduled with them.

During the tests with nylon 12 resin, however, it was indicated that a slightly higher modulus and heat distortion temperature might raise the margin of safety on firing trials run at 160°F. At this temperature the

TABLE 6.

PROPERTY COMPARISON FOR NYLON TYPES

	Test Temp. °F	6/6		6	6/10		6/12		11 BMNO-P49 TL	12 L1801
Moisture, %		0.2	2.5	0.2	0.2	1.5	0.2	1.3	1.1	0.9
Tensile Strength	-40	15.7	14.9	-	12.0	12.0	13.6	13.5	9.1	-
1000 psi	73	12.0	11.2	11.0	8.7	7.5	8.8	8.8	7.1	520 **
Ultimate	170	9.0	5.9	-	5.4	-	5.9	-	4.7	-
	250	6.2	5.5	-	-	-	-	-	2.8	-
Tensile	-40	20	20	-	25	40	15	30	61	-
Elongation, %	73	60	300	150	100	300	150	340	330	250
Ultimate	170	340	350	-	300	-	-	-	340	-
	250	340	340	-	-	-	-	-	380	-
Flexural Strength 1000 psi	73	-	-	14.0	11.0	-	-	-	-	600 **
Flexural	-40	470	500	-	330	360	340	400	270	-
Modulus	73	410	175	350	290	160	290	180	50	-
1000 psi	170	100	82	-	70	60	60	55	24	-
	250	78	60	-	-	-	48	44	21	-
Impact Strength	-40	0.6	0.5	0.8	0.5	-	0.9	0.6	2.1*	8-10 *
Izod in. lb. /in.	73	1.0	2.1	1.2	0.9	1.6	1.0	1.4	31 *	9-15 *
Notch	170									5- 7 *
Sp. Gr.		1.14	-	1.13	-	-	1.08	-	1.06	1.01
Melt Temp, °C		-	250	216	-	210	215	-	185	178
HDT 66 psi		470	-	350	-	-	340	-	284	293
°F 264 psi		220	-	150	-	-	140	-	118	131

* Kg cm/cm^2; ** Kg f/cm^2

nylon 12 has a tendency not to be able to impart full spin to the projectile because of slippage and smear in the engraving. It was, therefore, desired to investigate the properties of nylon 12 with small amounts of glass reinforcement, i.e., 5 and 10 percent.

To accomplish this, a trial was made using Thermofil nylon 12 N9-5000-FG (50 percent glass) and diluting with appropriate amounts of nylon 12 L2101 F without glass. These granules were dry blended and fed into a screw injection machine (Buehler, 2-3/8 inch diameter screw, nominal 10-oz. capacity) and injection molded into test bars.

The comparison of the bars to each other and to nylon 12 without glass showed the increasing stiffness and hardness which was expected; the glass appeared to be well dispersed and representative of the percentages added.

The compound employing 5 percent glass fiber was molded into rotating band samples as part of the 107677 series which is detailed on a following page.

Nylon 11. It is recognized that the foreign sourcing of nylon 12 and its potential unavailability is a problem. Trials were therefore reinstituted with nylon 11 molding compound in order to make a final comparison with procedures which had been developed for nylon 12. The comparison of nylon 11 and nylon 12 has already been made relating them as fluid bed coating powders; in that instance the nylon 11 processed better, primarily because of the greater experience and acceptability of nylon 11 as a fluid bed coating resin.

An unusually difficult time was had in getting information and test bars on this material from Fiberfil Corporation with the result that molding or firing trials had to be cancelled because of their delay.

Nylon 6/12. Nylon 6/12 was molded into rotating bands both with and without glass reinforcement. The latter material was duPont 77G/43, with 43 percent glass reinforcement. At the time of this trial, the anchorage was being made with the deeper cut and a pattern of mechanical anchorages. None of the preferred chemical primer systems were available at that time, and the reliance was primarily on the mechanical system. The molded samples were among the first to be screened by the modified Gardner drop test. They showed severe cracking and poor anchorage in this test and therefore were not submitted for firing trials. The drop test equipment and procedure is further shown in Figure 23 and Figure 36 (appendix).

Samples of nylon 6/12 without glass reinforcement were molded near the end of the investigational phase of the program and in a series with samples of nylon 12 and Trogamid T. For this series the final anchorage groove configuration (0.5 inch long and 0.020 inch deep) was used, along with the preferred primer system of M & T 253-P primer plus an afterbonding with induction heat. The initial molding trial was made with projectiles which had been primer coated and baked on a cement-asbestos board support in the oven. It was later determined that this caused the primer to be less effective, and the entire preparation of samples and molding was repeated successfully on a second try. The nylon used was formulation 158 L. However, of all of the samples molded in the second series, the nylon 6/12 material alone was found inadequate in the drop test, showing poor bonding adhesion of the nylon to the primed steel. The parts were not forwarded for firing trials.

Nylon 12. The lower modulus of nylon 12 was one of the considerations which established an early preference for this type of nylon as a rotating band. The majority of molding trials, bonding tests, and projectile firings were with samples of nylon 12 and its closest counterpart, nylon 11. The initial formulation used was L-1801, described as an injection molding grade suited to moldings subject to severe mechanical stresses. When firing tests indicated a tendency of the L-1801 material to be too temperature sensitive at the 160°F firing, the solution was sought by these two methods:

a. A formulation of nylon, Huels nylon 12, L-2101, described as a higher molecular weight material than L-1801, was used.

b. Small amounts of glass fiber reinforcement were added to the nylon 12 resin.

In the final comparative run of injection molded bands, the processing conditions for the nylon 11 and nylon 12 are given in Table 11.

TABLE 7.

RANGE OF GRADES OF NYLON 12

Grade	Processing	End Product
Nylon 12-Hüls L 1600	Injection moulding	Complicated industrial mouldings made in deep flow moulds
Nylon 12-Hüls L 1700	Injection moulding	Complicated industrial mouldings made in deep flow moulds
Nylon 12-Hüls L 1700 M	Extrusion	Monofilaments, paper coating, coating of metal foil and plastics film
Nylon 12-Hüls L 1801	Injection moulding	Industrial mouldings subject to severe mechanical stresses
Nylon 12-Hüls L 1801 F	Extrusion	Flat film, monofilaments, coating on paper, metal foil and plastics film, cable sheathing
Nylon 12-Hüls L 1901	Injection moulding	Industrial mouldings having high impact strength
Nylon 12-Hüls L 1901 E	Extrusion	Small bore pipes, solid profile sections
Nylon 12-Hüls L 1901 F	Extrusion	Flat and tubular film tubing
	Blow moulding (Extrusion blow moulding)	Small hollow mouldings
Nylon 12-Hüls L 2101	Injection moulding	Industrial mouldings with very high impact strength
Nylon 12-Hüls L 2101 E	Extrusion	Pipes, solid and hollow profile sections
Nylon 12-Hüls L 2101 F	Extrusion	Tubular film, sheet
	Thermo-forming	Thermoformed sheet
	Blow moulding (Extrusion blow moulding	Large hollow mouldings

TABLE 8.

EFFECT OF THE WATER CONTENT UPON THE TENSILE PROPERTIES, MEASURED ON NYLON 12-Hüls L 1901

Property	Unit	Dry	Conditioning	
			Saturated at 65% RH, 20°C	Saturated in Water, 20°C
Water content	%	< 0.1	~ 0.9	1.5
Tensile stress at yield	kgf/cm^2	475	360	310
Percentage elongation at yield	%	7	9	12
Tensile stress at break	kgf/cm^2	560	520	530
Percentage elongation at break	%	280	250	290

TABLE 9. DENSITY, WATER ABSORPTION AND THERMAL PROPERTIES OF NYLON 12 FORMULATIONS

Property	Test method			Unit	L1600	L1700	L1801	L1901	L 2101	L1640	L1940
	measured by	equivalent methods									
Density (Bulk Factor)	DIN 53 479	ISO R 1183	ASTM D 792 Method B	g/cm3	1.01-1.02	1.01-1.02	1.01-1.02	1.01-1.02	1.01-1.02	1.01-1.02	1.01-1.02
Apparent Density	DIN 53 468	ISO R 60	ASTM D 1895	g/cm3	0.5-0.6	0.5-0.6	0.5-0.6	0.5-0.6	0.5-0.6	0.5-0.6	0.5-0.6
Water Absorption	-	-	-	%	1.5	1.5	1.5	1.5	1.5	1.5	1.5
after immersion in water at 65% RH, 20°C	-	-	-	%	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Water Absorption	DIN 53 472	-	-	mg	29	29	29	29	29	29	29
Water Absorption	DIN 53 475	ISO R 62	-	mg	14	14	14	14	14	14	14
Melting Range	Polarisation Microscope			°C	172-180	172-180	172-180	172-180	172-180	170-178	170-178
Vicat Softening Point	DIN 53 460	ISO R 306 1kg load 5kg load	ASTM D 1525	°C	169-175 138-142	169-175 138-142	172-175 138-142	172-175 138-142	172-175 138-142	168-174 138-142	168-174 136-142
Deflection Temperature under Load	DIN 53 461	ISO R 75 Method A Method B	ASTM D 648	°C	53-57 140-150	53-57 140-150	53-57 140-150	53-57 140-150	53-57 140-150	53-57 130-145	53-57 130-145
Coefficient of Thermal Expansion	VDE 0304 Teil 1 § 4	-	ASTM D 696	(°C)$^{-1}$	1.6×10^{-4}	1.6×10^{-4}	1.6×10^{-4}	1.6×10^{-4}	1.6×10^{-4}	1.6×10^{-4}	1.6×10^{-4}
Thermal Conductivity	DIN 52 612	-	ASTM C 177	$\frac{kcal}{m\,hr}$ °C	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flammability (test specimen 4 mm thick)	ASTM D 635	-	-	-	non burning	non burning	self-extinguishing up to non burning	self-extinguishing up to non burning	self-extinguishing	self-extinguishing	self-extinguishing
Burning Rate	ASTM D 635	-	-	mm/min.	-	-	-	-	-	-	-

TABLE 10. MECHANICAL PROPERTIES OF NYLON 12 FORMULATIONS

Property	Test method			Unit	L1600	L1700	L1801	L1901	L 2101	L1640	L1940
	measured by	equivalent methods *									
Tensile Stress at Yield	DIN 53 455	ISO R 527	ASTM D 638	kgf/cm²	450-540	450-520	480-510	460-550	450-500	440-520	430-500
Percentage Elongation at Yield	Speed VI	Speed C	Speed C	%	7-10	7-10	7-10	7-10	7-10	7-10	7-10
Tensile Stress at Break				kgf/cm²	530-560	480-550	350-600	340-580	330-550	460-580	350-580
Percentage Elongation at Break	Test specimen Nr. 3	Test spec. acc. to fig. 1	Test spec. Type 4	%	150-310	150-300	150-300	150-300	150-300	100-300	120-300
Compressive Strength	DIN 53 454	-	-	kgf/cm²	480-540	450-520	480-560	480-560	480-560	400-460	400-480
Modulus of Elasticity	DIN 53 457 Section 2.3	-	-	kgf/cm²	12000 -16000	12000 -16000	12000 -15000	12000 -15000	12000 -15000	12000 -18000	12000 -18000
Flexural Stress at Conventional Deflection	DIN 53 452	-	-	kgf/cm²	600-660	600-660	600-650	600-640	580-640	500-650	500-650
Ball Indentation Hardness 10" 60"	DIN 53 456	-	-	kgf/cm²	C960-1050 C880-970	C960-1050 C880-970	C930-1050 C890-990	C920-1050 C880-970	C880-1050 C800-970	C950-1050 C880-970	C950-1050 C880-970
Shore Hardness	DIN 53 505	ISO R 868	-	D	74-78	74-78	74-77	74-77	74-77	74-78	74-78
Rockwell Hardness	ASTM D 785	-	-	R	108-110	108-110	108-110	108-110	108-110	108-110	108-110
Impact Resistance (Charpy Impact Flexural Test)	DIN 53 453 Test specimen Nr. 2	ISO R 179 Test spec Nr. 2	-	kgf cm/cm²	no break	no break	no break	no break	no break	no break	no break
Impact Resistance (notched) (Charpy Impact) (Flexural Test) + 20°C ± 0°C - 20°C - 40°C				kgf cm/cm² kgf cm/cm² kgf cm/cm² kgf cm/cm²	4-6 4-5 4-5 4-5	5-8 4-6 4-6 4-5	9-15 8-10 7-9 7-9	10-17 8-10 7-9 7-9	15-30 10-15 8-10 8-10	4-6 4-5 4-5 4-5	10-20 7-10 7-9 6-8
Impact Resistance (notched) Izod Impact Flexural Test	ISO R 180 Method A	-	ASTM D 256 Method B	kgf cm/cm of notch	4-6	4-6	5-7	6-8	10-20	4-6	6-8

C = Load C
B = Load B

The mechanical properties of a polyamide article largely depend on its crystalline state. The values indicated have been obtained from test specimens manufactured by injection moulding under standard conditions. Different manufacturing conditions may lead to test specimens exhibiting different properties.

*ISO = International Organization for Standardization

TABLE 11.

PROCESSING CONDITIONS FOR NYLON 11 AND NYLON 12

Material	Rilsan Nylon 11	Huels Nylon 12	
Formulation Number	BMNO	L-1801	L-2101
Lot	34047		
Machine settings			
Zone 1 front, °F	450	420	445
Zone 2 middle, °F	440	425	450
Zone 3 rear, °F	410	450	475
Nozzle-voltage	84%	80%	83%
T-1 injection time, sec	20	20	20 1/2
T-2 holding time, sec	5	5	5
T-3 mold closed, sec	20	20	20
Injection, psig	580	820	820
Holding, psig	420	820	820
Back pressure, psig			
Injection speed	0.99	0.9	
Screw speed - general purpose screw - 0.040 inch	10	10	
Feed Setting		1	
Cushion		1/4	
Mold temperature °F, front	280	280	280
Mold temperature °F, rear	280	280	280

A problem common to the molding of both nylon 11 and nylon 12 where an injection machine of large capacity compared to the shot size is used is that the residence time for the nylon is too long. In practically all molding trials of rotating band samples, this was compensated by periodic purging of the cylinder to lessen the residence time of the material which was actually molded.

The tabulation below summarizes one of the final investigational molding series which was pertinent to the selection of a final material and design. The materials molded were:

a. Nylon 12, Huels L-1801
b. Nylon 12, Huels L-2101F
c. Nylon 12, 5 percent glass fiber in L-2101F
d. Nylon 11, Rilsan BMNO
e. Nylon 11, Rilsan BMNO-P40TL flexibilized
f. Nylon 6/12, duPont 158 L

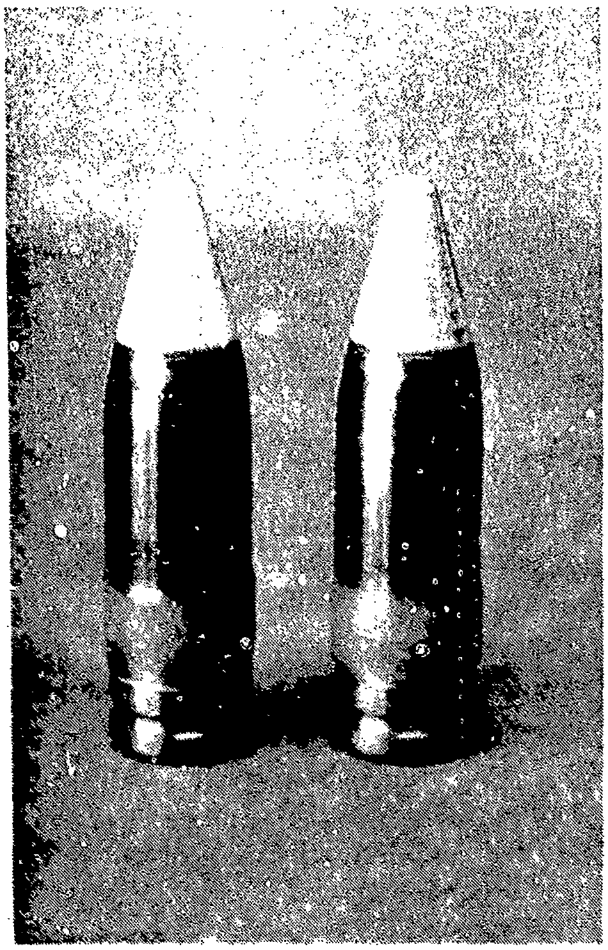


Figure 20. Molded Nylon 12 Rotating Bands, Style 107677

Final nylon 12 specimen, 107677 series

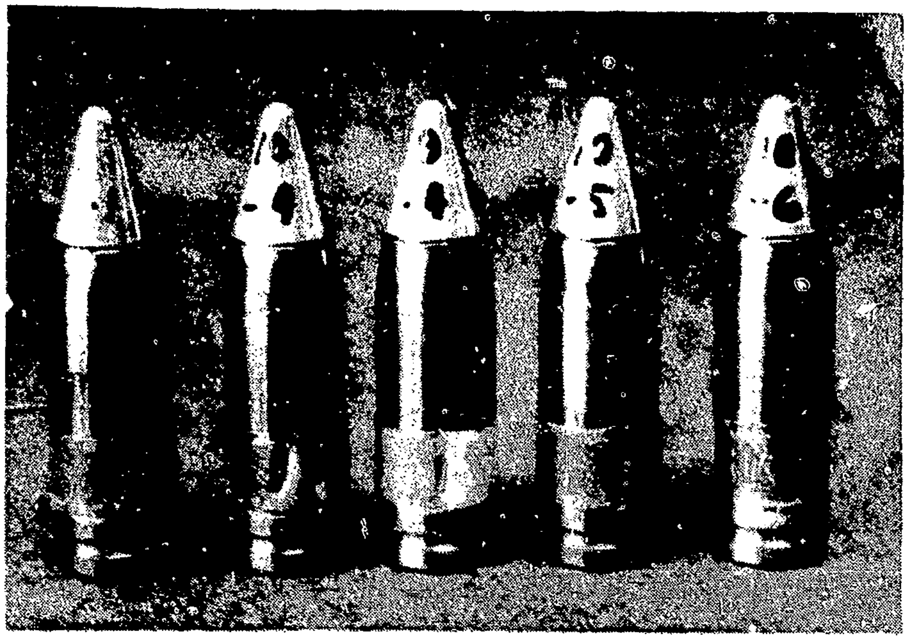


Figure 21. Nylon Rotating Bands After Drop Impact Test

Falling penetrator test specimen
from final elimination lot, 107677
series

Of these, the nylon 6/12 did not pass the screening trials for impact resistance and bonding; the remainder were finished to the final sample identification (see Table 12).

TABLE 12.

MATERIAL AND EDGE CONFIGURATION
OF ROTATING BAND SAMPLES

Part Number	Material	Entry Angle	Exit Angle
107677-1A	Nylon 12, Huels L-1801	15°	6°
107677-1B	Nylon 12, Huels L-1801	8°	13°
107677-2A	Nylon 12, Huels L-2101	15°	6°
107677-2B	Nylon 12, Huels L-2101	8°	13°
107677-3A	Nylon 12, 5 percent glass in Huels L-2101	15°	6°
107677-3B	Nylon 12, 5 percent glass in Huels L-2101	8°	13°
107677-5A	Nylon 11, flexible BMNO-P40TL	15°	6°
107677-5B	Nylon 11, flexible BMNO-P40TL	8°	13°

The results of the final set of experimental parts were reported on 12 December 1973. The test firings of the bands at ambient, -65°F, and +165°F for the nylon 12 and the nylon 11 were all satisfactory, even with the high twist (1 turn in 12 inches) barrel. All previous testing had been done in the 1 turn in 24 inches barrel or 1 in 20 inches.

In the photographs of the firing trials, samples 107677-1A and 107677-1B (DLDL M39-4 and DLDL M39-3) both showed excellent performance on the engraving pattern and flight characteristics. At 160°F, the performance of the 107677-1B sample (nylon 12, L-1801) was better than that of 107677-2B (nylon 12, L-1201), and L-1801 appears to be the best material in the sample group cited.

Trogamid T. The Air Force program manager relayed the information that concurrent work on rotating bands had indicated that Trogamid T was being used and was showing a ballistic characteristic believed to be due to the material or one that might be expected from the material. The greater hardness of Trogamid T compared to nylon 12 and nylon 11 was apparently responsible for a greater back pressure being developed in the breech and consequently a greater velocity for a given charge. The properties of Trogamid T, which is considered a type of semi-nylon, are shown in the tabulation of properties of nylon shown previously. Trogamid T was molded in a series of shots and did mold well. The projectiles used the conventional shallow band groove and a prime of M&T 253-P. The samples were induction heated in the same manner as the nylon 12 samples but did not develop the required bond. This was the only primer tried, and a discussion with Dynamit Nobel, suppliers of Trogamid T, did not suggest any alternate primer or procedure which they could recommend.

Tefzel Molding Material. In a response to a contract initiated by du Pont to Eglin Air Force Base with regard to the potential for Tefzel molding material, Mr. Charles R. Smoot and Mr. David B. Mooney of the du Pont Plastics Department, Wilmington, Delaware responded. Tefzel is a ETFE material, or a copolymer of TFE (Teflon) with ethylene. The properties and merits of Tefzel for this application were discussed; the properties of interest are tabulated, along with those of PFA.

TABLE 13.

PROPERTIES OF TEFZEL AND PFA

	Tefzel		
	without glass	with 25% glass	PFA TE 8704 perfluoropolymer
Tensile strength, psi	6,500	12,000	4,000
Ultimate elongation	200%	8%	300%
Flexural modulus, psi	200,000	950,000	95,000
Hardness, Durometer	D75		D60
Nominal melting point °F	520	520	575-590
Coefficient of linear thermal expansion, in./in. °F	0.00005	0.000017	0.000067
Impact, notched Izod ft lb/in. notch	no break	9	

The problem of bonding a fluorocarbon material to metal was recognized, and the work done by duPont in effecting a bond by using induction heating of the metal to establish a melt at the film surface has been recognized.

(5) Fluid Bed Coating Resins. Although the most promising resins for fluid bed coating are nylons, they have been separated from the previous listing of nylons for injection molding under this heading to emphasize the different design and process approach which would be used. The process itself has been covered in Section III along with results of the trials. Epoxy and thermoplastic polyester type coatings were considered but put into second place in preference to nylon 11 and nylon 12 coatings, which are standard materials for many fluid bed coating applications.

There are several points of significance in the consideration of fluid bed materials and process as a viable rotating band process:

1. The process lends itself readily to coating the entire projectile and providing the protection otherwise given by painting. Also small calibre (e.g., 5.56 or 7.62mm) projectiles could be readily handled.

2. Since a fluid bed coating of 0.020 inch is near maximum, there would be no anchorage groove used. There may, however, be alternate relief grooves between the multiple rotating bands to provide space into which the nylon material can be displaced after engraving.

3. The properties of nylon after either fluid bed coating or injection molding are similar. The preparation and priming of the steel projectile should be essentially the same for both processes. There is a difference in that the primed projectile must be heated to the fusion temperature of the nylon at the time it is dipped into the powder bath; this heating of the primer may present problems.

4. The results of fluid bed coated projectiles were encouraging, considering the small proportion of effort put into primer preparation and selection of nylon materials. It is quite possible that both could be improved to the point where a fluid bed coating would perform satisfactorily as a rotating band.

5. A fluid bed coating which is thick enough to sustain engraving as a rotating band is also inaccurate in its application as to thickness variation. Projectiles which were coated had a normal variation of plus and minus 0.008 inch on the body diameter on any given projectile.

(6) Nonmoldable High Performance Resins. There are some high performance resins worthy of consideration which do not lend themselves to the molding of rotating bands. An example of this is ultra-high molecular weight polyethylene. This material is generally shaped by compression molding, warm phase forging, or limited extrusion. This type of olefin material, if any, might function as a rotating band, and thus help prove or disprove the ability of other olefins to perform. To that end, several ring samples were machined from UHMWPE to permit handling and joining trials. Attempts to slip them into the undercut anchorage groove by heating and shrinking the band were inconclusive, with indications that an ultimate fit by this means would not be a tight mechanical fit.

Although the band seat might be knurled, it does not appear that this mechanical anchorage would be adequate even in combination with a nominal adhesive bond. Ability to achieve an adhesive bond is even poorer than with conventional olefins, and no promising answer appeared which would justify further work.

DEVELOPMENT PROGRAM

In addition to the main body of the development work described in the foregoing sections on mold design, molding, materials, anchorages, and alternate constructions, there were several other facets to the development work which will be described in this section.

IMPACT SCREENING TRIALS

Typical of a development need was to find a means of screening the performance of the bands in an approximate manner which would relate to the manner in which they performed in the firing trials. One approach to this was to measure the compressibility of a material sample under a Rockwell ball indenter. This was attempted on plastic rotating band material both with and without a steel backing. Trials with a 1/4 inch ball and a 100 Kg load gave readings of 38 on plastic without steel and values of 55 to 92 for plastic materials backed with steel. The Rockwell readings per se were not the information being sought, however; the interest was in the ability of a material to take an indentation and to either recover the compression or to displace the material and take a permanent imprint. A variation of the Rockwell test was then tried using a 1/4 inch dial diameter ball and pressing the ball into a test sample of plastic 0.1 inch thick to a depth of 0.050 inch. Typical of the results of these trials was that the sample broke when indented the full 0.050 inch but took a 60 percent permanent indentation when indented to 0.040 inch or to 0.025 inch.

These trials indicated that the indentation and recovery of the plastic-steel assembly might be informative but did not hold the necessary relationship to impact that the final performance required. A test which would provide the needed indenting but under higher loads and with greater impact was sought. A version of this is the standard Gardner drop test, but in a mold form compared to the needs of simulating a firing trial. The style of the test was retained and we constructed a heavier version of it, allowing a steel rod 1 inch diameter and 35 inches long to free fall (but guided) 5 feet to strike the sample. Samples can be plastic sheet or actual molded projectiles with the rotating band molded in place. The latter sample was held firmly in a vise with semi-circular jaw recesses which captured approximately 5/6 of the circumference and exposed 1/6. The end of the steel striking rod was machined to a bar shaped projection 0.071 inch wide by 1/4 inch long by 0.020 inch high which was indented cross-wise of the rotating band and axially on the projectile.

Impacts from this falling hammer against various molded in place rotating bands proved to be helpful in predicting those materials which did not have adequate impact resistance or malleability, and also in evaluating the effectiveness of the adhesive bond between the plastic and the steel. Materials which were inadequate in impact resistance characteristically would crack under the blow. Those which did not crack and which were transparent would show a whitening under the impact area if the adhesive bond was poor. The glass filled ABS (Absafil G-1200/20) and urethane (Urefil TF-1004) injection molded bands, for example, showed poor performance under this test and were not submitted for firing trials because of it. Samples of nylon 6/12 with glass (duPont 77 G 43) also showed brittleness and fracturing, as did molded-on bands of nylon 12 with 50 percent glass (Thermofil N9-5000-FG). The drop tests were also used to evaluate fluid bed coated samples; these samples presented larger areas and were opaque black so that the effect on the bond was not as evident. The fluid bed samples did show some fracturing but were better than the above cited molded bands.

Samples of nylon 12 rotating bands which passed this screening test are shown in Figure 22; note the lack of whitening under the impact area indicating good adhesion.

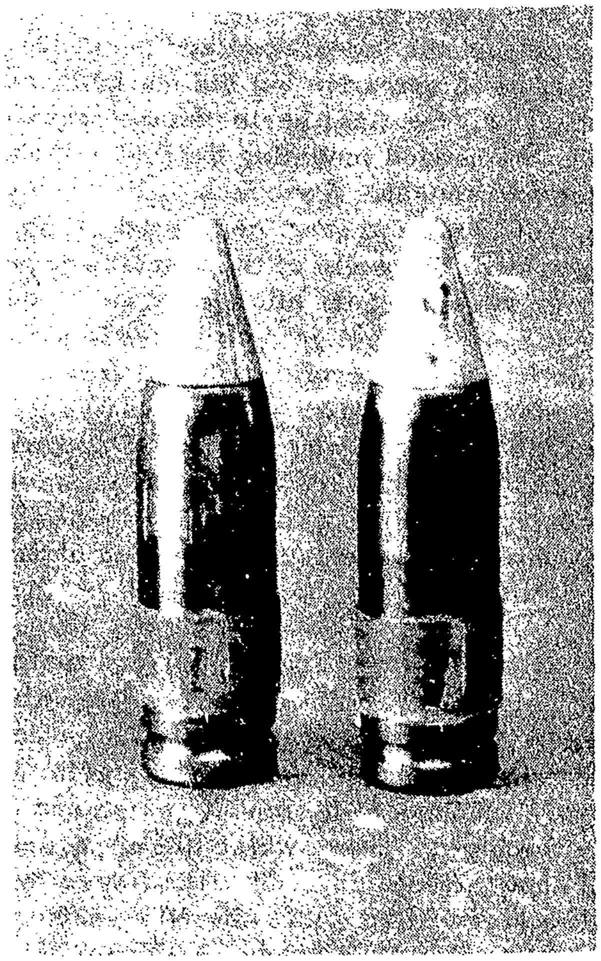


Figure 22. Nylon 12 Rotating Band After Impacting

Nylon 12 specimen from production lot which had been subjected to falling penetrator test

The manner in which the projectile is clamped and its relation to the falling rod impactor is shown in Figure 23.

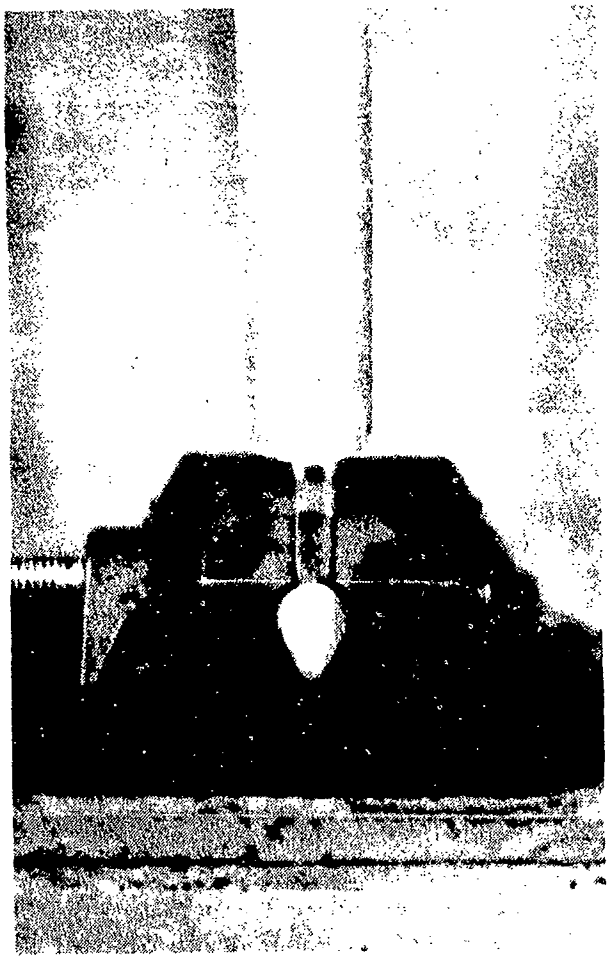


Figure 23. Clamping Fixture For Impact Test

Clamping fixture and guide tube
for falling penetrator test

A schematic view of the apparatus has been appended as Figure 36.

MOLD MODIFICATIONS

At the beginning of the project the width of the rotating band (the length measured axially) was not specifically known, and depended largely on the ability of the plastic material to transmit the necessary shear and compressive loads needed to overcome the rotational inertia of the projectile. Several band widths had been tried for the laminated rotating band constructions in which no mold was needed, and the indications were that a band width of 1 inch was not needed and probably contributed to failure. The initial mold design provided for a band width of 1/2 inch, and this was used for many of the first submissions of bands for firing trials.

Regarding the question of what the length of the rotating band should be, the most direct means of exploring the situation is to make bands of several lengths. The mold cavity is configured for a band of 0.5 inch length. However, it is possible to machine off any part of a band to adjust its length as long as the anchorage groove underneath is of the same length. To explore this 100 blank projectiles were machined so as to provide 50 with anchorage grooves 0.5 inch long and 50 with grooves 0.3 inch long. These were then molded with various materials to a full length band 0.5 inch long. Those with the 0.3 inch long anchorage groove were then machined so that the rotating band 0.3 inch long coincided with the 0.3 inch anchorage groove. Mold adjustments were made to allow for positioning the projectile vertically in the mold.

A molding trial using this approach is that recorded as notebook record 107673 and 107674; it can be summarized in this description.

> An injection molding trial was made with the prepared inserts primed with M&T 253-P nylon primer and molded with nylon 12. Of these, 32 projectiles were prepared in a combination of two band lengths and a variety of entering and exit angles according to the pattern given in Table 14.

TABLE 14.

BAND SAMPLE IDENTIFICATION

Quantity	Part No.	Projectile	Band Width (Inches)	Front Taper	Back Taper
4	107673-1A	Std. 20mm	0.50	8°	13°
5	107673-1B	Std. 20mm	0.50	15°	5°
4	107673-1C	Std. 20mm	0.50	10°	10°
4	107673-2A	Std. 20mm	0.30	12°	25°
4	107673-2B	Std. 20mm	0.30	25°	8°
5	107673-2C	Std. 20mm	0.30	15°	15°
3	107674-1	Special	0.30	12°	25°
3	107674-2	Special	0.30	15°	15°

All anchorage groove lengths were machined to 0.020 inch deep to the length indicated, cleaned, and primed. After molding, the primer was activated by induction heating the projectile and then quenching.

Firing trials detailed in this report establish that the best performance has been with the 0.5 inch band length with an intermediate leading and trailing edge angle which thus yields an adequate area of band to support the load due to rotational acceleration.

A second molding variation generated during the development program was the trial of a rotating band which extended over the back end of the projectile. Part of the reasoning for this variation was to evaluate the potential benefits of having a continuous plastic seal against the explosive gas force, eliminating the likelihood of the gas tending to lift and expand the rotating band due to pressure under the band and also possibly improving the obturation of the plastic band. From the molding point of view, the molding of the band in a cap-like shape provides an excellent gating and flow geometry. The projectile before and after molding is shown in Figure 24.

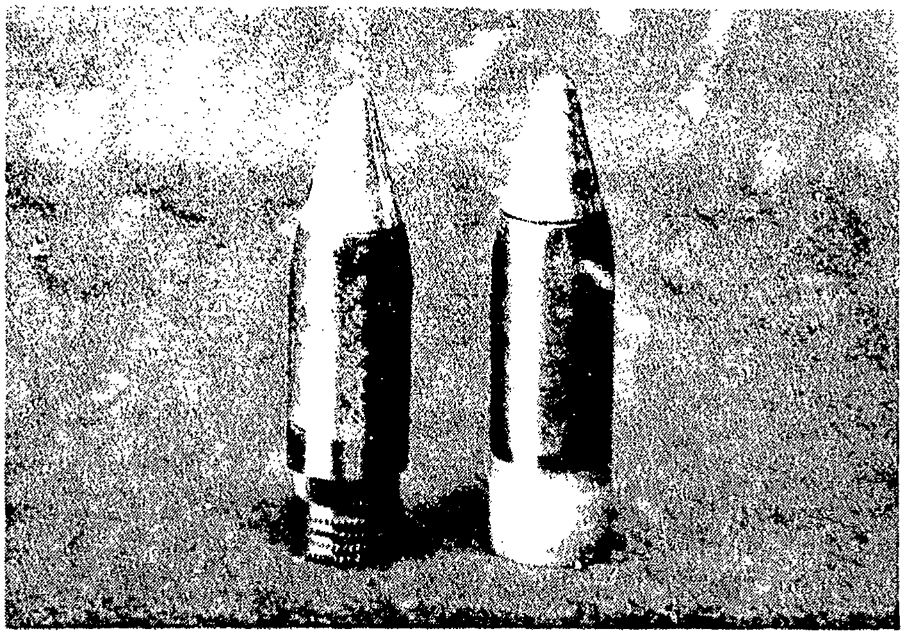


Figure 24. Projectile With Over-The-End Rotating Band

Anchorage style and completed molding
of an over-the-heel band configuration

The anchorage for this type of band is shown in a detail of drawing EG-A4-C covering the mold changes needed to convert one cavity to this style. The detail of the end of the projectile and the mechanical anchorage taken from EG-A4-C is shown in Figure 25.

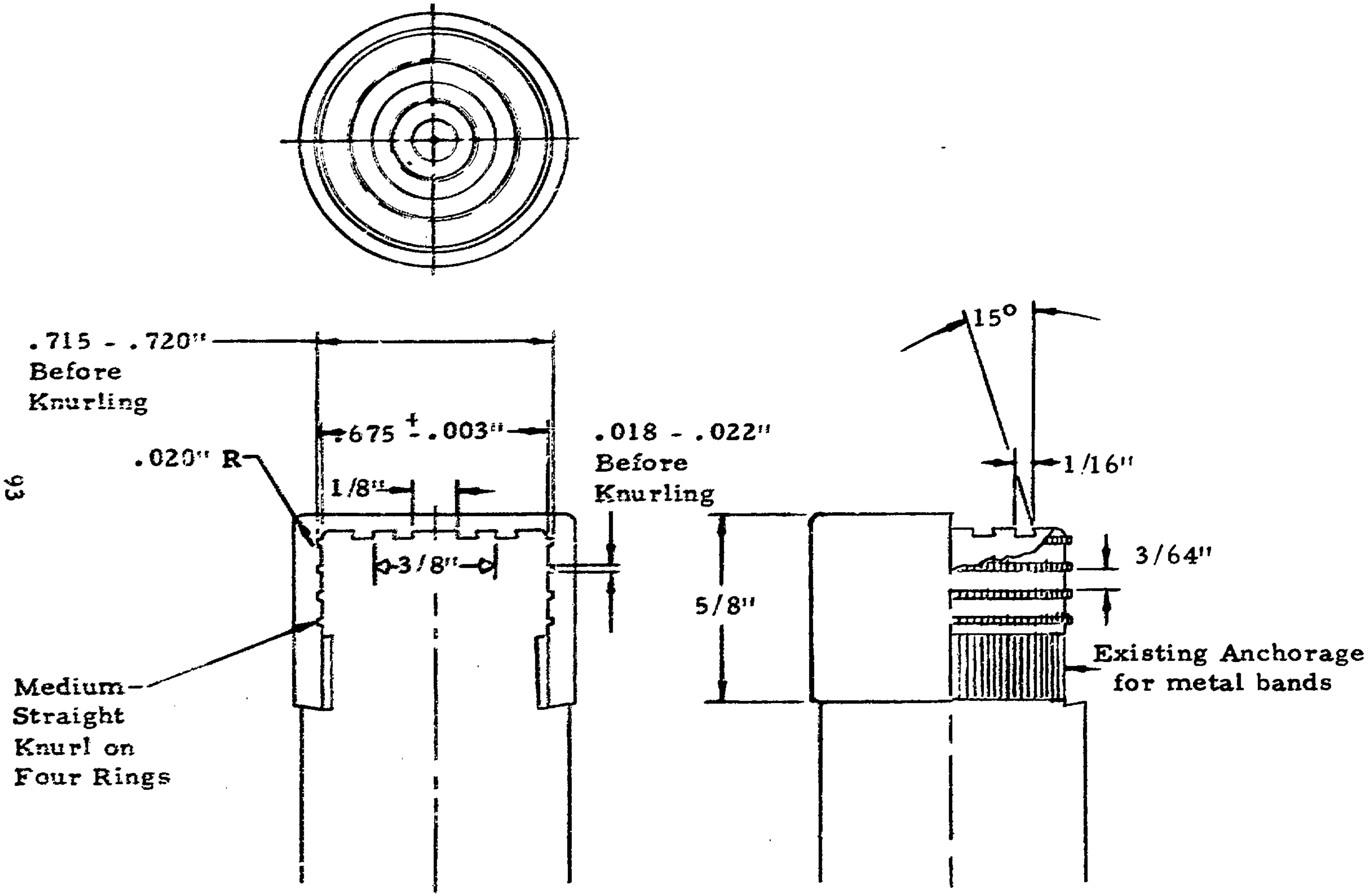


Figure 25. Anchorage Detail

PRIMING PROCEDURE DEVELOPMENT

Although the priming materials and procedure are described in this report in the section on chemical bonding anchorage, a typical developmental problem arose in respect to the procedure which required the discard of an entire lot of projectile samples after molding. The problem which arose is described below:

> A complete trial series of projectiles was prepared by the standard method of machining of anchorage, cleaning, priming, and molding. The materials included two variations of nylon 12, Trogamid T, and nylon 6/12. Upon checking the final samples prepared in this manner, some visual irregularities were noted. Samples were then impacted with the modified Gardner apparatus, and the bond of the molded nylon to the primed steel surface was found to be inadequate. The entire operation was double-checked, and the item of most question was the hot air bake of the primed projectile at 450°F for 45 minutes. It is believed that this cycle was held, although there is a possibility that the temperature could have exceeded 450°F. The item in the procedure which was most suspect was the presence of a sheet of cement-asbestos board in the oven on which the projectiles were placed. It appears that there may have been volatiles, including moisture, in this piece of board which seriously degraded the primer which is only about 0.001 inch thick. A repeat trial which compared projectiles baked on the board and without the board indicated that this probably was the cause of the failure. It should also be noted that there was a visual warning on the original pieces; they were darker in color than the light honey color which appears to indicate the optimum heating cycle.

Other investigations into special primer and bonding problems included those relating to a method for bonding polyethylene to steel and the problem of bonding Tefzel to steel. The former has been discussed under the section on consideration of polyolefins for rotating bands. The development sequence with Tefzel which led to the trial of induction heat for activating the plastic/steel interface melt continued into additional trials using Tefzel bands over A1100 primer in samples submitted by duPont. These primer trials were not successful in establishing a good bond.

CARTRIDGE ADAPTORS

For the firing trials of rotating bands which were molded cap-style over the end of the projectile, it became necessary to hold the projectile in a different manner in the powder case (Figure 26). Small adaptor sleeve and firing wads were devised and made which permitted the firing trials. Adaptor details are shown on notebook pages 107658 and 107659 of our laboratory record.

Figure 26. Projectile/Case Adaptor For Test Firings

Cartridge/Adaptor set-up for test firings

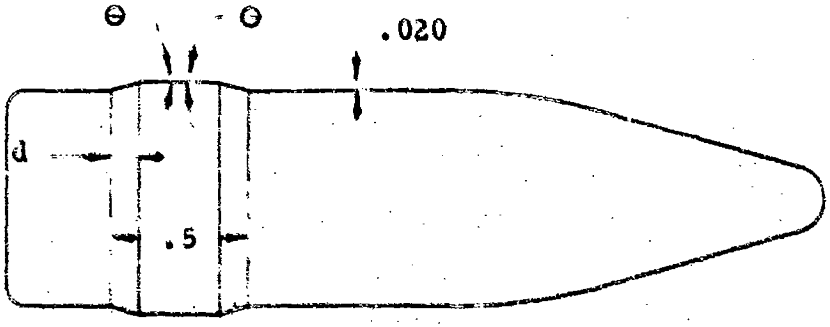
EFFECT OF ENTERING AND TRAILING EDGE OF ROTATING BAND

Practically all trials have indicated that an angled leading and trailing edge helps the rotating band resist the stress of impact and material deformation as it enters the rifling lands. Conversely, rotating bands with square abrupt leading and trailing edges are more prone to failure.

The problem in carrying highly angled edges into practice is that this significantly cuts down on the volume of plastic which is embossed, with consequently less area of plastic to transmit the compressive and shear forces on the sidewalls of the engraved grooves. Examples of the rapid diminution of contact area is shown in Table 15.

TABLE 15.

ENTERING AND TRAILING EDGE ANGLES



Angle θ	Tan θ	Distance d	Single embossed contact area (cross hatched)	Percent of full area
5	0.087	0.230	0.0054	54
8	0.141	0.142	0.0072	72
10	0.176	0.114	0.0077	77
13	0.231	0.087	0.0083	83
15	0.268	0.075	0.0085	85
90	0.0	0.0	0.0100	100

The first trials with selected leading and trailing edge angles were those of samples 107672. The summary of the construction and the results of the firing trials are given in Table 16.

TABLE 16.

PERFORMANCE OF EDGE ANGLES

Sample Identification	Velocity feet/sec	Trial No.	Comments	Performance
107672-1	4239	542	5^{0}angle trailing edge	Good appearance; slight feather leading edge
	4097	541	5^{0}angle trailing edge	Leading edge feather
107672-2	4152	543	0.100 inch wide grooved center	Leading edge feather; good band
	4167	544	0.100 inch wide grooved center	Some feathers
107672-3	4123	545	10^{0} angle both ends of band	Good appearance
	4158	546	10^{0} angle both ends of band	Good appearance

All firing trials were on projectiles held at ambient temperature. The importance of providing an entering angle and a trailing angle is indicated by the difference in the tendency of the samples to feather during flight, with the 107672-3 samples showing the best performance.

Examples of the combinations of angles used for leading and trailing edges are those of samples 107673 and 107674, using the tapers with two different band lengths as shown in Table 17.

TABLE 17.

EDGE ANGLE TEST BANDS

Quantity	Part No.	Projectile	Band Width (Inches)	Front Taper	Back Taper
4	107673-1A	Std. 20mm	0.50	8°	13°
5	107673-1B	Std. 20mm	0.50	15°	5°
4	107673-1C	Std. 20mm	0.50	10°	10°
4	107673-2A	Std. 20mm	0.30	12°	25°
4	107673-2B	Std. 20mm	0.30	25°	8°
5	107673-2C	Std. 20mm	0.30	15°	15°
3	107674-1	Special	0.30	12°	25°
3	107674-2	Special	0.30	15°	15°

The firing photographs of the firing trials for the 107673 series of samples were studied and the results are summarized in Table 18.

TABLE 18.

PERFORMANCE OF EDGE ANGLE COMBINATIONS

DLDL Trial	Velocity (ft/sec)	D&R Identification	Projectile Temperature	Comments
554	3918	107673-2B	160 F	Slight tumble; photo dark
555	4161	107673-2A	160 F	Full tumble; shaving shows
556	4065	107673-2C	160 F	Full tumble; feather shows
557	4029	107673-2B	160 F	Partial tumble; feather shows
558	4149	107673-1B	160 F	Full performance indicated
560	4252	107673-1C	160 F	No tumble; chips shown
561	4029	107673-2B	-65 F	No tumble; chips shown
562	4252	107673-1A	-65 F	Full performance indicated
563	4209	107673-1C	-65 F	Full performance indicated
564	4216	107673-1B	-65 F	Full performance indicated
565	4063	107673-2A	-65 F	Full tumble; small chip shown
566	4299	107673-1B	-65 F	Slight tumble; small chip shown
568	4146	107673-2A	-65 F	Good flight; photo not definitive
569	4209	107673-2B	-65 F	Full performance indicated
570	4202	107673-2C	-65 F	Full performance indicated

It should be kept in mind that the bands of 0.3 inch length are comparatively short, and a small taper angle decreases the effective length of the band proportionately more than for the 0.5 inch length. In general, if a low taper angle is found to be most effective, it will probably predicate the use of a rotating band of at least 0.5 inch length. This premise was verified by the results of the firing trials and the band length was established at 0.5 inch. Drawing EG-A8-B which is appended shows the projectile and band seat configuration before molding; this is shown in Figure 37.

Figures 27 and 28 show the photographic record of the firing of two of the samples of Series 107673. These are among the first of the samples using nylon 12 with an induction bonded interface and a shaped leading and trailing edge. Figure 27 shows sample 107673-1A fired at -65°F and a velocity of 4252 feet per second with full performance. Figure 28 shows sample 107673-1B (employing leading and trailing edge angles different from 107673-1A) fired at 4149 feet per second from a storage temperature condition of 160°F. The success of these firing trials served to crystallize the choice of the material, shape and method to proceed into the manufacture of the pilot lot. The final confirmation of performance was achieved with the production which followed and which is detailed in our report on Series 107678-2 and in Figures 29 and 30.

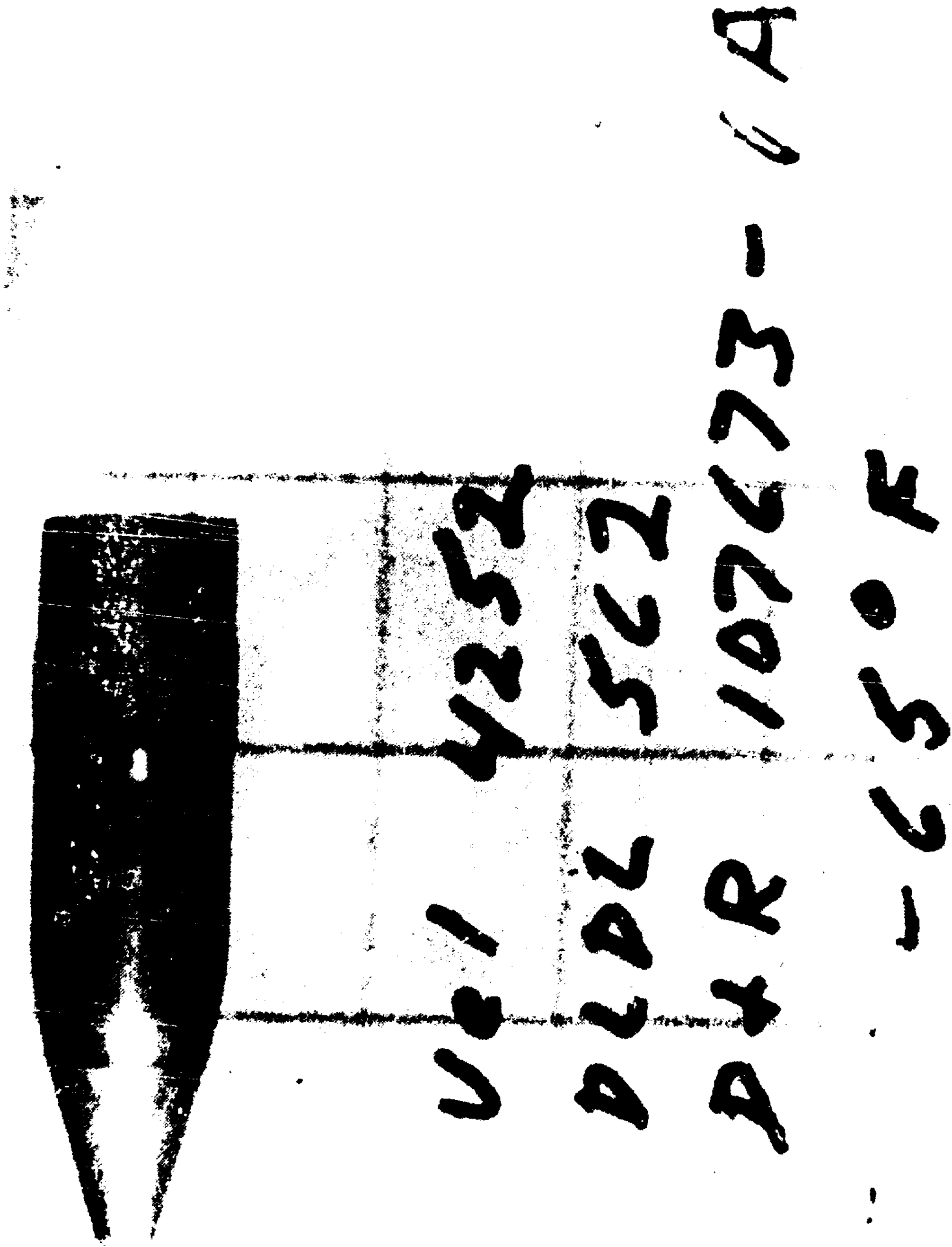


Figure 27. Firing Trial Of Sample 107673-1A at -65°F

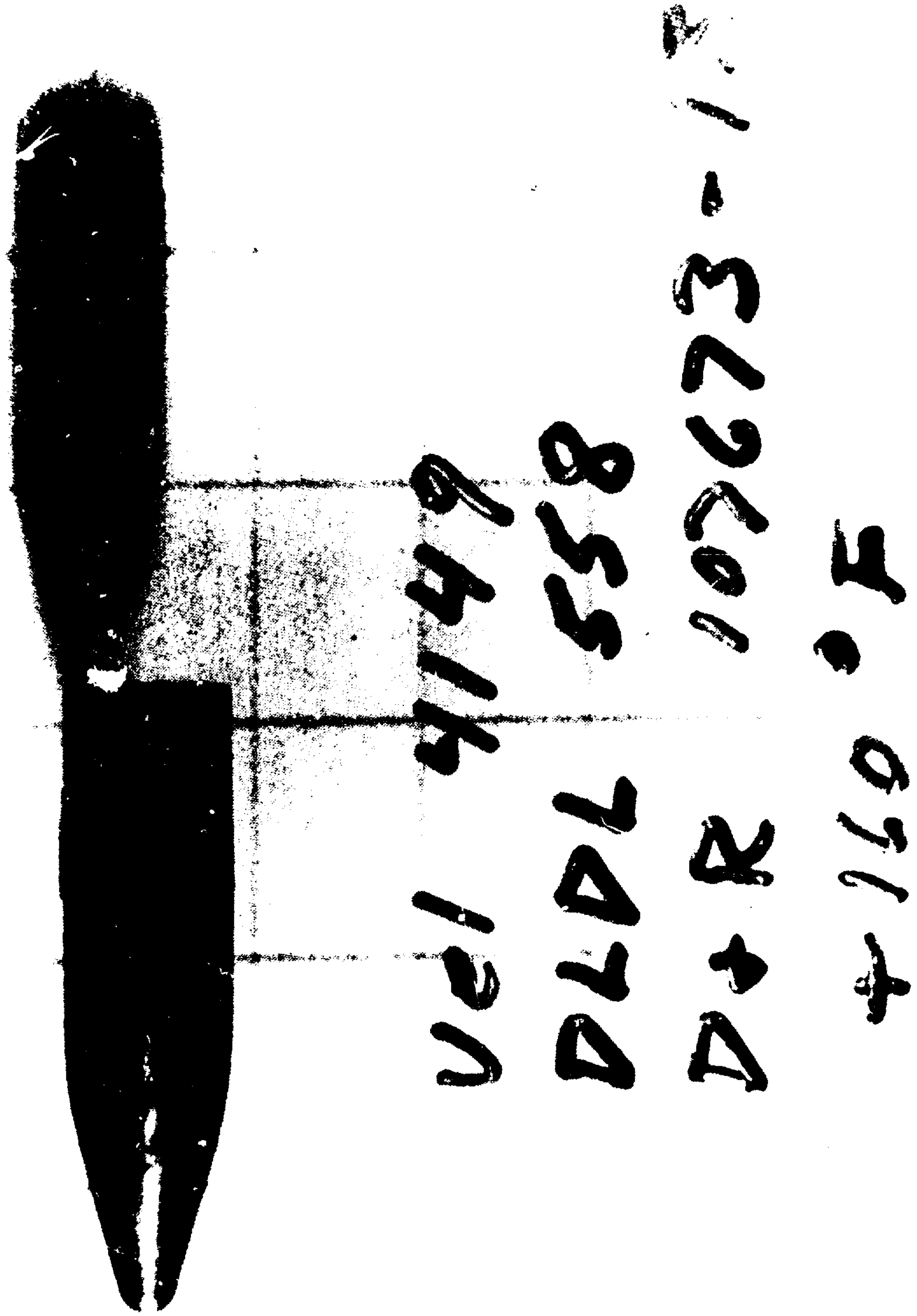


Figure 28. Firing Trial Of Sample 107673-1B at 160°F

FIRING TRIALS

The firing trials are documented by the in-flight photographs of the test projectiles during the course of the development work. Tables 19, 23, 24 and 25 list the individual photographs and test constructions which were fired. In the latter and more significant trials, comments on the individual test performance are included. The most significant part of the flight picture is the condition of the band, especially to note if it is cleanly engraved and does not show evidence of feathering, fraying, or fracturing. The manner in which the pictures are taken clearly show the loss of a band when it does occur. A misalignment or tumble of the projectile in the picture does not necessarily indicate that it is not in true flight.

TABLE 19.

PHOTOGRAPHIC RECORD OF TEST FIRINGS

Sample	DLDL*	Velocity (feet/second)	Performance	Anchorage	Construction
January 17, 1973					
105930-3	305	3278	Partial loss of band	Fig. 4, Groove B	Nylon/epoxy laminate
105930-4	307	3289	Partial " " "	" "	" " "
105930-5	306	3298	Partial " " "	" "	" " "
105930-6	308	3311	Partial " " "	" "	" " "
105930-7	316	3495	Partial " " "	" "	" " "
105930-8	309	3504	Partial " " "	" "	" " "
105932-1	302	2960	Band off	NP 105931	Rayon/epoxy laminate
105932-2	303	3420	Band off	"	" " "
105932-3	313	3593	Band off	"	" " "
105932-4	304	3601	Band off	"	" " "
105932-5	312	3646	Band off	"	" " "
February 27, 1973					
105933	362	3579	Partial failure	Figure 6	Light weight epoxy molded
105934	370	3650	Band good	Smooth groove	Tape wound laminate
105933	371	3519	Failure	Figure 6	Light weight epoxy molded
105934	372	3392	Band good	Smooth groove	Tape wound laminate

Abbreviations: T. E. - Trailing Edge; L. E. - Leading Edge; F. B. C. - Fluid Bed Coated

* Eglin AFB, Department DLDL, Test file number

Table 19 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Anchorage	Construction
105933	373	3369	Band failure	Figure 6	Light weight epoxy molded
105934	374	3351	No picture	Smooth groove	Tape wound laminate
105933	375	3243	Band failure	Figure 6	Light weight epoxy molded
105934	376	3237	No picture	Smooth groove	Tape wound laminate
105933	378	3270	No band	Figure 6	Light weight epoxy molded
105934	379	3173	Band on	Smooth groove	Tape wound laminate
May 7, 1973					
	427	4058	T. E. lost		
107656-2	426	4108	T. E. (deep groove) lost	NP 105936-4	L-200 MOCA urethane
107656-1	425	4067	Completely lost	NP 105936-4	L-200 MOCA urethane
105937	424	4000	Central mass lost	NP 105936-2	Tape wound laminate
105937	423	3870	Pocked	NP 105936-2	Tape wound laminate
105938-2	422	4098	Completely lost	Figure 6	
105938-2	421	4088	Completely lost		
June 4, 1973					
107666-1	483	3876	Good appearance	NP 107655	Adiprene L-200 no primer
107666-1	484	3817	Good appearance	NP 107655	Adiprene L-200 no primer
107652-1	502	4112	Flaking	NP 107652	Nylon 11 F. B. C. 4 groove

Table 19 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Anchorage	Construction
107652-1	501	4082	Fine flaking	NP 107652	Nylon 11 F.B.C. 4 groove
107652-1	500	4023	Forward ring flake	NP 107652	Nylon 11 F.B.C. 4 groove
107666-2	507	4129	Good appearance	NP 107655	Adiprene L-200 607 primer
107666-2	504	4122	Some tearing	NP 107655	Adiprene L-200 607 primer
107666-2	506	4329	Good appearance	NP 107655	Adiprene L-200 607 primer
107666-2	486	4125	Good appearance	NP 107655	Adiprene L-200 607 primer
107666-2	485	3978	Good appearance	NP 107655	Adiprene L-200 607 primer
107666-3	505	4303	Stripped	NP 107655	Adiprene L-200 1153 primer
107666-3	487	4184	Good - small feather	NP 107655	Adiprene L-200 1153 primer
107666-3	488	4191	Good	NP 107655	Adiprene L-200 1153 primer
107653-1	508	4125	Small feather groove	NP 107653	Nylon 11 F.B.C. 6 groove
107653-1	489	3751	Small flakes	NP 107653	Nylon 11 F.B.C. 6 groove
107653-1	496	3748	Good	NP 107653	Nylon 11 F.B.C. 6 groove
105943-2	477	3978	Feathers	Figure 7	Nylon 11 F.B.C. end cap

Table 19 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Anchorage	Construction
105943-2	478	4119	Fair	Figure 7	Nylon 11 F.B.C. end cap
105943-1	479	4049	No picture	Figure 25	TPPE F.B.C. end cap
105943-1	476	3997	Good	Figure 25	TPPE F.B.C. end caps
105942	469	4139	Stripped	EG-A3-C	ABSAFIL
107654-1	499	3900	Flaked T.E.	NP 107654	Nylon 11 F.B.C. no grooves
107654-1	498	3873	Good		Nylon 11 F.B.C. no grooves
107656-2	465	4055	T. E. Stripped		L-200 1153 primer
107656-2	466	4092	Complete strip	NP 105936-4	L-200 MOCA
June 18, 1973					
107652-2	514	4198	Cracked	NP 107652	Fluid bed polyester 4 groove
107652-2	513	4244	Cracked		Fluid bed polyester 4 groove
107653-2	516	4167	Cracked	NP 107653	Fluid bed polyester 6 groove
107653-2	515	4205	Cracked		Fluid bed polyester 6 groove
107654-2	517	4209	Cracked; peeled	NP 107654	Fluid bed polyester no grooves
107654-2	518	4227	Feathers; cracking		Fluid bed polyester no grooves
107667-2	510	3965	Stripped	NP 107655	Pellethane 2102-65 DX

Table 19 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Anchorage	Construction
107667-3	512	4088	Stripped		Estane 58111-021
107667-3	511	4049	T.E. chipped	NP 107655	Estane 58111-021
June 22, 1973					
107667-4	524	4205	Peeled	NP 107655	Nylon 11, 253-P Primer
107667-4	526	4255	Complete peel		Nylon 11, 253-P Primer
107667-4	525	4292	T.E. chipped		Nylon 11, 253-P Primer
107667-4	527	3990	L.E. flaked - peeled		Nylon 11, 253-P Primer
July 11, 1973					
107672-2	544	4167	Good - feather in groove	NP 107655	Nylon 12, 253-P Primer
107672-2	543	4152	Good - L.E. feather		
107672-3	545	4123	Good - slight tumble		
107672-3	546	4158	Good - slight tumble	NP 107655	
107671-2	539	4172	Flake L.E. plus tumble	NP 107655	
107672-1	541	4097	Good - feather L.E.	NP 107655	
107672-1	542	4239	Good - feather L.E.		
107671-1	533	3872	Feather L.E.	NP 107655	
107671-1	533A	3941	Good - slight feather L.E.		
107671-1	533B	4046	Slight flake plus tumble		

Table 19 (Concluded)

Sample	DLDL #	Velocity (feet/second)	Performance	Anchorage	Construction
August 10, 1973					
107673-1C	563	4209	-65^{o}F good	NP 107673-1	Nylon 12, 253-P Primer
107673-1B	564	4216	-65^{o}F good		
107673-2A	565	4063	-65^{o}F tumble	NP 107673-2	
107673-2B	569	4209	-65^{o}F appears to be good		
107673-1C	560	4252	$+160^{o}$F no tumble/ feathered		
107673-2B	561	4029	-65^{o}F no tumble/chipped		
107673-1B	566	4299	-65^{o}F slight tumble/ feather		
107673-2A	568	4146	-65^{o}F questionable		
107673-2C	573	4170	-65^{o}F good slight tumble		
107673-2C	571	4202	-65^{o}F good		Nylon 12, 253-P Primer
105939	552	4156	complete loss	NP 105936-3	-
105941-1	553	4023	1/2 band lost	NP 105936-2	-
107673-2B	554	3918	$+160^{o}$F slight tumble/ photo dark		Nylon 12, 253-P Primer
107673-2A	555	4191	$+160^{o}$F full tumble/chip		
107673-2C	556	4065	$+160^{o}$F full tumble/chip		
107673-2B	557	4029	$+160^{o}$F tumble/chip		
107673-1B	558	4149	$+160^{o}$F good		
107673-1A	562	4252	-65^{o}F good		Nylon 12, 253-P Primer

FINAL EVOLUTION OF NYLON 12 BANDS

At the first of January 500 projectiles were shipped to Eglin for final firing tests. Of these, approximately one-half were in nylon 12 and the other half in nylon 11. Half again of each were in two styles of band edge tapers. Details are given in Table 20.

TABLE 20.

IDENTIFICATION OF PRODUCTION SAMPLES

Part No.	Material	Leading Edge	Trailing Edge
107677-1A	Nylon 12	15°	6°
107677-1B	Nylon 12	8°	13°
107677-4A	Nylon 11	15°	6°
107677-4B	Nylon 11	8°	13°

The results are presented in Table 21.

TABLE 21.

SUMMARY OF RESULTS OF FINAL FIRINGS FOR ISOLATION OF FINAL MATERIAL AND BAND LEADING AND TRAILING EDGE CONFIGURATIONS

	38-3900 ft/sec	39-4000 ft/sec	40-4100 ft/sec	41-4200 ft/sec	42-4300 ft/sec	43-4400 ft/sec	Total
107677-1A							
ambient	8 of 9	5 of 5	no test	2 of 3	4 of 6	no test	19/23
-65°F	3 of 3	1 of 2	no test	4 of 9	0 of 1	no test	8/15
+160°F	no test	4 of 4	no test	10 of 11	no test	no test	14/15
	11/12	10/11		16/23	4/7		41/53
107677-1B							
ambient	no test	no test	3 of 5	6 of 8	2 of 2	no test	11/15
-65°F	no test	no test	no test	1 of 10	no test	no test	1/10
+160°F	no test	no test	no test	6 of 8	no test	no test	6/8
			3/5	13/26	2/2		18/33
107677-4A							
ambient	4 of 5	no test	no test	9 of 10	no test	no test	13/15
-65°F	2 of 5	no test	no test	4 of 10	no test	no test	6/15
+160°F	2 of 4	no test	no test	2 of 10	no test	no test	4/14
	8/14			15/30			24/44
107677-4B							
ambient	4 of 6	no test	no test	6 of 9	1 of 4	no test	11/19
-65°F	1 of 5	no test	no test	6 of 20	no test	no test	7/25
+160°F	2 of 5	no test	no test	5 of 10	no test	no test	7/15
	7/16			17/39	1/4		25/59

Barrel twist - 1 turn in 24 inches

Although the results were erratic, they were definitive enough to choose a final band shape and material. It was decided to finalize with the 107677-1A configuration. Moreover, the erratic results suggested process problems, so an additional lot of projectiles were produced under rigorous controls and retested at the same temperatures but at higher velocities. The results are given in Table 22.

TABLE 22.

SUCCESSFUL FIRINGS OF STYLE 107677-1A
(Nylon 12 band, 6° aft taper, 15° forward taper)

	40-4100 ft/sec	41-4200 ft/sec	42-4300 ft/sec	43-4400+ ft/sec	Total
ambient	2 of 2	8 of 8	5 of 5	2 of 2	17/17
-65°F	no test	no test	1 of 1	13 of 15	14/16
+160°F	no test	no test	0 of 1	13* of 13*	13/14
	2/2	8/8	6/7	28/30	44/47

* Of the 13, 10 smeared but the projectiles were ballistically stable.

Figures 29 and 30 show the photographic record of the firing of two of the samples of Series 107678-2 which are the same construction as the selected design 107677-1A. Figure 29 shows a successful firing at 4409 feet per second at -65°F, and Figure 30 shows a corresponding performance at +160°F.

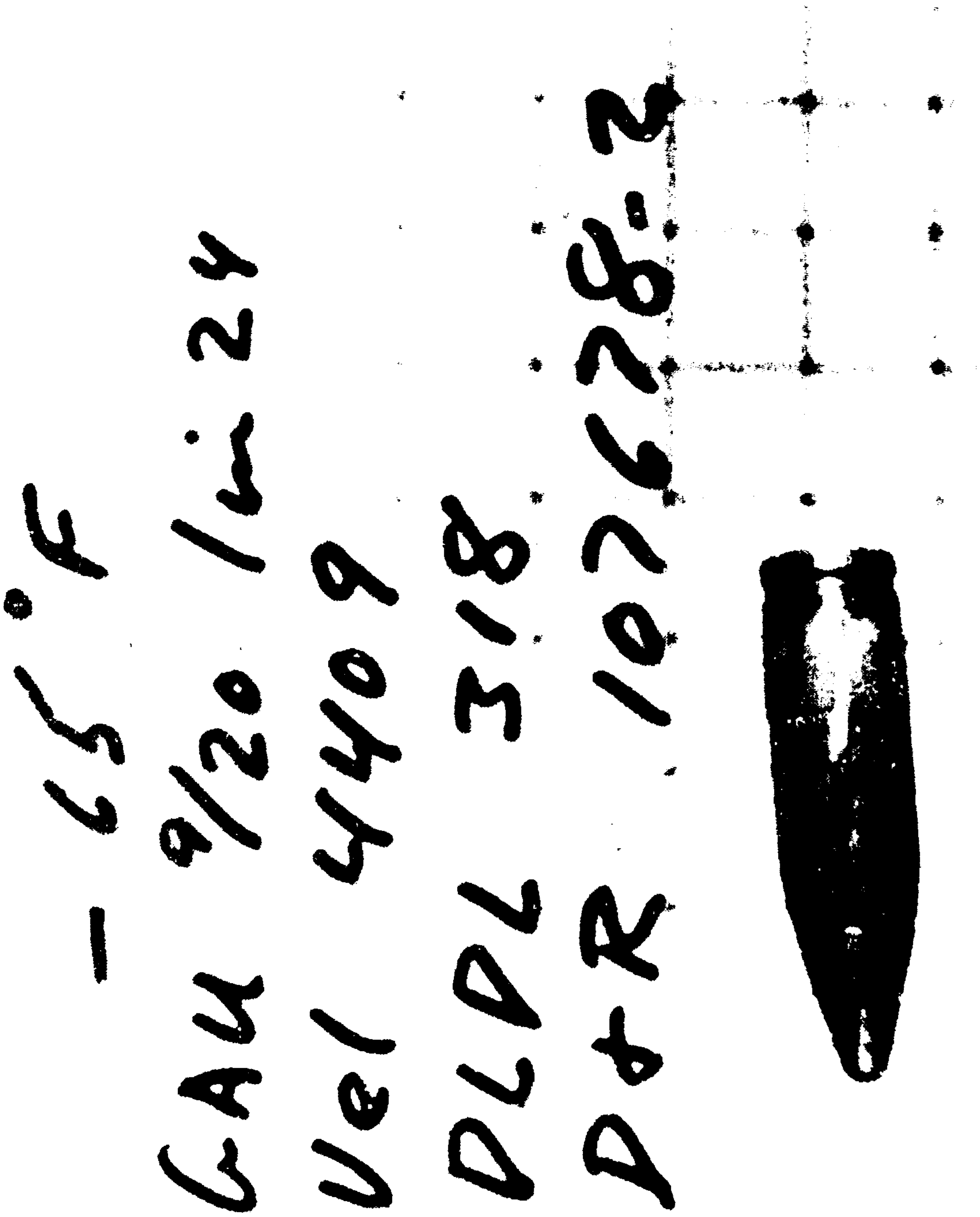


Figure 29. Firing Sample Of 107678-2 at -65°F

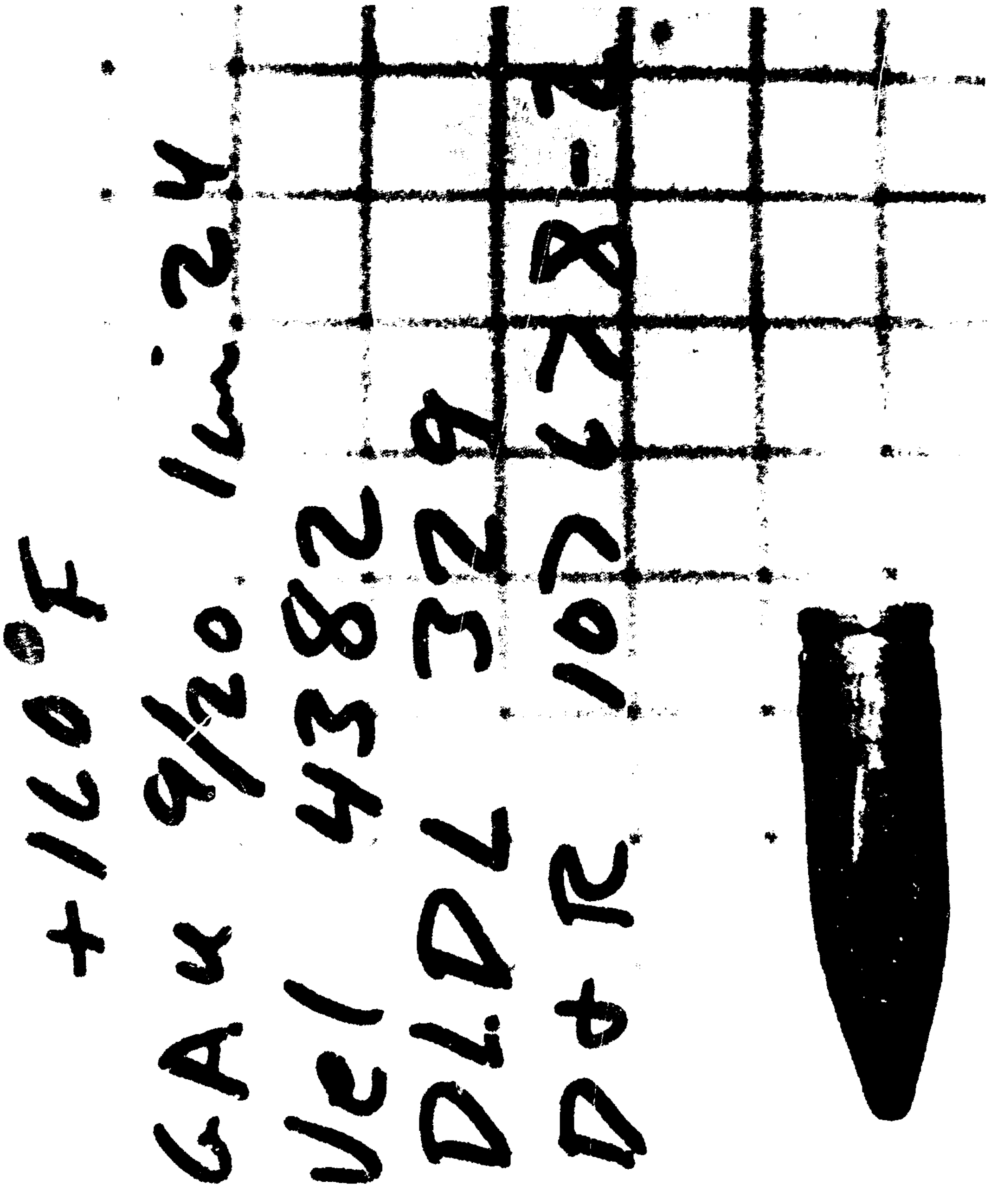


Figure 30. Firing Sample Of 107678-2 at +160°F

TABLE 23.

PHOTOGRAPHIC RECORD OF TEST FIRINGS

January 1974		Velocity		
Sample	DLDL*	(feet/second)	Performance	Construction
107677 -4B	76	4153	Good, ambient	Nylon 11, 253-P Primer
-4B	77	4136	Good, ambient	
-4B	78	no data	T. E. breakage, ambient	
-4B	79	4167	Good, ambient	
-4B	80	4174	T.E. chips, ambient	
-4B	81	4174	Good, ambient	
-4B	82	4252	Good, ambient	
-4B	84	4255	Partial loss, ambient	
-4B	85	4255	Partial loss, ambient	
-4B	86	4209	Partial loss, ambient	
-4B	87	4153	Good, ambient	
-4B	88	4184	T.E. loss, ambient	
-4B	89	4160	T.E. chips, ambient	
-4B	90	4156	Good, ambient	Nylon 11, 253-P Primer
-1B	91	4216	Good, ambient	Nylon 12, 253-P Primer
-1B	92	4209	Good, ambient	
-1B	93	4177	Partial loss, ambient	
-1B	94	4167	Good, ambient	
-1B	95	4191	Good, ambient	
-1B	96	4177	Good, ambient	
-1B	97	4177	Good, ambient	Nylon 12, 253-P Primer

Abbreviations T. E. - Trailing Edge; L. E. - Leading Edge

* Eglin AFB, Department DLDL, 1974 Test File Number

All anchorages smooth steel groove with primer - drawing EG-A8-B

Barrel twist - 1 turn in 20 inches

Table 23 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Construction
107677 -1B	98	4195	T.E. feathers, ambient	Nylon 12, 253-P Primer
-1B	99	4181	Good, ambient	
-1B	100	4181	Good, ambient	
-1A	101	4181	Good, ambient	
-1A	102	4212	Good, ambient	
-1A	103	3906	Good, ambient	
-1A	104	4195	T.E. chips, ambient	
-1A	105	4216	T.E. feathers, ambient	
-1A	106	4209	Good, ambient	
-1A	107	4284	Good, ambient	
-1A	108	4288	Good, ambient	
-1A	109	4284	T.E. flaking, ambient	
-1A	110	4198	Good, ambient	Nylon 12, 253-P Primer
-4A	111	4163	Good, ambient	Nylon 11, 253-P Primer
-4A	112	4177	Good, ambient	
-4A	113	4167	Good, ambient	
-4A	114	4177	Good, ambient	
-4A	115	4167	Good, ambient	
-4A	116	4181	Good, ambient	
-4A	117	4177	Good, ambient	
-4A	118	4188	Good, ambient	
-4A	119	4170	Good, ambient	
-4A	120	4174	T.E. chips, ambient	Nylon 11, 253-F Primer
-1A	121	4198	T.E. chips, -65°F	Nylon 12, 253-P Primer
-1A	122	4191	T.E. chips, -65°F	
-1A	123	4195	Flaking, -65°F	
-1A	124	4219	Partial loss, -65°F	Nylon 12, 253-P Primer

Table 23 (Continued)

Sample		DLDL#	Velocity (feet/second)	Performance	Construction
107677	-1A	125	4191	Flaking, -65°F	Nylon 12, 253-P Primer
	-1A	126	4195	Good, -65°F	
	-1A	127	4192	T.E. chip, -65°F	
	-1A	128	4174	Good, -65°F	
	-1A	129	4198	Good, -65°F	
	-1A	130	4195	Good, -65°F	Nylon 12, 253-P Primer
	-1B	131	4195	Total loss, -65°F	Nylon 12, 253-P Primer
	-1B	132	4160	Total loss, -65°F	
	-1B	133	41[illegible]3	Good, -65°F	
	-1B	134	4156	T.E. fraying, -65°F	
	-1B	135	4191	T.E. fraying, -65°F	
	-1B	136	4170	Total loss, -65°F	
	-1B	137	4170	Partial loss, -65°F	
	-1B	138	4174	T.E. chips, -65°F	
	-1B	139	4181	Total loss, -65°F	
	-1B	140	4188	Partial loss, -65°F	Nylon 12, 253-P Primer
	-4A	141	4149	Good, -65°F	Nylon 11, 253-P Primer
	-4A	142	4146	Partial loss, -65°F	
	-4A	143	4149	Good, -65°F	
	-4A	144	4136	Good, -65°F	
	-4A	145	4160	T.E. fraying, -65°F	
	-4A	146	4160	Partial loss, -65°F	
	-4A	147	4167	T.E. chip, -65°F	
	-4A	148	4146	Partial loss, -65°F	
	-4A	149	4160	L. E. chip, -65°F	Nylon 11, 253-P Primer

Table 23 (Continued)

Sample	DLDL*	Velocity (feet/second)	Performance	Construction
107677 -4A	150	4149	Good, -65°F	Nylon 11, 253-P Primer
-4B	151	4125	T.E. chips, -65°F	
-4B	152	4125	Good, -65°F	
-4B	153	4160	T.E. chip, -65°F	
-4B	154	4156	Partial loss, -65°F	
-4B	155	4181	Partial loss, -65°F	
-4B	156	4153	Good, -65°F	
-4B	157	4139	Apparent chip, -65°F	
-4B	158	4143	Partial loss, -65°F	
-4B	159	4143	L.E. fraying, -65°F	
-4B	160	4156	Good, -65°F	
-4B	161	4198	Partial loss, -65°F	
-4B	162	4181	Good, -65°F	
-4B	163	4177	Partial loss, -65°F	
-4B	164	4163	Partial loss, -65°F	
-4B	165	4146	Good, -65°F	
-4B	166	4163	Fraying, -65°F	
-4B	167	4160	Partial loss, -65°F	
-4B	168	4170	Good, -65°F	
-4B	169	4156	Partial loss, -65°F	
-4B	169	4163	T.E. loss, -65°F	Nylon 11, 253-P Primer
-1B	172	4010	Almost total loss, ambient	Nylon 12, 253-P Primer
-1B	173	4010	Good, ambient	
-1B	174	4052	T.E. fraying, ambient	Nylon 12, 253-P Primer

Table 23 (Continued)

Sample	DLDL*	(feet/second)	Performance	Construction
107677 -1E	175	4039	Good, ambient	Nylon 12, 253-P Primer
-1E	176	4016	Good, ambient	
-1A	177	4153	Good, +160°F	
-1A	178	4149	Good, +160°F	
-1A	179	4167	Good, +160°F	
-1A	180	4153	Partial loss, +160°F	
-1A	182	4153	Good, +160°F	
-1A	183	4163	Good, +160°F	
-1A	184	4156	Good, +160°F	
-1A	185	4160	Good, +160°F	
-1A	186	4156	Good, +160°F	
-1A	187	4146	Good, +160°F	
-1A	188	4156	Good, +160°F	Nylon 12, 253-P Primer
-1B	189	4129	Good, +160°F	Nylon 12, 253-P Primer
-1B	190	4153	Good, +160°F	
-1B	191	4156	Good, +160°F	
-1E	192	4143	Good, +160°F	
-1B	194	4139	Good, +160°F	
-1B	195	4156	T.E. feathers, +160°F	
-1B	196	4163	Partial loss, +160°F	Nylon 12, 253-P Primer
-4A	197	4119	Good, +160°F	Nylon 11, 253-P Primer
-4A	198	4119	Partial loss, +160°F	
-4A	199	4139	T.E. chip, +160°F	Nylon 11, 253-P Primer

Table 23 (Concluded)

Sample	DLDL*	Velocity (feet/second)	Performance	Construction
107677 -4A	200	4143	T.E. fraying, +160°F	Nylon 11, 253-P Primer
-4A	201	4119	Partial loss, +160°F	
-4A	202	4129	Partial loss, +160°F	
-4A	203	4119	Partial loss, +160°F	
-4A	204	4122	Good, +160°F	
-4A	205	4143	Good, +160°F	
-4A	206	4115	Partial loss, +160°F	
-4B	207	4139	Partial loss, +160°F	
-4B	208	4132	Partial loss, +160°F	
-4B	209	4149	Good, +160°F	
-4B	210	4132	Partial loss, +160°F	
-4B	211	4136	Good, +160°F	
-4B	212	4146	Good, +160°F	
-4B	213	4149	T.E. feathers, +160°F	
-4B	214	4132	Good, +160°F	
-4B	215	4129	Partial loss, +160°F	
-4B	216	4115	Good, +160°F	Nylon 11, 253-P Primer

TABLE 24.

PHOTOGRAPHIC RECORD OF TEST FIRINGS

February 1974 (Final Firing)

Sample	DLDL*	Velocity (feet/second)	Performance	Construction
107677 -1A	220	3971	Good, ambient	Nylon 12, 253-P Primer
-1A	221	3959	Good, ambient	
-1A	223	3882	Good, ambient	
-1A	224	3867	Good, ambient	
-1A	225	3867	Good, ambient	
-1A	226	3867	Good, ambient	
-1A	227	3873	Good, ambient	
-1A	228	3879	Good, ambient	
-1A	229	3858	Good, ambient	
-1A	230	3870	Good, ambient	Nylon 12, 253-P Primer
-4B	232	3894	Good, ambient	Nylon 11, 253-P Primer
-4B	233	3870	T. E. Flake, ambient	
-4B	234	3852	Good, ambient	
-4B	235	3849	Good, ambient	
-4B	236	3867	Good, ambient	
-4B	237	3870	T. E. loss, ambient	Nylon 11, 253-P Primer
-4A	238	3840	Good, ambient	Nylon 11, 253-P Primer
-4A	239	3858	Good, ambient	Nylon 11, 253-P Primer

* Eglin AFB, Department DLDL, 1974 Test File Number

Barrel twist - 1 turn in 24 inches

Abbreviation - T.E. - Trailing Edge

Table 24 (Concluded)

Sample	DLDL*	Velocity (feet/second)	Performance	Construction
107677 -4A	240	3861	T. E. feather, ambient	Nylon 11, 253-P Primer
-4A	241	3852	Good, ambient	
-4A	242	3858	Good, ambient	
-4B	266	3861	T. E. feathers, -65°F	
-4B	267	3885	Partial loss, -65°F	
-4B	268	3861	Partial loss, -65°F	
-4B	269	3897	Good, -65°F	
-4B	270	3873	T. E. chips, -65°F	Nylon 11, 253-P Primer
-1A	271	3909	Good, -65°F	Nylon 12, 253-P Primer
-1A	272	3894	Good, -65°F	
-1A	273	3912	Chips, -65°F	
-1A	274	3876	Good, -65°F	
-1A	275	3888	Good, -65°F	Nylon 12, 253-P Primer

TABLE 25.

PHOTOGRAPHIC RECORD OF TEST FIRINGS

May 13, 1974 (Retest)

Sample		DLDL*	Velocity (feet/second)	Performance	Construction
107678	-1	287	4009	Good, 70°F	Nylon 12, 253-P Primer
	-1	288	4042	Good, 70°F	
	-1	289	4198	Good, 70°F	
	-1	290	4188	Good, 70°F	
	-1	291	4292	Good, 70°F	
	-1	292	4266	Good, 70°F	
	-1	294	4219	Good, 70°F	
	-1	295	4303	Good, 70°F	
	-2	296	4149	Good, 70°F	
	-2	297	4307	Good, 70°F	
	-2	298	4119	Good, 70°F	
	-2	299	4219	Good, 70°F	
	-2	300	4188	Good, 70°F	
	-3	301	4259	Good, 70°F	
	-3	302	4146	Good, 70°F	
	-3	303	4108	Good, 70°F	Nylon 12, 253-P Primer

Abbreviation T. E. - Trailing Edge

* Eglin AFB, Department DLDL, 1974 Test File Number

Barrel twist - 1 turn in 24 inches

Table 25 (Continued)

Sample		DLDL*	Velocity (feet/second)	Performance	Construction
107678	-3	304	4195	Good, 70°F	Nylon 12, 253-P Primer
	-3	305	4139	Good, 70°F	
	-1	308	4374	Good, -65°F	
	-1	309	4367	Good, -65°F	
	-1	310	4355	Good, -65°F	
	-1	311	4390	Good, -65°F	
	-1	312	4277	Good, -65°F	
	-1	313	4390	Good, -65°F	
	-2	314	4352	T. E. Chips, -65°F	
	-2	315	4417	Good, -65°F	
	-2	316	4399	T.E. flake, -65°F	
	-2	317	4409	Good, -65°F	
	-2	318	4409	Good, -65°F	
	-3	319	4363	Good, -65°F	
	-3	320	4359	Good, -65°F	
	-3	321	4409	Good, -65°F	
	-3	322	4394	Good, -65°F	
	-3	323	4394	Good, -65°F	
	-1	324	4382	Good, +160°F	
	-1	325	4405	Smeared but stable, +160°F	
	-1	326	4371	Smeared but stable, +160°F	
	-1	327	4374	Smeared but stable, +160°F	
	-1	328	4367	Smeared but stable, +160°F	

Table 25 (Concluded)

Sample	DLDL#	Velocity (feet/second)	Performance	Construction
107678-2	329	4382	Good, +160°F	Nylon 12, 253-P Primer
-2	330	4355	Smeared but stable, +160°F	
-2	331	4359	Good, +160°F	
-2	333	4274	Smeared, perhaps unstable, +160°F	
-3	334	4384	Smeared but stable, +160°F	
-3	335	4374	Smeared but stable, +160°F	
-3	336	4367	Smeared but stable, +160°F	
-3	337	4355	Smeared but stable, +160°F	
-3	338	4355	Smeared but stable, +160°F	Nylon 12, 253-P Primer

BARREL TWIST

Samples of nylon banded 20mm projectiles have been fired in a variety of barrel configurations including the M39 cannon with a gain twist, in a standard twist GAU-9 barrel with one twist in 12 inches, in the standard one twist in 20 inches barrel and the GAU-9/20 with one twist in 24 inches.

A comparison of performance between the conventional metal rotating band performance and the nylon band performance when fired in the GAU-9/20 barrel, with one twist in 12 inches is offered in Figures 31 and 32. Figure 31 shows the complete loss of the gilding metal band at a velocity of 3902 feet per second as contrasted to the full performance of the nylon band at 4000 feet per second from a storage condition of 160°F.

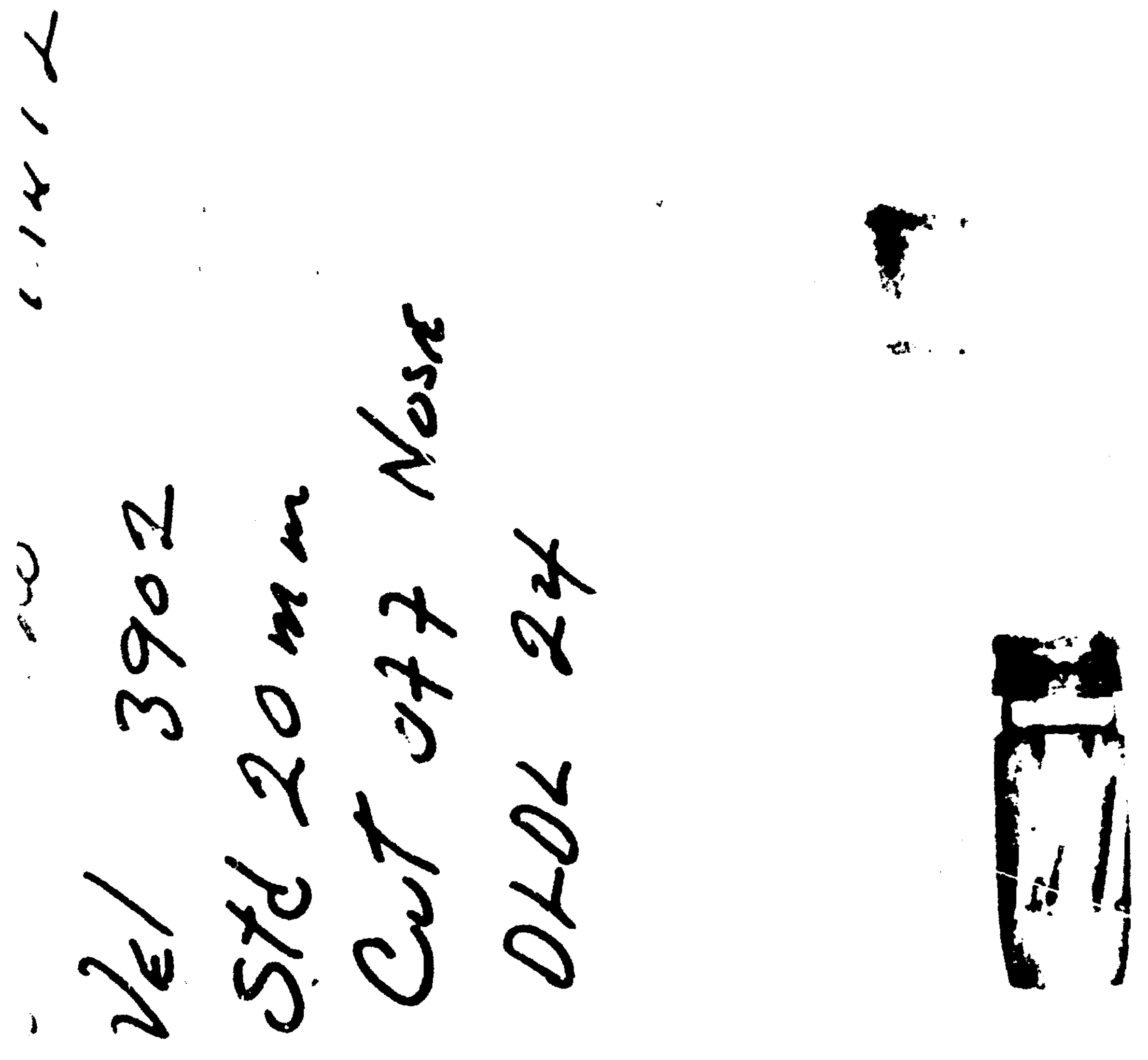


Figure 31. Firing Test Of Metal Rotating Band At 3902 Feet Per Second

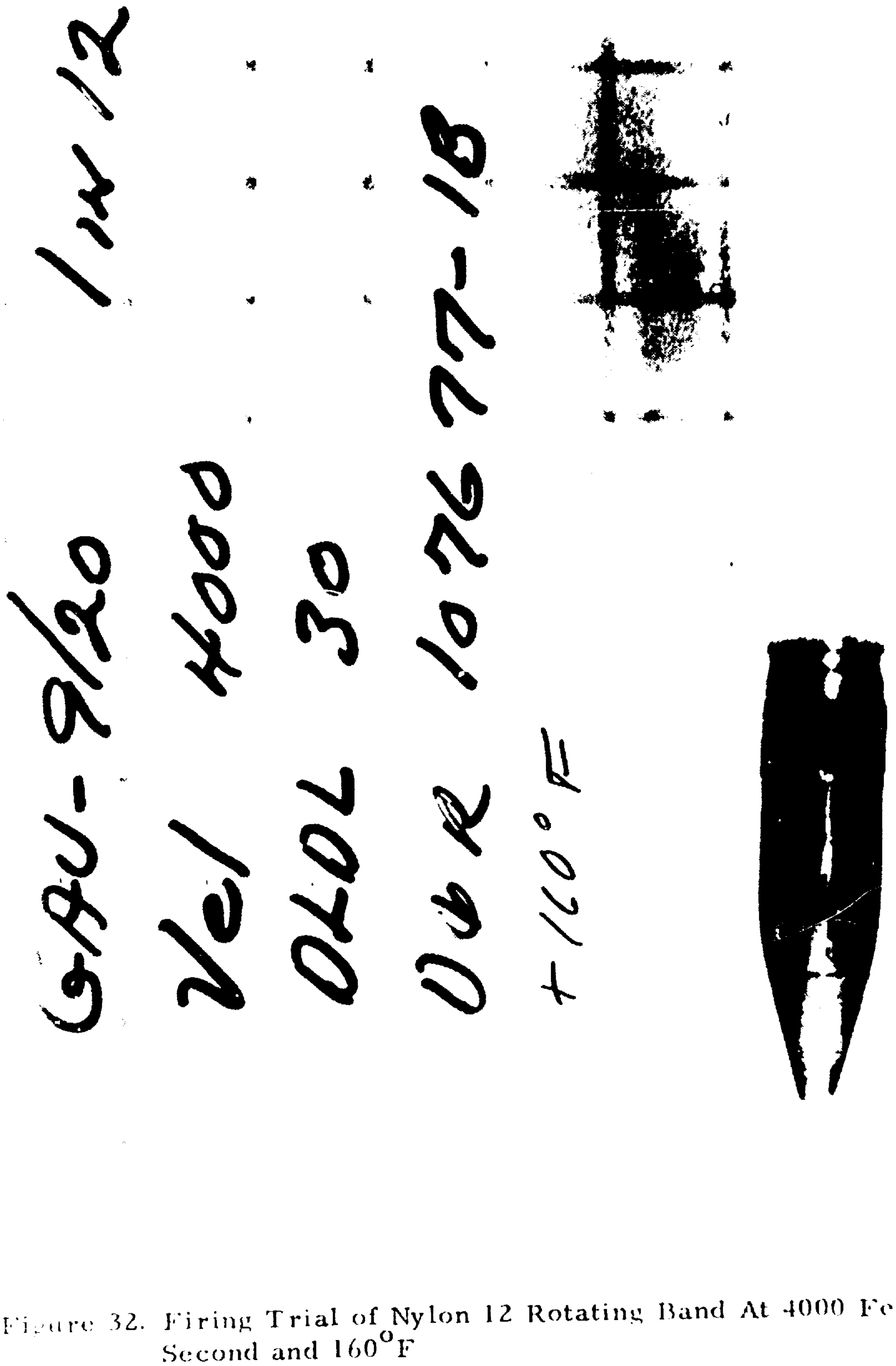


Figure 32. Firing Trial of Nylon 12 Rotating Band At 4000 Feet Per Second and 160°F

MANUFACTURING SEQUENCE

The final manufacturing sequence was that of molding 250 projectiles, each with rotating bands of nylon 11 and nylon 12. Each of these lots was, in turn, divided into equal quantities of projectiles with two different patterns of trailing and leading edge angles.

PREPARATION OF PROJECTILES

The projectiles were procured as smooth sided shapes with no anchorage groove of any type machined into them. They were then machined separately with the needed anchorage groove, at this time specified as 0.020 inch deep and extending from 0.420 inch to 0.920 inch as measured from the back end of the projectile. After the machining of the anchorage groove with a typical smooth lathe cut finish, the projectiles were cleaned and primed. Because of the relatively clean condition from the machining operation, it proved adequate to simply swirl the parts in two successively cleaner baths of perchloroethylene at room temperature. Following the final drain, the projectiles were dried in warm air. See Figure 37.

The projectiles are then removed by tongs or gloved hands and placed for priming. The solution used is M&T 253-P cut with an equal volume of methyl ethyl ketone solvent. The projectiles are dipped individually and held on the bourrelet section. The excess primer is shaken off manually and the projectiles set on their flat end to air dry at room temperature. This is followed by an oven bake at 450°F for 45 minutes. The projectiles are removed from the oven in tray batches to slow cool. They are then packaged in polyethylene bags which are tied or sealed to keep the projectiles clean and protected from moisture pick-up.

INJECTION MOLDING OF NYLON 11

The primed projectiles were removed from their protected storage and handled in a manner to avoid pickup of dirt, oils or moisture. Preparatory to molding, parts were heated in a stabilized oven at 225°F for 60 minutes. The molding machines conditions for molding nylon 11 were:

Melt temperature

Zone 1	445°F	(front)
Zone 2	450°F	(middle)
Zone 3	475°F	(rear)

Nozzle heater set at 85 percent of full voltage.

Molding pressure

Injection	650 psi gage; 9100 psi material pressure
Injection hold	450 psi gage; 6300 psi material pressure

Timers

Injection	20 seconds
Hold	5 seconds
Mold closed	20 seconds

Screw - General Purpose 10 oz.

Rotation	Fast
Injection	Slow

Mold Temperature	280°F
Overall cycle	2 minutes (45 sec preheat, 30 sec demold and reload, 45 sec clock times)

The molding granules were pre-dried for 8 hours at 80°C (175°F)

INJECTION MOLDING OF NYLON 12

Huels 1801 was the formulation used for the final injection molding trials. Material which was not received in sealed cans directly from the factory was given a pre-dry of 8 hours at 80°C (175°F). Projectiles which had been previously primed and protectively stored were then preheated in an oven for 60 minutes at 225°F. They were then used as inserts in the molding operation in the Buehler screw injection machine operating at the following settings:

Melt temperature

Zone 1	425°F (front)
Zone 2	435°F (middle)
Zone 3	450°F (rear)

Nozzle heater set at 80 percent of full voltage.

Molding pressure

Injection	820 psi gage; 11,480 psi material pressure
Injection hold	820 psi gage; 11,480 psi material pressure

Timers

Injection	20 seconds
Hold	5 seconds
Mold closed	20 seconds

Screw - General Purpose 10 oz.

Rotation	Fast
Injection	Slow

Mold Temperature	280°F
Overall cycle	2 minutes (45 sec preheat, 30 sec demold and reload, 45 sec clock times)

The molding granules were pre-dried for 8 hours at 80°C (175°F).

POST-MOLDING OPERATIONS

Following the injection molding operation, the projectiles are stored for the induction bonding operation. Good results have been achieved by bonding in the time period of 1/2 hour to 4 hours after molding, and it is also probable that the bonding operation could be postponed for a matter of days after molding, particularly if the projectiles were protectively packed against moisture; however, data on the effectiveness of the bond versus the delay time is incomplete, and hence a controlled experiment to establish the relationship is recommended. One of the significant variables will be the change in crystallinity of the nylon.

The induction bonding was done in two different machine units during the course of the project. Initial experimental series were done at C & W Heat Treat, East Hartford, Connecticut. The final lot of 500 moldings was done at D&R using a 5000-watt induction heat power unit by the RFC Corporation.

In each instance the electrode was wound with three overlapping coils of 3/16 inch diameter copper tubing. The diameter of the coil measured 1-1/4 inches inside diameter. The thickness (or height) of the electrode coil is pertinent in that it established the amount of heat at the edges of the rotating band. The preferred heating pattern was such that the clear melt pattern would show simultaneously over the whole rotating band interface and without overheating or overmelting the band itself. A heating cycle of approximately seven seconds is used to induce the heating. The projectile is then immersed in room temperature water to chill the melt and the projectile rapidly and to solidify the fused and primed interface between metal and nylon.

Figures 33, 34 and 35 show details of equipment and the manufacturing sequence.

FINAL MACHINING

The final machining consisted simply of trimming the ring gate and machining the preferred tapers at the leading edge and at the trailing edge. In later production, these tapers can be molded into place and the final finishing effort will simply be that of removing the gate section which could also be done in the mold if so chosen.

Because the optimum taper combination is not known, the two lots of projectiles (one lot of nylon 11 and one lot of nylon 12) were further divided into equal lots of two taper combinations. These tapers were:

Lot	Leading Edge Angle	Trailing Edge Angle
A	15 degrees	6 degrees
B	8 degrees	13 degrees

In each instance the angle is measured as the angular separation of the taper to the axis of the projectile.

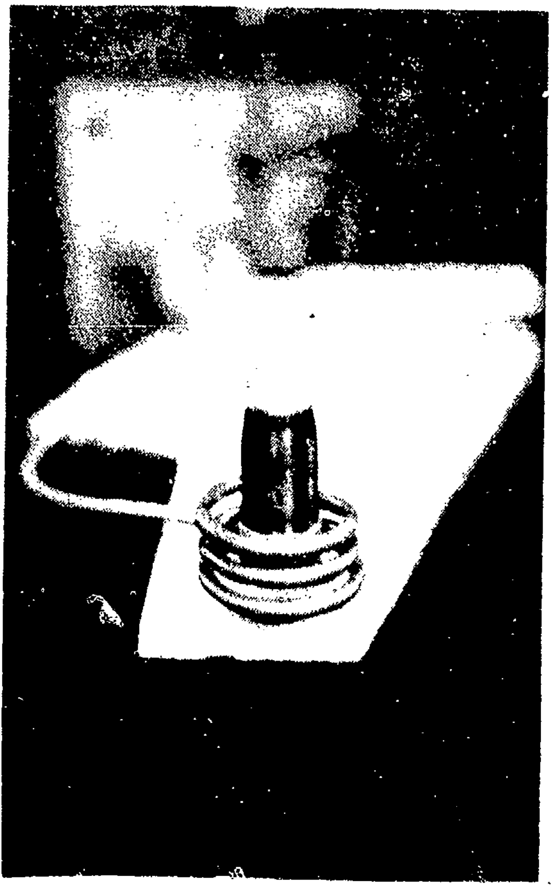


Figure 33. Coil For Induction Bonding With Projectile In Place

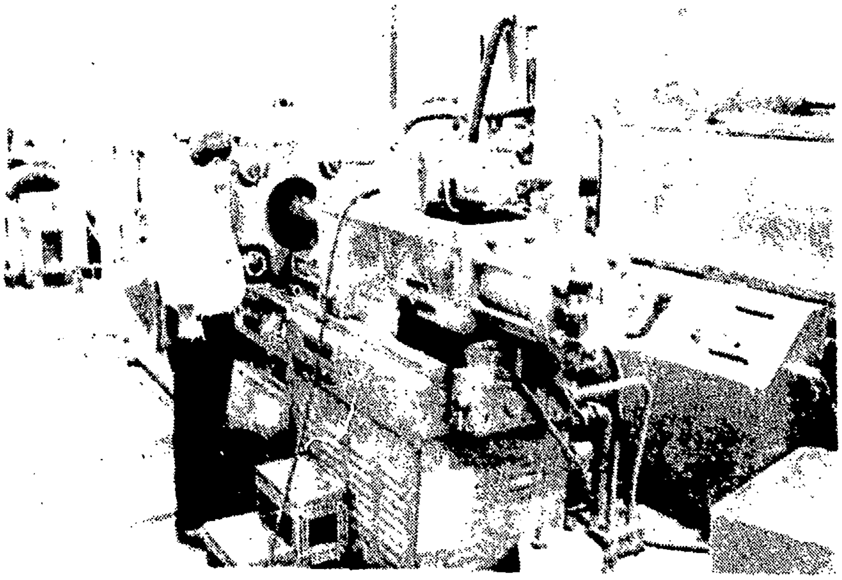


Figure 34. Injection Molding Press For Molding Rotating Bands

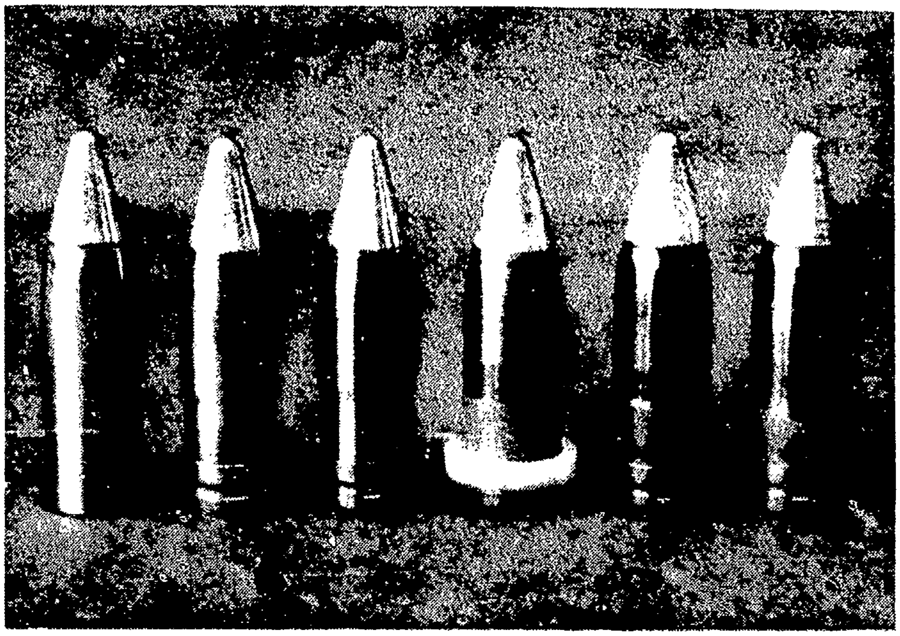


Figure 35. Stages In Process For Rotating Band Manufacture

Various Stages In Final Process

1. Projectile Blank
2. Machined groove and heel detail
3. Primed projectile
4. Molded in place and induction bonded nylon band
5. Final machining of band tapers in two styles

SECTION IV

EFFECT OF PLASTIC ROTATING BANDS ON INTERIOR BALLISTIC PERFORMANCE

A factor of major importance which must be considered in the ammunition usage of non-metallic rotating bands is the impact of the shot start pressure of the material on the interior ballistic cycle. The term "shot start" refers to the pressure at which the rotating band material will engrave and start the motion of the projectile. The chamber pressure at which projectile motion is initiated has as effect of major importance on the design of the ignition system and also the selection of the web of the main charge of propellant.

To illustrate the shot start pressure variability of different rotating band materials, the following shot start pressures for 30mm projectiles, in a GAU-8 size system, extracted from reference 1 are presented below:

Copper Band	11,000 PSI
Glass Filled Polyurethane Band	6,000 PSI
Polyarylene Band	5,000 PSI
Soft Iron Band	15,000 PSI

The very strong effect of non-metallic band lowered, shot start pressures is also demonstrated by the following series of firings in a high gage capacity (5 cubic inch) 20mm gun system. All projectile weights are 92 grams. The propellant type and web as well as the ignition system is identical for all shots. The results of this firing series were:

Band Type	Peak Pressure PSI	Muzzle Velocity Ft/Sec	Shot Start Pressure, PSI
Copper	53,750	3960	14,000
Soft Iron	54,100	3923	15,000
Nylon 12, 0.5 inch length	39,000	3821	11,000
Nylon 6/6, 0.3 inch length	35,300	3770	10,000

It is seen that with the lower plastic band shot start pressures, a drastic change has occurred in the interior ballistic cycle of an otherwise identical ammunition configuration. Thus, to compensate for the earlier motion in the non-metallic band, a thinner web main charge propellant is always required and a more energetic, faster acting ignition stimulus may be required. Alternatively, in the infrequent instance where excess chamber volume exists for a metallic band, a plastic band would allow a greater charge of the same web propellant. In this case for the nylon 12 band an increase of 7 grams of main charge propellant brought the chamber pressure up to 53,300 with an increase of muzzle velocity to 4,150 ft/sec.

In summation, it can be stated that plastic banded aircraft cannon projectiles have reached a design maturity where operational deployment is now possible. However, for satisfactory operation, the interior ballistic cycle differences caused by these non-metallic bands must be carefully considered during the ammunition ignition system and propellant selection process.

Ref: Heiney, O. K. "Interior Ballistic Characteristics GAU-8/9
30mm Ammunition" AFATL-TR-73-118 May 1973

SECTION V

CONCLUSIONS

The development work and test results indicate that a significant step has been achieved in further translating the use of plastics to high performance ordnance applications. The performance of these test projectiles has now exceeded the capability of metal bands at high velocities and, in addition, will cost less and offer considerably less wear in the gun barrel. Prior investigators speak of a phenomenal increase in gun barrel life due to the use of nylon rotating bands.

The process developed and used for the shaping of this 20mm rotating band makes optimum use of the nylon material and is a highly efficient and fast mass production method. Standard injection molding presses and induction heating equipment can be used, although the ultimate efficiency will come from a modification of this equipment to automatic molding and handling.

The principle of molding the band in place insures good conformance to the band seat. The principle of fusing the interface by means of induction heating offers greater range and closer control than would be available by a preheating of the insert before molding. However, this project was not extensive enough to select optimum conditions and controls or to develop automatic equipment.

SECTION VI

RECOMMENDATIONS

Significant progress has been made in the selection of materials and fabricating methods for manufacturing high performance plastic rotating bands for ammunition. There appear to be many incentives to improve and optimize this work to benefit from the lower costs and increased performance over metal bands.

The 20mm band should be further investigated to finalize the selection of materials, the identification and specification of controls on material and process variables, and the additional testing needed to confirm full performance.

The results of this program may suggest answers to similar problems and applications with ammunition of other sizes or in which the performance requirements indicate the need for a similar development of design, materials, and process to improve performance. The present availability of new types of plastic materials with high temperature resistance would offer additional scope to the range of applications which can be considered.

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APPENDIX A

EXCERPTS FROM PERTINENT TECHNICAL REPORTS

Development of 20mm and 30mm Plastic/Aluminum Cartridge Cases

Technical Report AFATL-TR-72-201 October 1972

Air Force Armament Laboratory, Eglin Air Force Base, Florida

Matthew G. Popik Robert W. Schnepfe

Molded plastic casings mechanically joined to aluminum bases were successfully fired in 20 and 30mm sizes at temperature extremes of 160°F and -65°F and at ambient. In 20mm, the weight saving over the standard M103 brass cartridge case is 0.186 lb per round. Compared to brass, the plastic case material is non-critical and inexpensive. For the 20mm cast, type 12 nylon (Huels No. L-1801) with 50 percent 1/4 inch long glass fibers mixed by Thermofil, Inc., Ypsalanti, Michigan, was used. The munition weight is: PAC case 38 grams; WC 870 propellant 37.3 grams; M55A2 Projectile 99 grams. Firing velocities of 3300 to 3400 fps were achieved and peak pressures of approximately 53,000 psi.

For the 30mm case, 43 percent glass filled 6/12 nylon (duPont Zytel 151) was used. Munition weights are: PAC case 153.7 grams; CIL 1379 C propellant 160 grams; T328 projectile (weighted) 324 grams. Peak pressure of 42,000 psi yielded velocities of 3500 fps.

Comments on the development of the 20mm case: Unfilled polyethylene and 30 percent glass-filled polyethylene from duPont showed circumferential failures in the joint area. The 6/6 nylon with 40 percent glass was too brittle to allow assembly of the projectile into the case without cracking. The 6/12 nylon with 43 percent glass showed best performance of these materials. Attempts to bond the projectile into the case with epoxy were unsuccessful compared to the use of a molded shear ring. Adjustment of the size of the shear ring and the fit of the case in the gun barrel proved sensitive to prevent failure of the end of the plastic case. Details of the dimensions of the case and base are shown; also details of the gating methods for the plastic case. Test firings hot performed well, but a large percentage of the -65°F firings cracked longitudinally; reduction of glass from 43 to 25 percent did not help. Polycarbonate cases (Lexan 191) did not crack at -65°F but broke at the retention ring of the projectile. At 160°F the cases were distorted in the delinking feed operation of the gun; the delinking ramp cracked the middle wall; once delinked, however, the cases could be chambered, fired and extracted normally at 160°F. Stress crazing of polycarbonate from chlorinated hydrocarbons was feared and the material was considered only as a back-up material.

To solve cracking at low temperature, adjustments were made in the fit and angle of the front end of the case. Moldings from 6/12 nylon/43 percent glass were annealed in Primol 355 at 350°F for 20 minutes as recommended by duPont; this did not improve performance. Similarly, annealing in an oven at 200°F and at 300°F and in boiling water were tried but did not help. Trials were made with propellants with flatter pressure time curves but the only lessened cracking was from lower velocities. In these trials, silicone rubber, epoxy and polysulfide rubber were tried as sealants between the case and base for moisture sealing; the sealant was also used to seal the neck/projectile interface. The case joint by itself is a good seal, and the sealant trials were also successful.

LNP 6/12 nylon/45 percent glass and Fiberfil 6/10 nylon/40 percent glass were tried for low temperature performance; neither was successful. The potential advantages of using polyarylsulfone (3M) were outweighed by the difficulty of molding (40 to 50M psi and 450°F mold) and price ($25/lb); it was not tried. At the end of the regular contract Zytel 77G43 was the favored material but still showed 40 percent splitting at -65°F.

In an extension of the work contract, the fit of the case to the gun barrel was improved a matter of a few thousandths of an inch, resulting in an elimination of burn throughs and a reduction of cold cracks from 30 percent to 10 percent. A new core was made with a different gate to improve glass dispersion, a change to eliminate one buttress groove at the base (2 instead of 3), and a molded instead of machined retention bead. New Materials were also tried:

Tenite PTMT unfilled--6 cases cracked at -65°F
Tenite PTMT 20 percent glass--6 cases cracked at -65°F
Huels type 12 nylon/30 percent glass--5 of 6 cases broken in delinking from high friction; remaining round was fired with no case damage.

Celanese X917/30 percent glass--cases cracked during assembly indicating extreme brittleness. (non-glass filled materials shrink more and therefore create tighter fits; i.e., PTMT above).

7075-T6 aluminum alloy is the preferred metal for the machined base of the PAC case.

Lexan polycarbonate was again tried with 4 and 8 percent glass (Lexan 141) to split the difference in previous trials of unfilled and 20 percent glass materials. The -65° firings were satisfactory, but the high temperature firings failed in tension. Lexan 500 with 10 percent glass gave 12 firings at -65°F without failure and 5 out of 6 failed at 160°F by separating at the joint. Testing with polycarbonate was discontinued.

Valox 420 with 30 percent glass failed at -65°F.

Tefzel ETFE fluoropolymer unfilled and with 25 percent glass was tried; the higher shrinkage posed a fit problem. Firing at -65°F gave a 15 percent failure because of undersize cases. A corrected size case might be satisfactory, but the cost of Tefzel at $6.50 per pound does not make further trials attractive.

Trials with duPont FE 5024 nylon 6/12 (modified) with 43 percent glass showed failure rate of 67 percent at -65°F. The modified resin has added tougheners. The 6/12 nylon with 50 percent glass (duPont FE 5030) was then tried and gave the best performance to date, with 20 good firings at -20°F and 10 at 160°F (100 percent). However, in subsequent retrials failures were experienced at -65°F and the material and molding was suspect. A raise in melt temperature from 510°F to 560°F was recommended by duPont and 1 case in 12 cracked. A new lot of material was kept dry (0.024 percent moisture) and molded at the higher melt temperature; 8 cracked of 50 fired at -65°F. Cases were then coated with Teflon and Xylon to reduce friction but the use of coatings does not look promising; failure rate continued high.

Type 12 nylon (Huels) with 30 percent 0.25 inch long glass fibre was used instead of the 0.125 inch fibre previously tried. Two failed of 25 at -65°F. When fired hot the cases lacked tensile strength.

The mold core was modified to give a thicker case wall. Moldings were then made from 6/12 nylon with 50 percent glass and from nylon 12 with 50 percent glass. The cases experienced failures at -65°F, and a correlation was noted between a smaller diameter at the small end of the body and the failures. The mold was increased 0.0045 inch in diameter at this point. The 6/12/50 percent glass molded cases still showed failure but the type 12 nylon/50 percent glass fired 100 pounds at -65°F without failure. Nineteen at 160°F were also successful. The latter material was considered most successful and was stipulated. It is designated Thermofil N9-5000-FG.

In a brief review of the 30mm PAC cases, 6/12 nylon with 43 percent glass was the preferred material at the beginning of the trials. At 3500 fps and pressures of 40,000 psi, it gave ten good firings, establishing basic feasibility. At -65°F problems occurred with the primer and the firing time. A booster was used which raised velocity to 3500 fps. Seven firings at ambient and six at -65°F performed well.

Drawings of 20 and 30mm PAC constructions and of the molds for the 20 and 30mm cases are shown in the report.

Philco-Ford Report, 15 November 1972, No. 725331, GAU-7/A Process Specification, "Process Selection and Identification Guide for Plastic Projectile Rotating Band"

This report is a reference index showing the marking system used for samples. The listing of adhesives and molding compounds is of interest and is as follows:

Adhesives

1. NARMCO No. 332 liquid; roller and spray coat
2. 3M AF-42 film, 0.003 inch (with and without BR-1009-49 primer)
3. Emerson and Cumings polyamide epoxy No. 45 Eccobond
4. Stabond Rubber Products No. U136 for urethane and nylon
5. Dayton Chemical (Thixon) AB-936
6. American Cyanamid No. FM1045
7. American Cyanamid No. FM1000 film, 0.005 inch with BR-1009-49 primer
8. du Pont Elvamid EA-8018
9. du Pont Elvamid PB-8019
10. du Pont Elvamid 8061, (with and without Shell 828 and Dicy)
11. Poly-EP No. 810 clear A&B
12. 3M EC 1022
13. Thixon AB-1153
14. Eccobond 787A, Cat. No. 9, 100/14 mix
15. Eccocoat C26
16. FM123 OST

Plastic Materials

1.	LNP No. 1F 1004	20 percent glass filled, non-lubricated
2.	LNP No. 1F 1003	31 percent glass filled, non-lubricated
3.	LNP No. 1F 1002	10 percent glass filled, non-lubricated
4.	LNP No. 1F 1002 (East)	10 percent glass filled, (supplied by Avco)
5.	LNP No. 1F 1002	8 percent glass filled, non-lubricated
6.	LNP No. 1F 1001	4 percent glass filled, non-lubricated
7.	LNP No. 1F 1001	5.6 percent glass filled, non-lubricated
8.	Type 6/6 nylon	30 percent glass filled (1/3) plus 6/6 nylon 0 percent glass filled (2/3)

9.	Type 6/6 nylon	No glass, Zytel 408, non-lubricated
10.	Type 6/12 nylon	No glass, Zytel 158, non-lubricated (0.10 - 0.25 percent moisture content, as received, with no additional drying)
11.	Type 6/6 nylon	30 percent glass, Nypel GS 30
12.	Type 6/6 nylon	No glass, Zytel 101-L1, non-lubricated
13.	2/3 of (12) and 1/3 of (11)	
14.	Type 612 nylon	No glass, Zytel 158, non-lubricated (vacuum dried to 0.1 percent moisture or less)
15.	Type 6/6 nylon	No glass, Zytel 103HS, non-lubricated
16.	Polyurethane LNP TF 1004	10 percent glass
17.	Polyurethane #902 Mobay Chemical Co.	No glass
18.	Type 6/6 nylon	40 percent mineral filled, Minlon 10A-40, non-lubricated

Philco-Ford Report, 15 November 1972, No. 725332, GAU-7/A
Process Specification, "Process Record for
Plastic Projectile Rotating Band"

This report consists merely of 3 blank data forms which can be used to record the processing of plastic rotating bands.

Philco-Ford Report, 15 November 1972, No. 725333, GAU-7/A Process Specification, "Application of Nylon 6/12 Rotating Band to GAU-7/A 25mm Projectile"

Applicable specifications, handling and safety precautions, lot identification and materials requirements are covered. Nylon shall be unfilled nylon 6/12, natural color, non-lubricated; sole source is du Pont Zytel 158. Maximum moisture content shall be 0.25 percent. Adhesive shall be nylon-epoxy FM-1000 film adhesive and BR-1009-49 primer. Aluminum oxide shall be 120-150 grit. Caustic cleaner shall be Parko Cleaner No. 303 manufactured by Parker Division of Hooker Chemical Corporation, Maywood, California.

The process sequence shall be:

1. Solvent wash in wire basket in room temperature trichloroethylene.
2. Solvent spray rinse: spray rinse washed projectiles with clean trichloroethylene.
3. Ultrasonic cleaning: place projectiles on base end in ultrasonic cleaner containing Parko No. 303 Cleaner at 180°F; use 34 grams to one quart deionized distilled water. Fluid level shall be at least 1/2 inch above band seat area. Activate for 30-second minimum and follow with 10 minute soak. Replace solution after cleaning each lot.
4. Water rinse: agitate in distilled water for 10 minutes followed by forced hot-air dry.
5. Sandblast: do this step not more than 2 hours before coating adhesive to projectiles. Mask projectile adjacent to band seat area; use 120 to 150 grit virgin aluminum oxide. Sandblast clean and uniformly; take care not to entrain water or oil in air supply.
6. Solvent wash: repeat step 1.
7. Ultrasonic cleaning: repeat step 3.
8. Solvent spray rinse: repeat step 2.

9. Adhesive application: brush a uniform coat of BR-1009-49 primer having 20 percent solids content. After primer becomes tacky in approximately 10 minutes, apply firmly one wrap of FM1000 film adhesive with up to 0.06 inch overlay.

Instructions for injection molding of the bands include:

a. Melt temperature shall be 580°F plus or minus 10°F measured by pyrometer in the melt.

b. Vacuum dry polymer at 175°F maximum to moisture content of 0.1 percent or less.

c. Air to hopper shall not exceed 170°F and a dewpoint of 32°F.

To assemble, the steel cover sleeve is placed over the nylon band which is assembled over the adhesively coated projectile. Place in oven at 340 to 350°F for 60 minutes. Cool to 150°F before removing the outer sleeve. Machine rotating band and package.

Philco-Ford Report, 27 November 1972, GAU-7/A Process Specification No. 725334, "Adhesive, Nylon Epoxy-Film/Phenolic Epoxy Primer"

Adhesive film shall be a white elastomeric film formulated and processed to meet requirements. Thickness shall be 0.005 ±0.001 inch. The film shall be supplied in 0.990 to 0.060-inch-wide rolls in 50-foot minimum lengths.

The tack primer shall be sprayable low viscosity primer for the specific use of heat tacking the adhesive film prior to bonding. The material shall be a natural (amber) color unless otherwise specified. The primer shall have a solids content of 20 ± 2 percent.

The above system is intended to bond injection molded nylon to steel. The test specified is performed with 0.064 inch thick Alclad 2024-T3 bonded 0.5 inch depth with film and primer and cured for 60 minutes at 350°F with 25 psi pressure. Minimum tensile shear shall be 5000 psi at -67° and 75°F, and 3000 psi at 180°F, and 4000 psi after 30 days at 165°F 95 percent relative humidity. The "T" peel strength shall be 90 lb/in. min on 0.020 inch 2024-T3 Alclad.

Philco-Ford Report, 21 November 1972, GAU-7/A
Process Specification No. 725335, "Nylon Polymer"

The material shall be type 6/12 nylon resin formulated and processed to meet the requirements of this specification. The material shall be natural color unless otherwise specified. Property requirements are:

	-40°F	73°F	170°F
Tensile strength, min psi	13,600	8,800	5,900
Yield stress, min psi	13,600	8,800	4,300
Elongation at break, min percent	15	150	
Elongation at yield, min percent	8	7	
Shear strength, min psi		8,600	
Izod impact, min ft lb/in.	0.9	1.0	
Melting point (Fisher-Johns)		406 - 420°F	
Coefficient of linear thermal expansion, max in./in.°F		5×10^{-5}	
Specific gravity		1.06 - 1.08	
Hardness, Rockwell R		R114	
Water absorption (saturation) percent		3.0	

NPG Report No. 1342 "Development and Test Of Nylon Rotating Band For 20mm High Velocity Projectile," 10 March 1955

Work to date has indicated excellent performance of nylon bands in slow fire for a Mk 12 gun at muzzle velocities up to 3500 ft/sec and at temperatures from -65°F to +160°F. This report extends the development and testing.

Lot 4A and Lot 4B were fired at -65°F and +160°F. Lot 4A was molded at a mold temperature of 190°F and a projectile temperature of 160°F, and lot 4B at 60°F mold and projectile at 75°F. Both lots were 0.3 inch length bands molded on Type 2 Mod 2 projectiles. Three conditioning cycles were used:

1. Dry at 160°F for 7 days, ambient for 24 hours, -65°F for 4 hours, fired at -65°F.

2. -65°F for 4 hours, +160°F (dry) for 4 hours, ambient for 16 hours; this cycle was repeated seven times. Projectiles were brought to -65°F for 4 hours and fired.

3. 160°F and 100 percent relative humidity for seven days, fired at 160°F.

Of 20 projectiles from lot 4A fired at -65°F (conditions 1 and 2) six showed some band loss.

The 0.2 inch long band is judged too short, and all work will be done with a 0.3 inch long band length.

Pressure time data shows that the peak pressure for nylon banded projectiles is 1 or 2 tons lower than metal bands. This is attributed to the lower engraving force and diminished bore friction for nylon.

Accuracy of the nylon-banded projectiles is not as good as for the metal banded shots, perhaps because of some degree of fringing. The disadvantage is not considered great in light of the other advantages.

Various rapid fire tests and firing in a hot gun showed acceptable performance for the nylon bands. Phenomenal increase in barrel life observed with nylon bands in plated barrels confirms previous observations.

NPG Report 1357, "Development of Nylon Rotating Bands: Artificial Aging Tests," 25 March 1955

The nylon rotating band developed for the 20mm high performance aircraft gun Mk 12, which had previously shown excellent performance in the gun, has been subjected to artificial aging followed by firing tests to obtain some information on the storage life to be expected of it. The artificial aging was conducted at 150°F or at 160°F and at 95 to 100 percent relative humidity for periods up to 16 weeks. The results tend to indicate that the storage life of this band under service conditions will be adequate. Mold temperature tests indicate superior performance for nylon bands produced in cool molds. Limited tests of injection molded pvc bands in the Mk 12 gun showed satisfactory ballistic performance as regards projectile spin and band retention.

In July 1952 an informal report from the United Kingdom indicated that artificial aging of nylon under high temperature and high humidity gave marked deterioration of the properties of the material. Therefore, 20 nylon banded 20mm projectiles were stored 3 months at 160°F and 95 to 100 percent relative humidity; some bands and rings were coated with plastic waterproofing material. The uncoated rings turned brown in color and were extremely brittle. The brown discoloration was 20 to 30 mils deep and when removed by machining the ring regained its original ductility. The coated rings did not turn brown or become brittle. Hardness of both coated and uncoated rings decreased considerably from exposure but was regained after 10 days standing in the laboratory. The bands grew 0.005 inch diameter from exposure and sustained firing trials at ambient and 160°F, but bands were lost when fired at -65°F. Diametral increase of 0.005 inch persisted after 10 days drying and regain of hardness. For this trial, the quality of the nylon was suspect.

Further information on the British test showed that ICI nylon grade AF was used, and injection molded specimens exposed to 140°F and 95 to 100 percent relative humidity for 3 months became embrittled and degraded. The molding powder was brown, making it suspect.

A second exposure trial was planned with both projectiles and molded tensile and impact specimens and spare rings. The projectiles banded were Type 2 Mod 2 nominal band diameter of 0.828 inch. Previous experience with nylon FM 10001 bands were preferentially molded at low mold temperature and lower ram hold time. The test projectiles were molded and divided into 3 lots: Lot A was fired soon after molding;

Lots B and C were conditioned for 10 and 16 weeks at 150°F and 95 to 100 percent relative humidity; Lot C was similarly conditioned for 16 weeks. Lot B projectiles were not dried after aging, and Lot C was dried.

Lot A projectiles were divided into 3 lots and fired at -65°F (AL), ambient (AM) and +160°F (AH). The performance for all three groups was highly satisfactory.

After 10 weeks of aging, portions of lots B and C were withdrawn for test; C projectiles were dried one week in a desiccator at 77°F and another week at 77°F and 50 percent relative humidity. Similarly, after 16 weeks the remaining samples were divided into B and C lots. Various problems in firing were experienced associated with heavy rust on the steel and an enlarged diameter at the sprue gate ring which was not fully cleaned to size. After various adjustments, all lots fired satisfactorily except the 16-week samples fired without drying at 160°F. This group showed 59 percent band retention and spin of 63 to 97 percent of nominal.

A separate report is understood to show that the samples exposed and tested separately showed marked deterioration early in the aging period.

Mold temperature effect

Bands were molded on projectiles at three mold temperatures: 60°F, 140°F and 200°F. They were fired at -65°F. Ten firings of each type showed no band loss for 60°F molding; one band loss for the 140°F molding; and three band losses for the 200°F mold. Mold temperatures of 60°F were recommended and used for production.

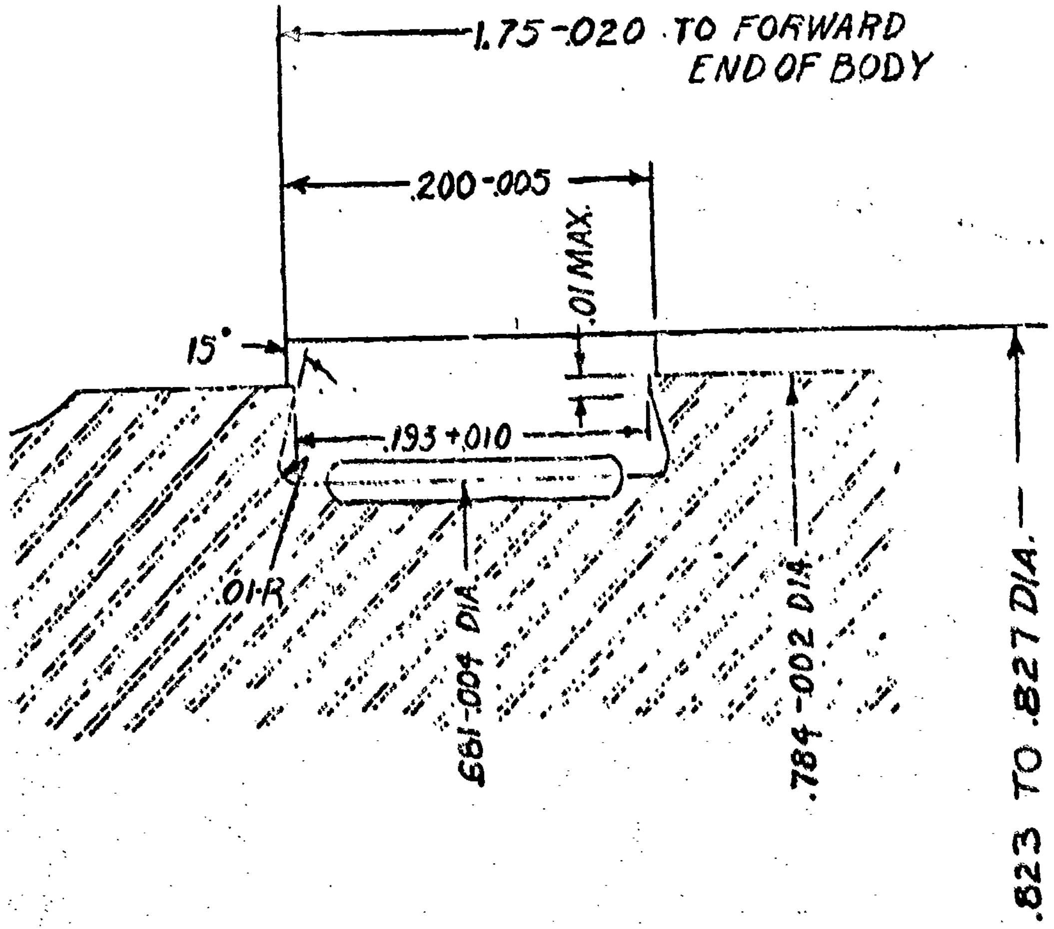
Polyvinyl chloride bands

Bands were molded of Exon 402A (Firestone) and Geon 8700A (Goodrich). The bands were molded in a Jackson and Church machine. Firings at -60°F and -65°F and +160°F and ambient were successful. Geon bands engraved slightly better and retained better; they also showed slightly more fringing when fired at 160°F.

First Partial Report on Nylon Rotating Band for 20 mm High Velocity Projectile Project NPG-Re3b-225-1-53 Feb. 28, 1953

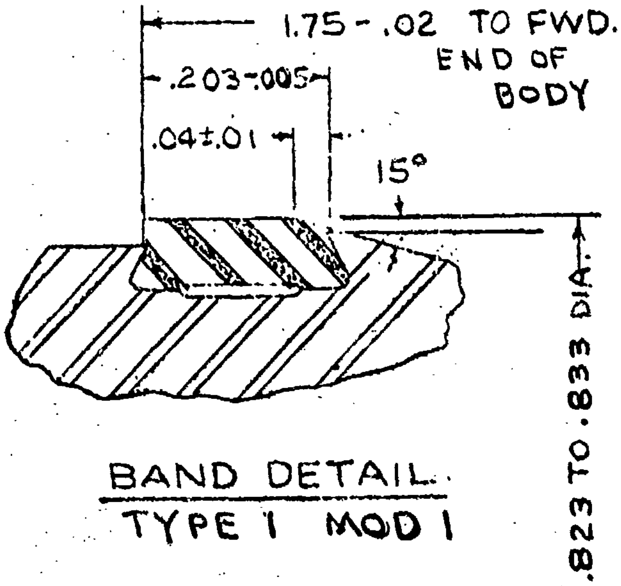
Summary: Nylon rotating bands have been developed which impart full spin to the projectile, obturate satisfactorily and do not fringe, or produce yaw to an unacceptable extent, in a 20 mm Mk 12 gun at muzzle velocities up to 3500 ft./sec., over a temperature range from -65°F to + 160°F. These models appear, on the basis of a relatively small amount of firing, to be completely retained in flight even at the temperature extremes.

Type 1 band is .2" wide and Type 2 band is .3" wide. First trials with Type 1 band were with these sizes:



20 MM PROJECTILE
TYPE I MOD. O.

Note: **Drawings included in this abstract are taken directly from the original report.**

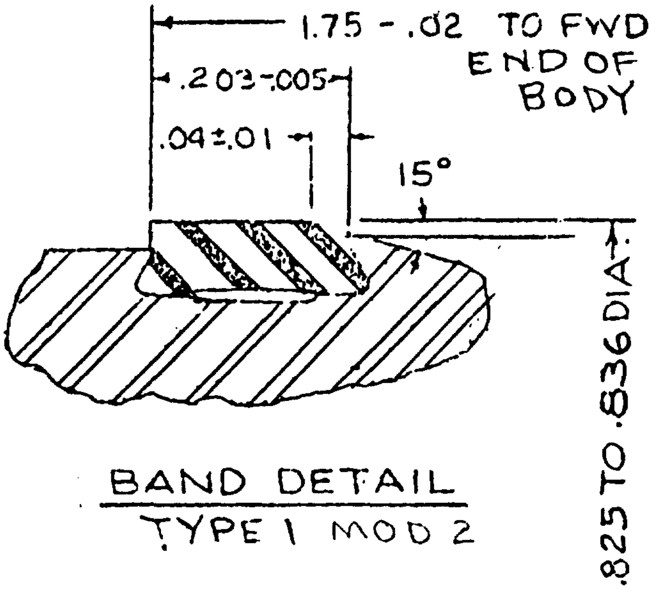


BAND DETAIL
TYPE 1 MOD 1

Both designs failed; they did not produce full spin, fringed badly and came off near the muzzle. These bands were very soft -- about 9 BHN. Previous good experience with nylon were harder -- about 15 BHN. Hardnesses to 20 BHN show improvement; full spin is imparted and some of the band is retained. Fringing is still severe and the bands show some wear. The soft samples were made by molding and then boiling in water which accounted for the softness of the nylon; the trials at 20 BHN were accomplished by drying the samples before firing.

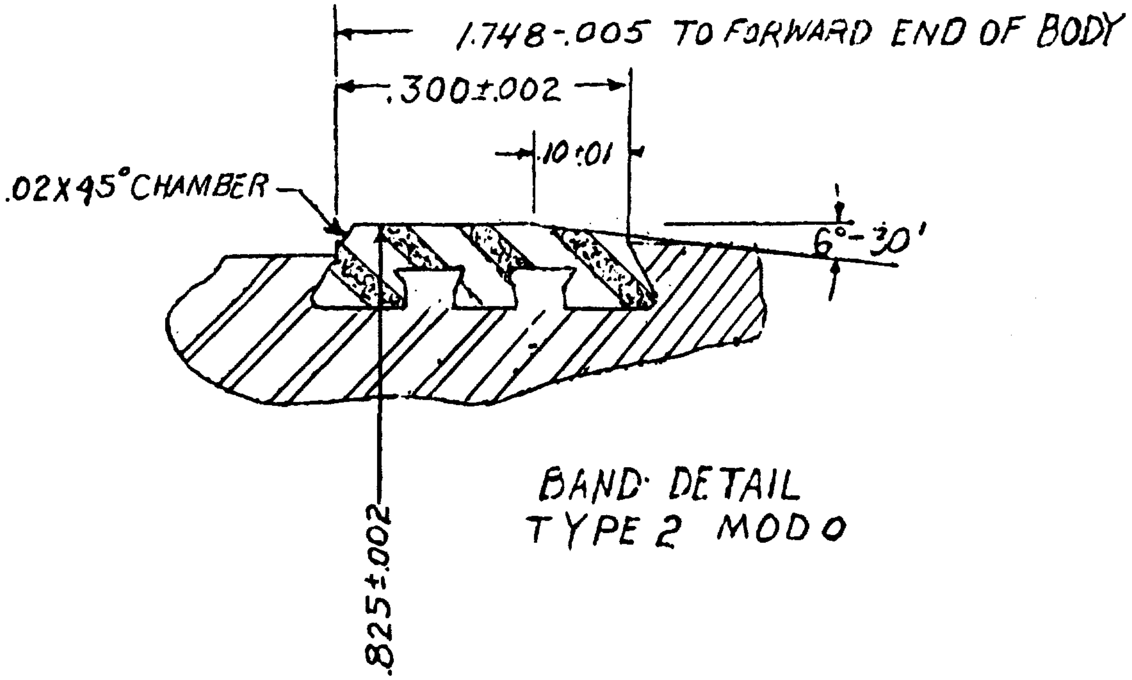
Note: **Drawings included in this abstract are taken directly from the original report.**

In Phase 2, Type 1 design was modified to Mod 2 by changing the undercut at each end to 30 degrees and adding a 15 degree taper .04" long at the forward end:



BAND DETAIL
TYPE 1 MOD 2

Also, a Type 2 Mod O was designed with a band length of .3". Since this creates a longer span, central undercuts were added:

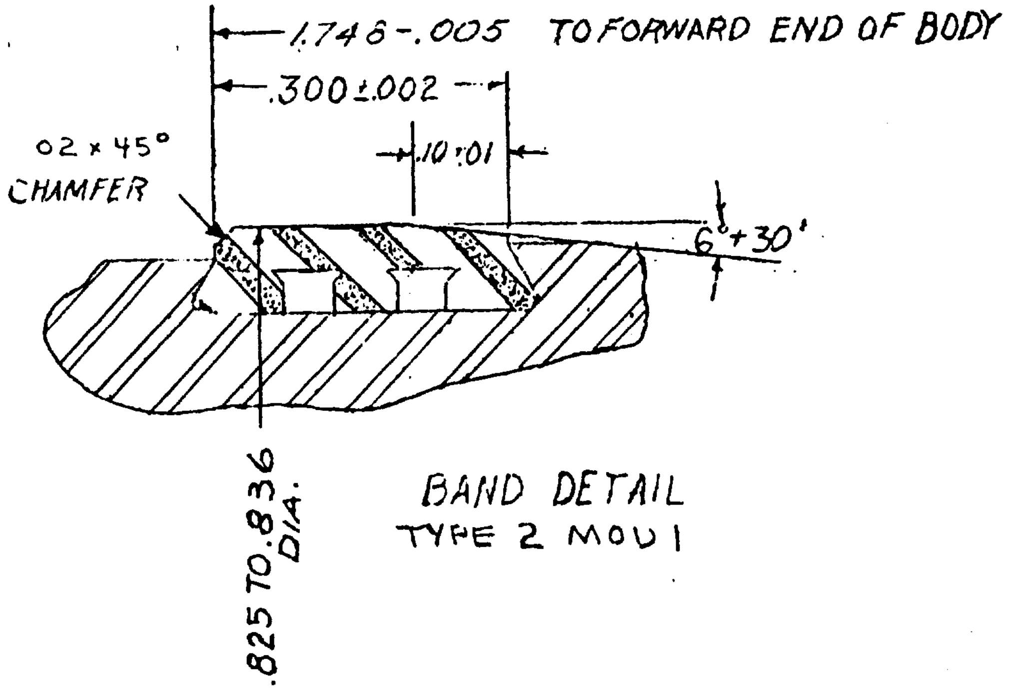


BAND DETAIL
TYPE 2 MOD O

Note: Drawings included in this abstract are taken directly from the original report.

The firing results of these two types were satisfactory. Full spin was attained and only 1 round of 25 lost any band. Two Type 1 Mod 2 rounds which had been boiled lost their bands, confirming the need to omit this step. Band diameters varied from .825" to .836" with no significant difference in results. Fringing was less on the Type 2 Mod O design.

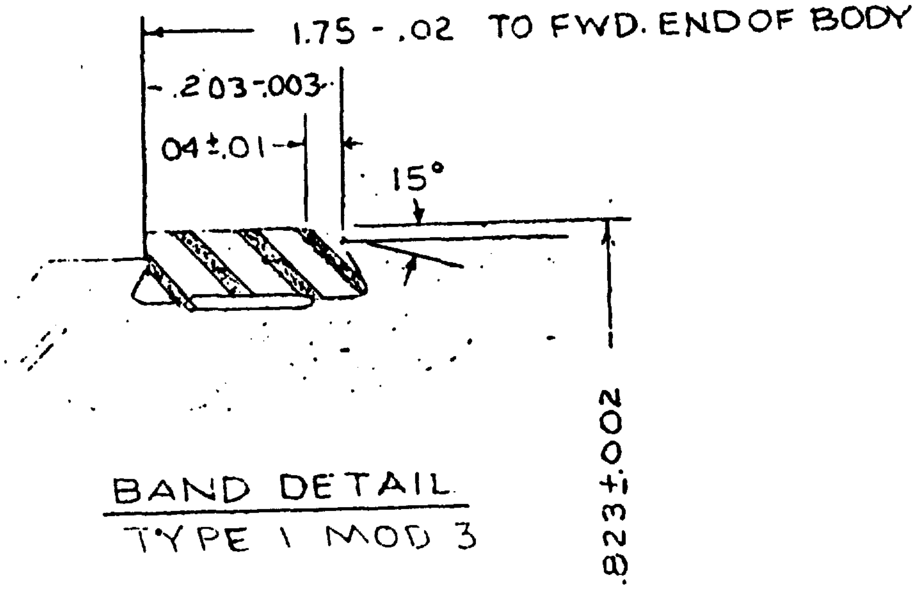
In Phase 3, Type 2 Mod 1 samples were made with shallower band seats:



The first 5 rounds showed considerable band wear but good spin and retention at .825" and .828" diameter. 6 more rounds at .830" and .836" diameter were fired and band wear decreased but also decreased band retention. 3 rounds each were fired at .825" diameter at ± 160°F and -65°F; results were not good and the thin band seat work will be discontinued.

Note: Drawings included in this abstract are taken directly from the original report.

In Phase 4, lots of Type 2 Mod O and Type 1 Mod 3 were molded to size. The latter differs from Mod 2 by molding bands to .823" diameter:

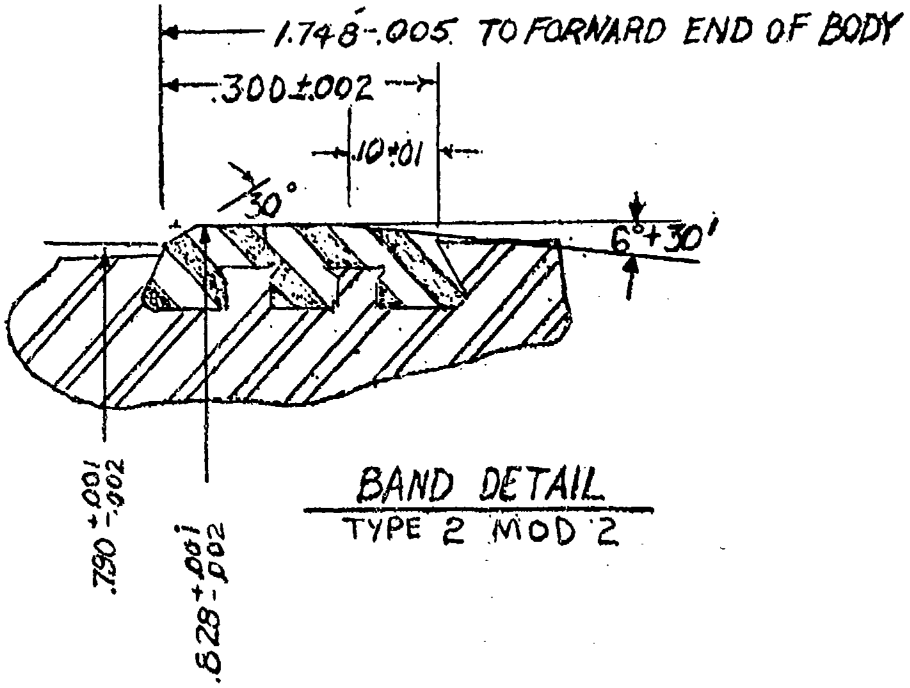


BAND DETAIL
TYPE 1 MOD 3

5 rounds were fired: 1 failed to give full spin and 4 showed band wear. Retention was complete and fringing small. The 5 rounds of Type 2 Mod O with molded finish gave full spin and complete retention. 3 had bad welds molded deliberately. 3 of each of Type 2 Mod O fired at -65 F and + 160 F gave poor results.

Note: Drawings included in this abstract are taken directly from the original report.

In Phase 5, the molded diameter was increased to .828" and the after taper was increased to reduce fringing. This is Type 2 Mod 2:

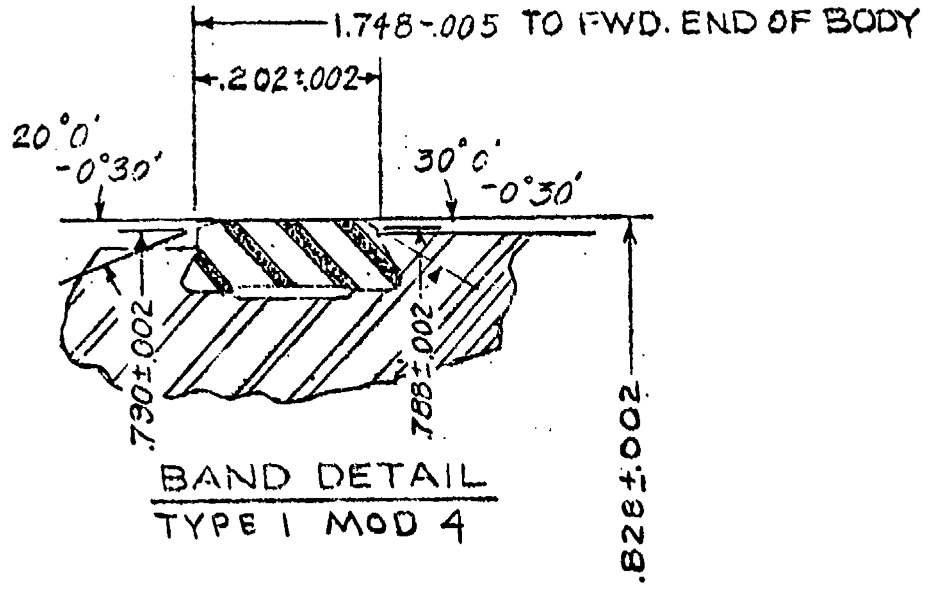


BAND DETAIL
TYPE 2 MOD 2

Molded samples were divided into Lot 4, molded the same as Type 2 Mod O, and Lot 4B, molded at a lower temperature. 3 rounds of each type fired at ambient performed well. 5 of each were then fired at -65°F and +160°F. Bands of the Lot 4B were retained, as was 4A fired hot. In cold firing, 2 bands of 4A were lost. The decrease in mold temperature appears to be beneficial.

Note: Drawings included in this abstract are taken directly from the original report.

In Phase 6, the .3" bands appear to have greater yaw than the .2" bands. Hence Type 1 Mod 4 variation of the .2" band was compared with Type 2 Mod 2 and the metal band. Type 1 Mod 4 is shown:



BAND DETAIL
TYPE 1 MOD 4

After the firing trials, no difference in the yaw was detected and previous results are unexplained. It is believed that these latter two designs will be satisfactory for performance trials. The .2 and .3" long bands are both being kept in development for further investigation of gun wear, etc.

Note: Drawings included in this abstract are taken directly from the original report.

APPENDIX B

DRAWINGS, AND NOTEBOOK PAGE RECORDS

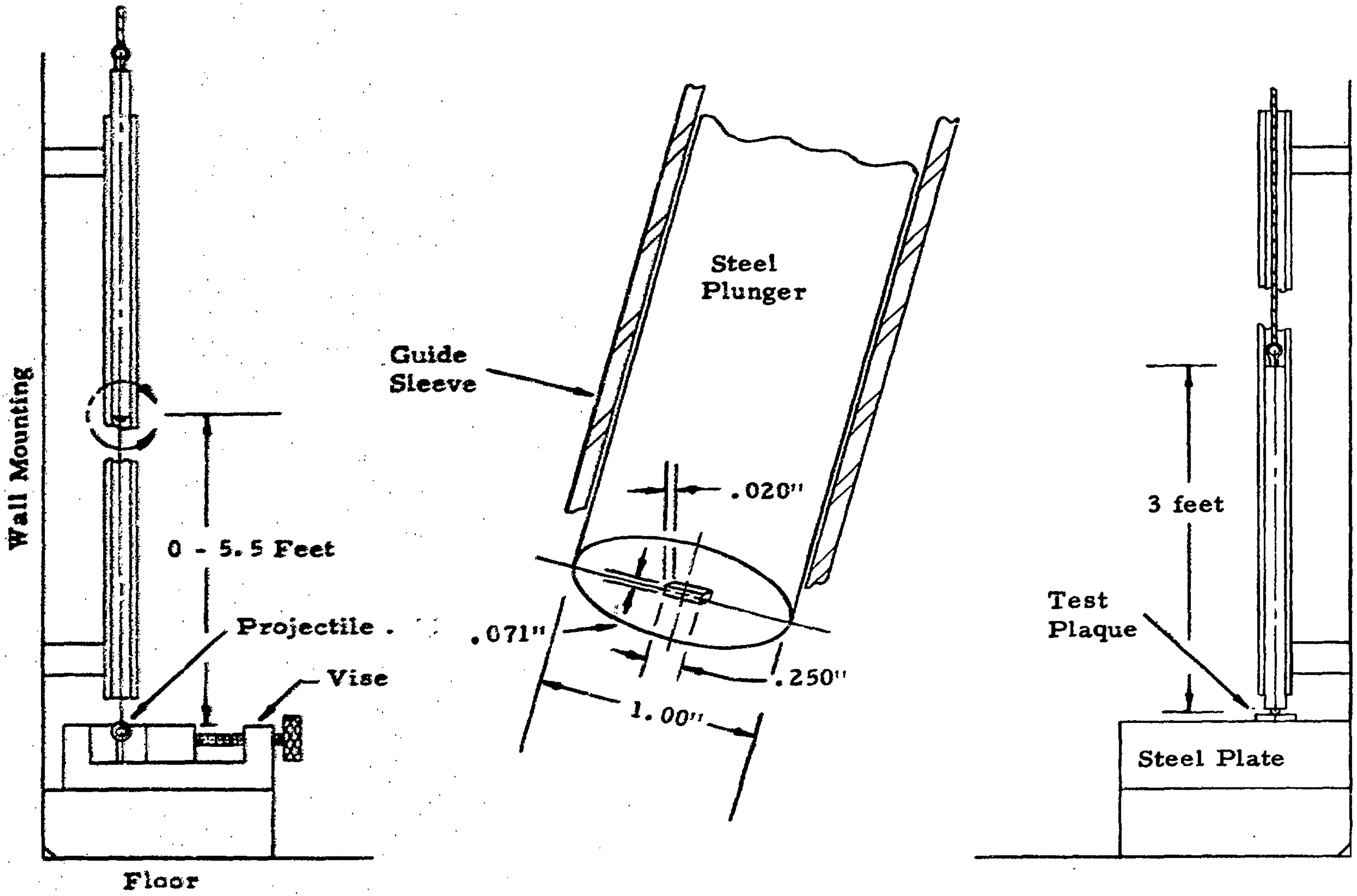


Figure 36. Modified Gardner Impacting Device

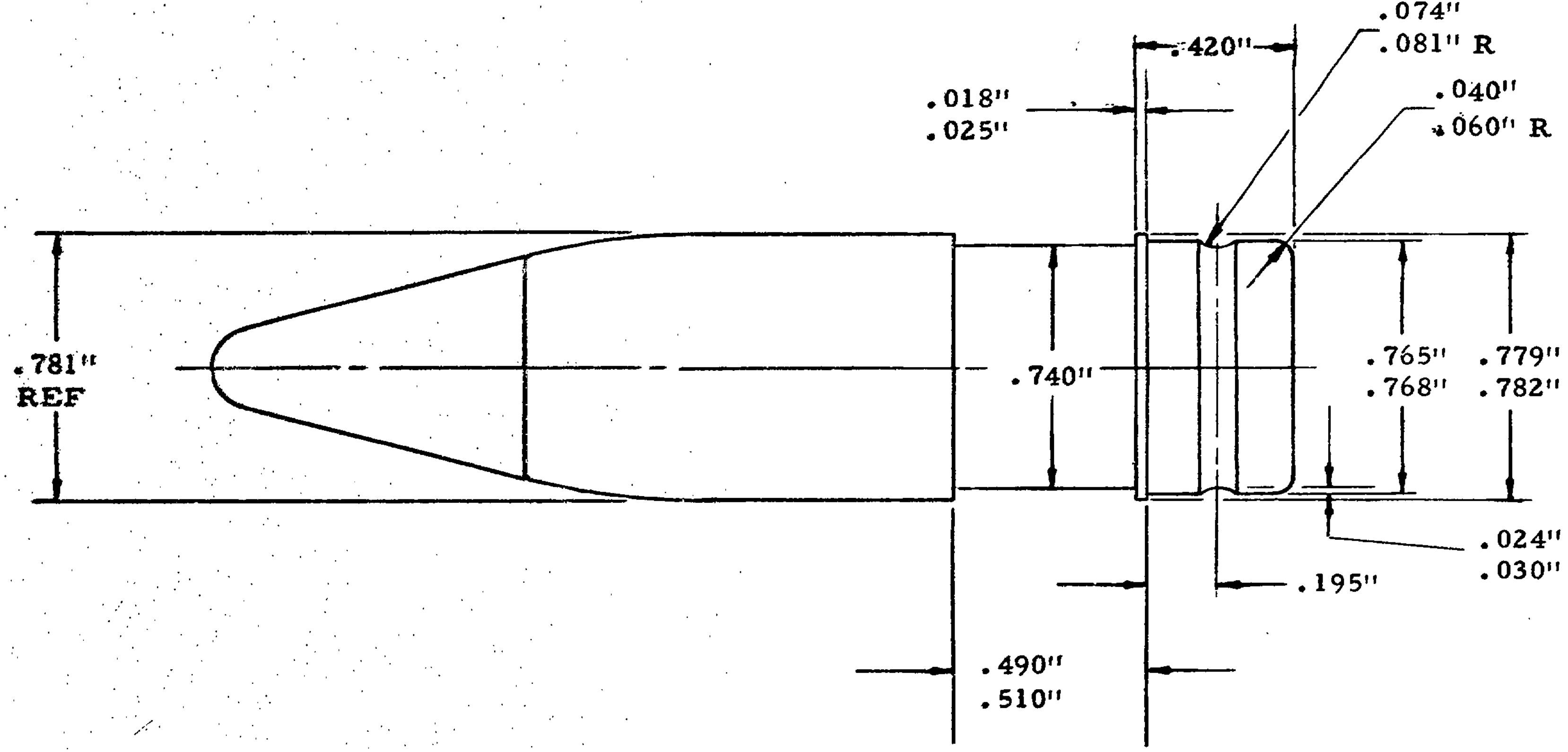


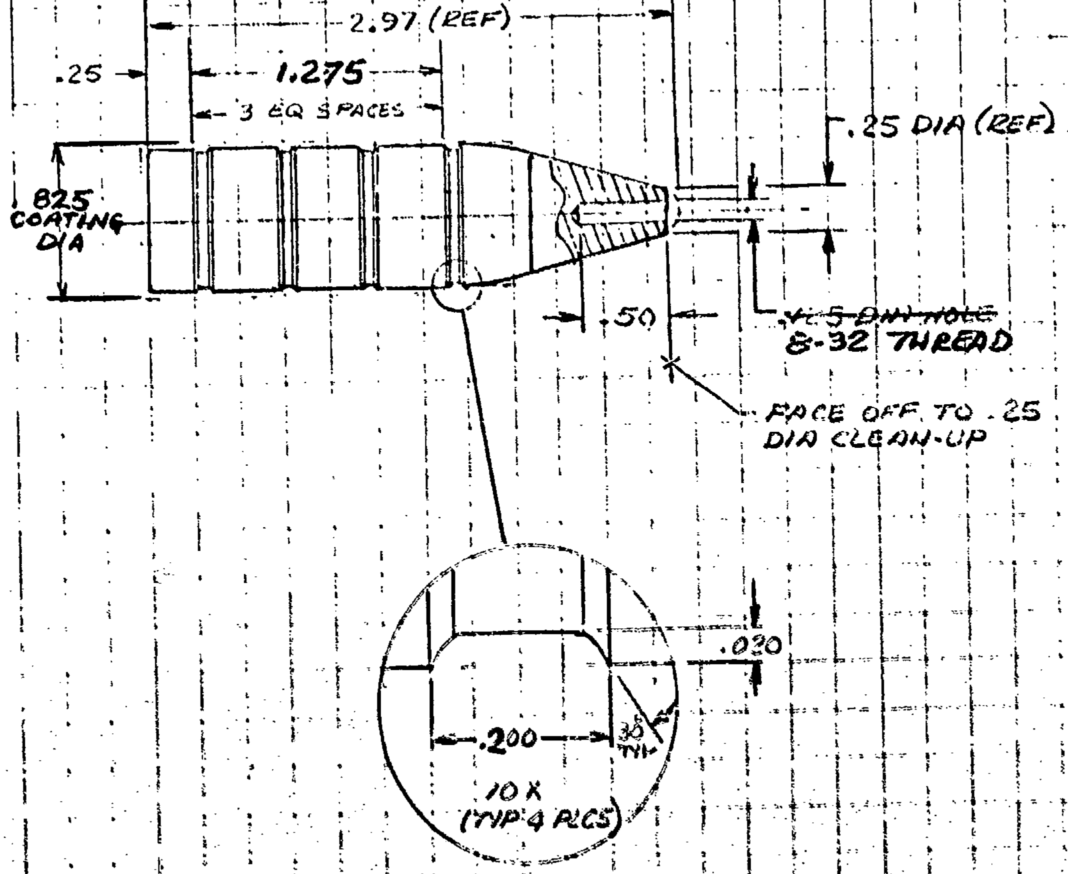
Figure 37. Anchorage Groove

DeBELL & RICHARDSON Nº 107652

PROJECT NAME EGLIN AFB - DEPT OF ARMY PROJECT NO. 6046.1

BULLET SHAPE FOR FLUID BED COAT DATE 4-12-73

REV. 4-25-73



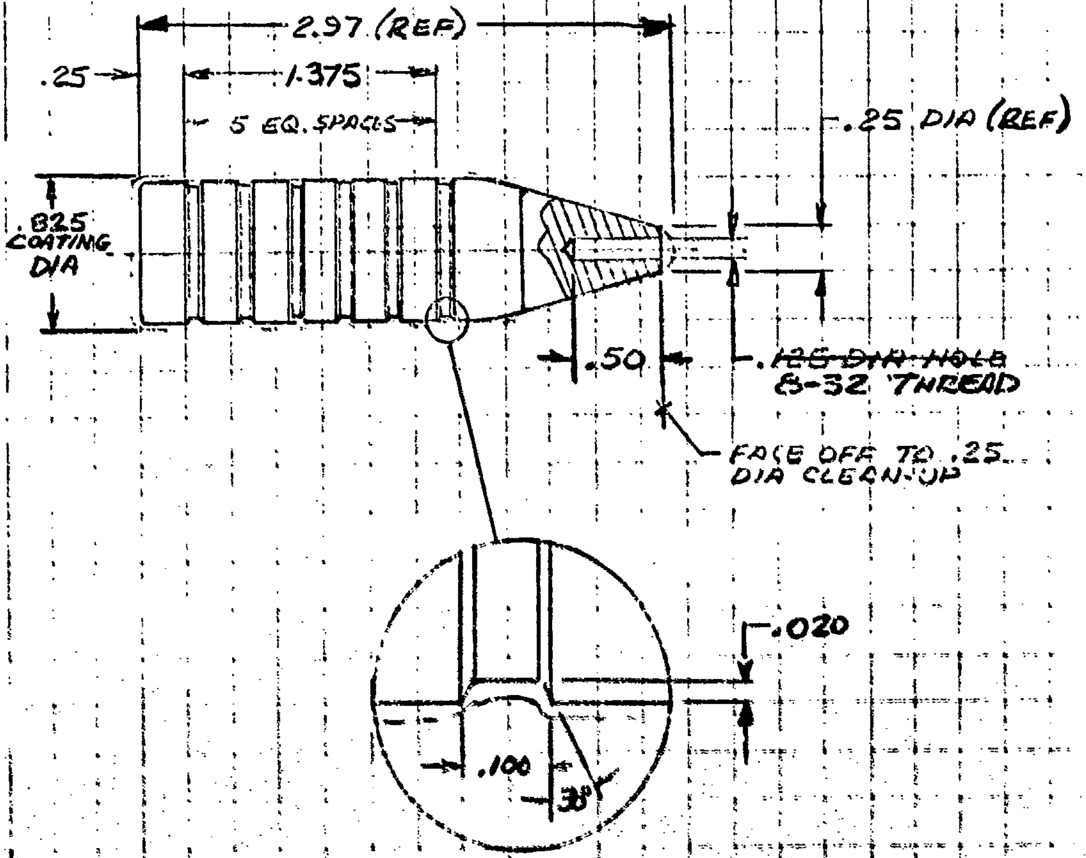
1. FLUIDIZE BED COAT ALL OVER .017 THICK.
2. MATERIALS TO BE USED:
   - A. ~~NYLON 12~~ UNSATISFACTORY FOR THICKNES.
   - B. NYLON 11: MOLDED 5/9/73, P/N 107652-1
   - C. EPOXY BRITTLE
   - D. THERMOPLASTIC POLYESTER, P/N 107652-2, MOLDED 6-1-73

DeBELL & RICHARDSON № 107653

PROJECT NAME EGLIN AFB - DEPT OF ARMY **PROJECT NO.** 6046.1

BULLET SHAPE FOR FLUID BED COAT **DATE** 4-12-73

REV. 4-25-73

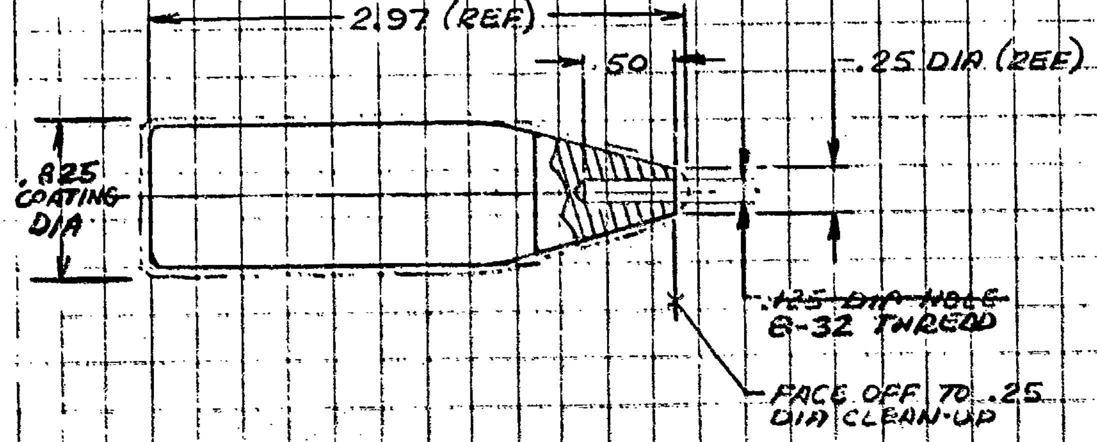


1. FLUIDIZE BED COAT .017 ALL OVER
2. MATERIALS TO BE USED:
   - A. ~~NYLON 12~~ UNSATISFACTORY @ THICKNESS REQD
   - B. NYLON 11: MOLDED 5/9/73, P/N 107653-1
   - C. ~~EPOXY~~ TOO BRITTLE
   - D. THERMOPLASTIC POLYESTER, P/N 107653-2 MOLDED 6-4-73

DeBELL & RICHARDSON **Nº 107654**

PROJECT NAME EGLIN AFB - DEPT OF ARMY **PROJECT NO.** 6046.1

BULLET SHAPE FOR FLUIDIZE BED COATING **DATE** 4-12-73



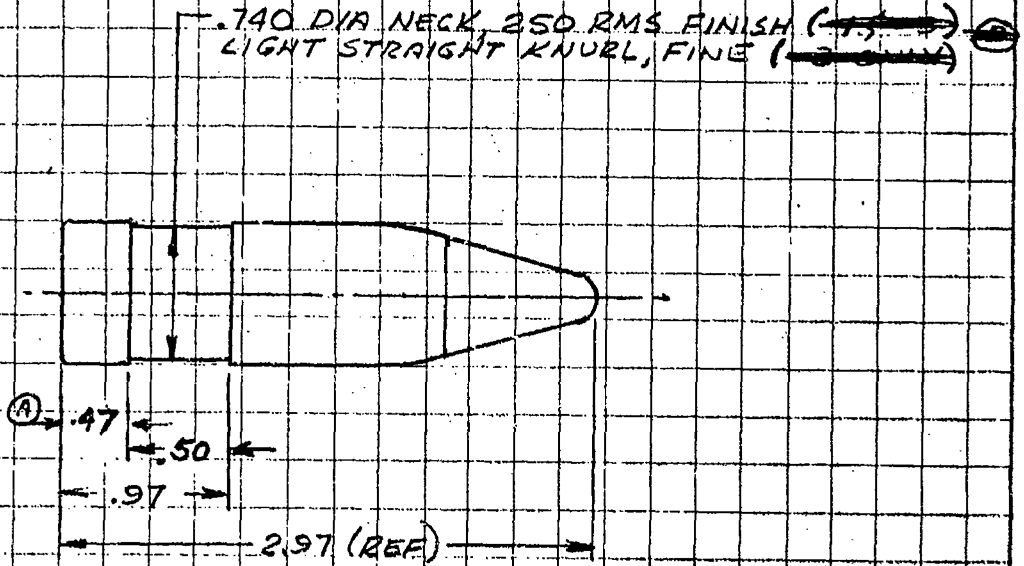
1. FLUIDIZE BED COAT ALL OVER WITH .017 THICKNESS
2. MATERIALS TO BE COATED:
   - A. ~~NYLON 12~~ : UNSATISFACTORY @ THICKNESS REQD
   - B. NYLON 11: COATED 5/9/73, 107654-1
   - C. ~~EPOXY~~ TOO BRITTLE
   - D. THERMOPLASTIC POLYESTER, 107654-2 MAILED 6-4-73

DEBELL & RICHARDSON **Nº 107655**

PROJECT NAME EGLIN AFB - DEPT OF ARMY **PROJECT NO.** 6046.1

BULLET SHAPE FOR INJECTION & COMPRESSION MOLD **DATE** 4-13-73

REV: 5-8-73 Ⓐ

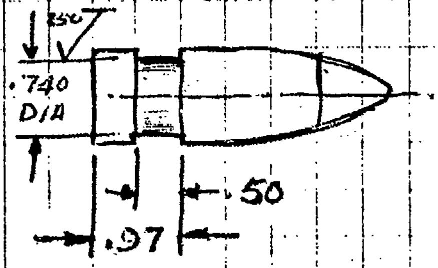


1. FOR COMPRESSION, INJECTION, OR CAST MOLDING OF VARIOUS CANDIDATE MATERIALS.
2.

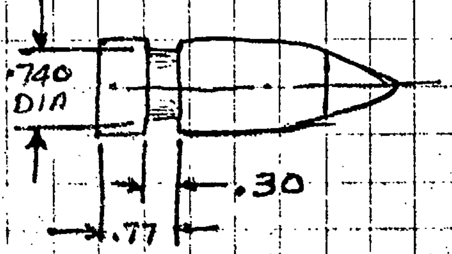
PROJECT NAME EGLIN AFB - DEPT OF ARMY PROJECT NO. 6046.1

REVISED ANCHORAGE SYSTEMS & ROTATION BAND, NYLON 12 DATE 7-2-73

BASED ON THE SUCCESSFUL FIRING TESTS OF THE 107671 & 107672 SERIES NYLON 12 BANDS, THE ANCHORAGES (WITHOUT KNURLING) WERE REVISED AS FOLLOWS:



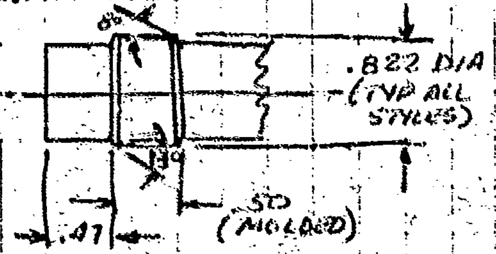
107673-1 ANCHORAGE



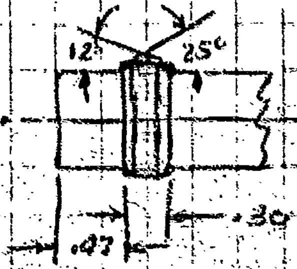
107673-2 ANCHORAGE

ROTATION BANDS WERE MOLDED USING THE PROCEDURES & PROCESSES FOR NYLON 12 AS DEFINED ON P. 107671. ROTATION BANDS WERE MOLDED AS IN STYLE 107673-1A BELOW, & MACHINED TO THE CONFIGURATIONS INDICATED.

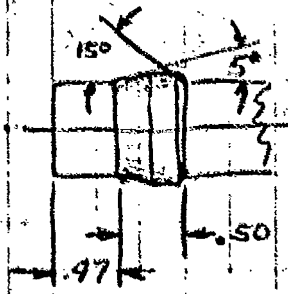
SAMPLES SENT TO EGLIN 7-18-73



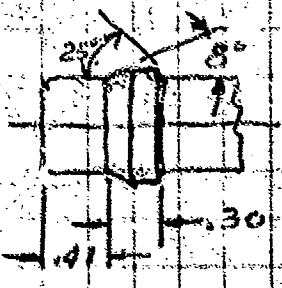
107673-1A



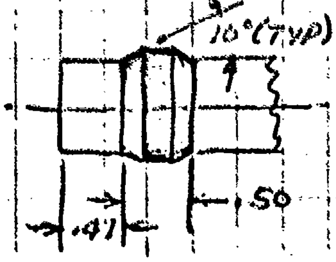
107673-2A

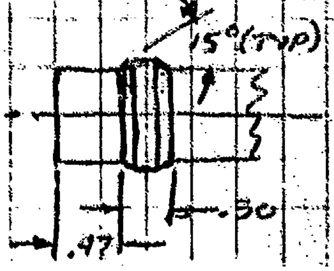


107673-1B



107673-2B

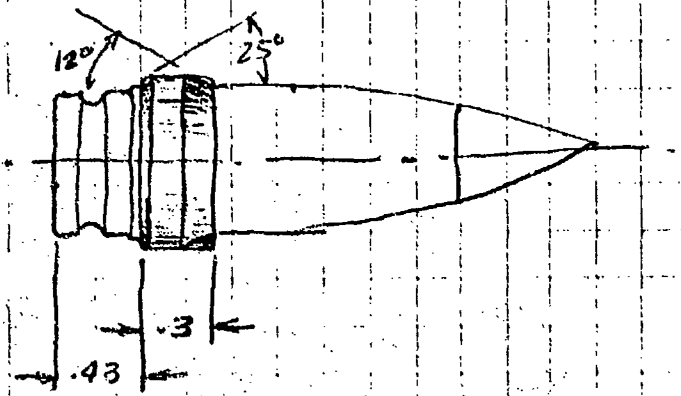




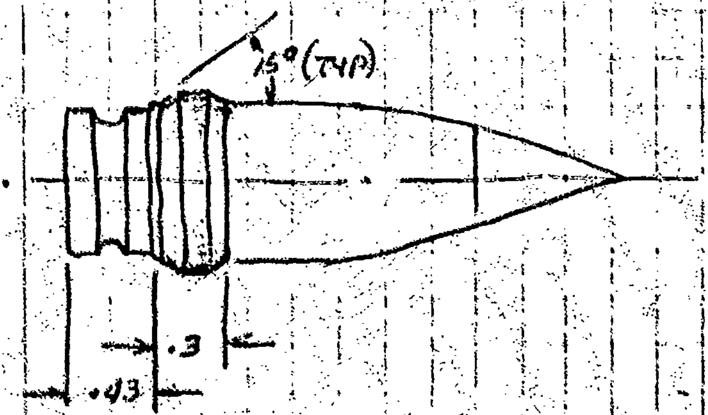
PROJECT NAME EGLIN AFB - DEPT OF ARMY PROJECT NO. 6046.1

SPECIAL 20 MM PROJECTILE & NYLON 12 BAND DATE 7-18-73

USING THE PROCESS DEFINED ON P. 107671 & THE SPECIAL GROOVED (NO SERRATIONS) 20 MM. BULLETS SENT BY EGLIN, NYLON 12 BANDS WERE MANUFACTURED ONTO THE BULLETS & MACHINED TO THE CONFIGURATIONS SHOWN. BULLETS SENT TO EGLIN 7-18-73



107674-1



107674-2

APPENDIX C

TRADE NAME REFERENCES

TRADE NAME REFERENCES

Absafil G 1200/20	ABS plastic with 20 percent glass	Fiberfil Corporation
Adiprene L 200	Urethane liquid resin	DuPont Corporation
Allied AC-1221	Ultra-high molecular weight polyethylene	Allied Chemical Company
Astrel 360	Polyarylsulfone	3M Company
B-25 beads	Glass microspheres	3M Company
BMNO - P49TL	Nylon 11	Rilsan Company
CTFE	Chloro-trifluoroethylene	3M Company
Cycolac GSM-1	ABS resin	Marbon Corporation
Cab-O-Sil	Silica filler	Cabot Corporation
CAYTUR - 21	Catalyst for liquid urethane	DuPont Corporation
Compo XL-901-1	Urethane Primer	Compo Industries
Chemlok 607	Primer	Hughson Chemical Company
Dexon XPA - 3	Polyolefin terpolymer	Exxon Corporation
Delrin 570 X	Acetal homopolymer	DuPont Corporation
Diamond 8620 PP	Polypropylene	Diamond Shamrock
Delrin AF	Acetal	DuPont Corporation
Elvamide PB - 8019	Low molecular weight nylon primer	DuPont Corporation
ERL 2772	Epoxy resin	UCC Corporation
Estane 58111-021	Urethane thermoplastic	B. F. Goodrich Company

Trade Name References - continued 2

Epon 815	Epoxy resin	Shell Chemical
Epiall 1288	Epoxy molding compound	Allied Chemical Corporation
FM - 1000	Polyamide epoxy tape	3M Company
Fiber B	Organic fiber	DuPont Corporation
FM 1303	Phenolic molding compound	Fiberite
FM 1132 P	Phenolic molding compound	Fiberite
Kynar	Polyvinylidene fluoride	Pennwalt
Lexan 141	Polycarbonate	General Electric Company
M & T Primer 253 P	Primer solution	M & T Chemicals
MOCA	4, 4' methylene (bis)-2-chloroaniline	DuPont Corporation
Marlex TR 880 HD	High density polyethylene	Phillips Chemical Company
Milvex 1235	Polyamide	General Mills
Noryl SE-1	Modified PPO	General Electric
Nylon RF 1006	Nylon 66 with 30 percent glass	LNP Corporation
Nylon 11	Nylon	Rilsan Corporation
Narmco 332		Narmco/Whittaker
Nylafil F 3/15	Reinforced foam nylon	Fiberfil Corporation
P 1700	Polysulfone	UCC Corporation
PRD - 49	Also known as Fiber B and currently as Kevlar	DuPont Corporation

Trade Name References - continued 3

Pellethane 2102- 65 DX	Thermoplastic polyurethane	Upjohn Chemicals
PFA TE 8704	Perfluoro-polymer	DuPont Corporation
Phenoweld #7	Phenolic Adhesive	Hardman, Inc.
Phenolic butyral 1P7	Phenolic varnish	SeaGuard
Premix 1100 - 30	Polyester glass compound	Premix Corporation
Thixon AB-1153	Urethane primer	Whittaker
Thixon D 12809	Primer	Whittaker
Thermofil N9-5000-FG	50 percent glass reinforced nylon 12	Thermofil Corporation
Trogamid T	Special polyamide	Dynamit Nobel
Tefzel	Ethylene tetrafluoroethylene	DuPont Corporation
TFE	"Teflon" tetrafluoroethylene	DuPont Corporation
UHMWPE	Ultra high molecular weight polyethylene	Hercules, Inc.
Upjohn 2102-65 DX	Thermoplastic polyurethane	Upjohn Chemical
Urefil	Glass fiber reinforced thermoplastic polyurethane	Fiberfil Corporation
X-917	Thermoplastic polyester glass fiber reinforced	Celanese Corporation
XX-1000	Polyamide	General Mills

Trade Name References - concluded

ZZLA 0831	Epoxy catalyst	UCC Corporation
Zytel 77-G-43	Nylon 6/12	DuPont Corporation
Curing Agent "Z"	Epoxy catalyst	Shell Chemical

INITIAL DISTRIBUTION

Hq USAF/RDQRM	2
Hq USAF/SAMID	1
Hq USAF/XOXFCM	1
Hq USAF/XOOW	2
Hq USAF/RDPA	1
AFSC/IGFG	1
AFSC/DLTW	1
AFSC/SDWM	1
ASD/TWT	1
ASD/TWD	1
ASD/ENYS	1
ASD/ENVW	1
ASD/ENWS	2
FTD/PDXA	1
AFML/LNP	1
AFML/LPH	1
AFML/LAM	1
AFAL/LVA	1
AFFDL/FBS	1
TAC/DMW	1
TAC/DRFM	1
TAC/DMAX	1
SAC/OAI	1
SAC/DMW	1
WRAMA/MMEBL	1
CIA/CRE/ADD	2
SAMSO/XRTD	1
AEDC/ARO, Inc	1
AFWL/DOGL	1
AF Spec Comm Ctr/SUR	2
AUL/AUL-LES-70-239	1
Chief of R&D/CRDAM	1
Redstone Science Info Ctr Chief, Doc Sec	2
USA Armament Comd/AMSWEREW	2
USA Mat Sys Analysis Agcy AMXRD-AS	1
USA Mat Sys Analysis Agcy AMXRD-AA	1
USA Mat Sys Analysis Agcy AMXRD-DB	1
USA Aberdeen R&D Ctr/AMXRD-BTL	1
Frankford Ars/Library	1
Picatinny Ars/SMUPA-RT-S	1
Nav Air Sys Comd/Code AIR 350B	1
USN Wpns Lab/Code TR	1
USN Ord Lab/Tech Lib	1
USN Ord Lab/Code 730	2
Nav Ord Stn/Tech Lib	1
Nav Wpns Stn/Code 64	1
Naval Sys Ctr/Tech Lib	1
Safety Resch Ctr/Doc Lib	1
USN Wpns Ctr/Code 753	2
USN Wpns Eval Fac/Code WE	1
57 Ftr Spn Wg/FWOA	1
Nav Air Sys Comd/Code AIR-5323	1
Nav Air Sys Comd/Code AIR-5324	1
Chief of Nav Ops/OP-722	1
USN Rsch Lab/Code 2027	1
USN Rsch Lab/Code 5180	1
Office Nav Rsch/Code 473	1
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Battelle Memorial Inst/ Reports Library	1
Infrared Info Analysis Ctr/ Univ of Mich	1
Inst for Defense Analysis Classified Library	1
Sandia Corp/Tech Lib	2
Sandia Corp/Div 2341	1
Rand Corp/Lib-D	1
Army Materiel Comd/AMCRD-BN	1
USAF TAC Ftr Wpns Ctr/CRCD	1
Harry Diamond Labs/AMXDO-TC	1
DDC	2
CINCUSAFE/DMW	1
CINCUSAFE/OA	1
CINCPACAF/DMWXE	4
USAFTAWC/AY	1
AFATL/DL	1
AFATL/DLB	1
AFATL/DLD	1

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AFATL/DLRD	1
AFATL/DLRW	1
AFATL/DLIM	1
AFATL/DLII	1
AEC Library	1
Dept of the Army, Chief R&D (ORCD)	1
BRL (AMXBR-XBL)	1
BRL (AMXRD-BTL)	2
BRL, Aberdeen Pg Gnd	2
BRL (Tech Lib)	1
Watervliet Ars	1
USNOL (Aerodynamics Dept)	1
Naval Wpns Lab	1
Goodyear Aerospace Corp	2
Naval Wpns Ctr (Code 50704)	1
Naval Wpns Ctr (Code 3015)	1
AFIT Tech Lib	1
4525 Ftr Wpns Wg (FWOA)	1
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Dir Rsch Lab (Aerodynamics Rsch Gp)	1
Sandia Corp (Org No 9322)	1
Alpha Rsch Inc	3
Univ of Notre Dame (Dept of Aero Space & Mech Engr	1
Picatinny Ars	1
AFSC (Tech Lib)	2
ADTC (WE)	1
AFATL (DLDL)	20
AFATL (DLDG)	20
SARFA-J5100	1
Dept of the Army (Rsch Ctr)	1
ATD	3
Frankford Ars (Bridge & Tacony Sts)	1
Plastec	3
US Naval Wpns Lab (Code EAD)	1
Naval Wpns Ctr (Code 3015)	1
US Naval Wpns Ctr (Code 4544D)	1
ORD-04M/B21L/NBB	1
SMUFA-J5300	1
SMUFA-J6300	1
Naval Wpns Lab (Code GW)	1
Picatinny Ars (Materiels Engineering Lab)	1
TAC (DOXBE)	1
USA Armament Cmd (SARRI-LW)	3
USN Wpns Ctr (Code 407)	1
BRL (AMXBR-VL)	1
BRL (AMXBR-TBW)	
SMUFA-J7400	1
TRADOC/ADTC-DO	1
Hq USAF/SAMI	1
Hq 4950 TESTW/TZHM	1
Ogden ALC/MMNOP	2
AFWL/LR	2
SMUEA-CL-PA	1
AFML/MBM	1