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MANUFACTURING TECHNOLOGY FOR FIBER OPTIC BUNDLE CABLING.(U)
JUL 78 G M HOLMA, R A GREENWELL

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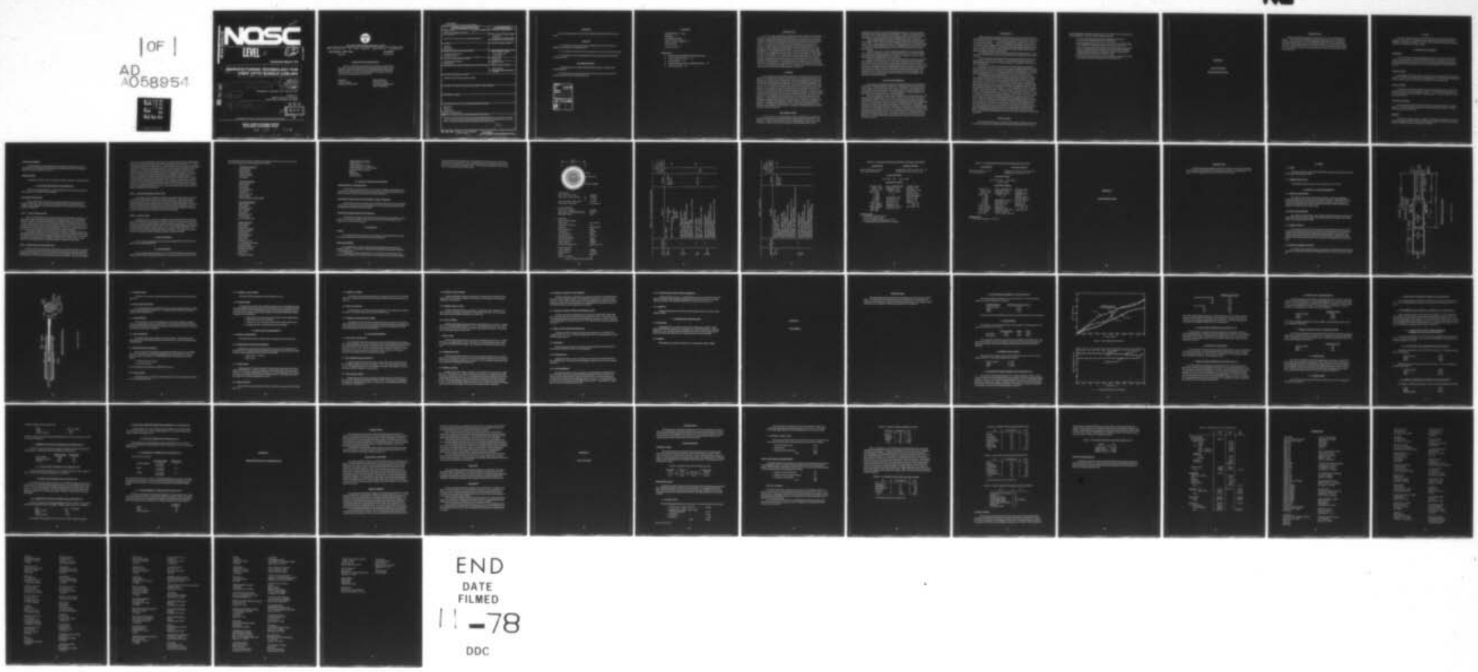

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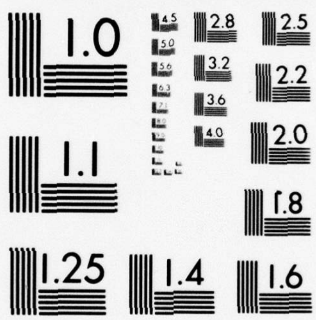

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Technical Report 274

MANUFACTURING TECHNOLOGY FOR FIBER OPTIC BUNDLE CABLING

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10 Jul[redacted]78

Technical rept. Dec 75-Feb 78,

Development: December 1975 - February 1978

58p.

Prepared for
Naval Air Systems Command
NAVAIR 520, Washington DC 20360

NOSC/TR-274

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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SAN DIEGO, CALIFORNIA 92152

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ADMINISTRATIVE INFORMATION

Work was conducted by personnel of the Naval Ocean Systems Center, San Diego, as part of the Manufacturing Technology Program of the Naval Air Systems Command (NAVAIR 520) under Program Element APN, Work Unit T306. This report covers work from December 1975 to February 1978 and was approved for publication on 10 July 1978.

Released by
CL Ward Jr, Head
Design Engineering Division

Under authority of
CD Pierson Jr, Head
Electronics Engineering and
Sciences Department

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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOSC Technical Report 274 (TR 274)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) Manufacturing Technology for Fiber Optic Bundle Cabling		5. TYPE OF REPORT & PERIOD COVERED Development December 1975 to February 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) GM Holma RA Greenwell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, CA 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program element APN, work unit T306
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command (NAVAIR 520)		12. REPORT DATE 10 July 1978
		13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Optical fibers
Fiber optics
Aircraft cabling
Manufacturing specifications

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

A manufacturing process was developed for the cabling of bundle optical fibers for use on aircraft. The process produces ruggedized optical fiber in large quantities, achieves production cost reduction, and meets the environmental requirements for military aircraft. Specifications for the process are given.

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S/N 0102-LF-014-6601

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OBJECTIVE

Develop manufacturing processes for the cabling of bundle optical fibers for use on aircraft.

RESULTS

1. An optical fiber cabling process was developed which can be used to produce ruggedized optical fiber cable in large quantities.

2. A cost reduction was achieved for the production of this type of optical fiber cable.

3. An optical fiber cable was developed that meets the environmental requirements for military aircraft.

RECOMMENDATIONS

1. Tighten specifications for glass fiber bundle procurements to alleviate cable processing problems.

2. Reduce the number of strength members within the cable, since the cable far exceeds the specified tensile strength requirements.

CONTENTS

INTRODUCTION

In 1976, a contract was awarded to Times Wire and Cable Company to develop manufacturing processes for the cabling of bundle optical fibers for use on aircraft. The contract was part of the Navy's Manufacturing Technology Program funded by the Naval Air Systems Command (NAVAIR 520) and administered technically by the Naval Ocean Systems Center (NOSC). The objective of the Manufacturing Technology Program was to develop the necessary expertise in industry to produce optical fiber cables on a production basis, at reduced cost, which would meet the requirements for military airborne applications. The optical fiber cable was designed with glass bundles, which have optical losses between 400 and 600 dB km. It was specified that the cable be reinforced with Kevlar strength members. This cable was to be applicable for point-to-point systems in aircraft, where the cable lengths would be less than 100 feet. The strength members would make it possible to use this cable in "stand-alone installations," where the cable is not harnessed with other cables. Optical fiber glass clad/glass core bundles were delivered as GFM (Government Furnished Material) to Times Wire for the cabling process. The glass clad glass core bundles were produced by three major glass fiber manufacturers – Galileo Electro-Optical Corp, American Optical, and Valtec Corp. Times Wire developed the cabling process which resulted in the cable construction shown in the Manufacturing Process Description (appendix A, figure A-1).

SUMMARY

Times Wire developed an optical fiber cabling process which meets the majority of the requirements established at the beginning of this program. The cable requirements are documented in the Cable Specification (appendix B). The contract required that the cable design meet the MIL-E-5400 environment. Based upon results in the Test Report (appendix C), the Times Wire process will produce cable that will meet the requirements of MIL-E-5400 operation on aircraft. The contract also required a description of the manufacturing process. (This description will be provided to other industrial organizations so that they will also have the benefits of the lessons learned under this manufacturing technology effort.) Finally, the contract required that cable processes be developed for high-volume production. Wherever possible, existing production equipment used for electrical cabling was to be used. All equipments used by Times Wire for optical fiber cable manufacturing were standard items used in wire cable production. The most difficult task performed under this contract was the development of handling and cabling process techniques for the glass bundles. In addition to the manufacturing process specification, the identification of certain problem areas concerning the glass bundles was most significant in the production of this cable. By proper specification of the glass bundle, these problems can be eliminated. Using these manufacturing processes, volume production easily can be achieved.

RECOMMENDATIONS

Under this contract, it became apparent that tighter specifications were required for the glass bundle procurements to alleviate cable processing problems (see appendix D). For production extrusion of the cable jacket, the glass bundles must have uniform cross sections. To maintain a uniform cross section during extrusion, individual fiber tension must be controlled so that all fibers in the bundle have the same tension. This results in a uniform cable jacket diameter, with a minimum of broken fibers. In addition, a serving thread lay of between 0.75 and 1 inch was discovered to be optimum for a uniform bundle cross section. Uniform fiber tension and thread lay should be specified in glass bundle procurement.

During the high-temperature extrusion process, the glass bundle is exposed to temperatures as high as 338°C. Because of this high temperature, the glass bundle serving thread must be made of a high-temperature material. A temperature specification should be included for the serving thread in glass bundle procurement. A flammability requirement should also be included in the glass bundle procurement to cover the serving thread and the lubricant used on the glass.

During the extrusion process, two bundle types tended to bind on the reels during payout. The binding problem occurred with the smaller 4-inch reels. One bundle manufacturer supplied larger reels (approximately 12 inches), and no problems occurred. Thus the bundle specification should include a minimum reel size.

During the mechanical tests, it was found that the optical fiber cable far exceeded the tensile requirement of 45 kg necessary for "stand-alone" aircraft applications. Because of this, a smaller amount of Dupont Kevlar strength members should be used in the cable construction. By reducing the amount of strength members, the thickness of the inner cable jacket could be increased slightly, while still maintaining the outside jacket diameter at 0.150 inch. This would further reduce the number of fibers broken during the jacketing process (even though the number of fibers broken with the present cable is within specifications). The reduction would also eliminate the cable's present tendency toward kinking slightly when exposed to an extreme bend radius.

CABLE CHARACTERISTICS

The fiber optic cable construction produced by Times Wire is shown in the Manufacturing Process Description (appendix A, figure A-1). The glass bundle is covered by an inner jacket of Dupont Tefzel 280 with an outside diameter of 0.110 inch. Kevlar strength members are braided along the cable length. Then an outer jacket of Tefzel is extruded over the strength members and the inner jacket. The outside diameter of the finished cable is 0.150 inch. The full cable specification can be found in appendix B.

The cable was designed to comply with the environment specified in MIL-E-5400. The temperature range specified was −55°C to +150°C. However, the cable should perform well at temperatures to 200°C. The jacket construction gives excellent protection for the glass bundle. The strength members provide less than 1% elongation when the cable is tensile loaded with 45 kg. This guarantees no glass fiber breakage at the full tensile load. The strength members also provide a strong cable-connector junction. No separation of a properly prepared connector occurred during the tensile tests. The maximum load applied to the cable was 91 kg. The cable construction makes it well suited for installation on military aircraft. Because of the high tensile strength, the cable can be used in retrofit "stand-alone" applications, where the cable is not harnessed with other cables. The cable construction is also well suited to volume production. The jacketing process uses existing production equipment that is employed for wire cable production.

TEST RESULTS

NOSC performed mechanical and environmental testing on the optical fiber cable as delivered from Times Wire. In addition, Times Wire performed mechanical and environmental tests on the cable. The test results can be found in appendix C. The tests were performed according to the methods of DOD-STD-1678, Fiber Optics Test Methods and Instrumentation. The optical fiber cable produced by Times Wire met the majority of the requirements as listed in the cable specification. The average fiber breakage during the cabling process was less than specified. The tensile strength of the cable, even after humidity and accelerated aging, far exceeded the specified tensile strength.

The optical fiber cable did not meet the specification in three areas, however. It did not meet the cable diameter and concentricity requirement, the impact test, and the flammability test.

The small variation in cable diameter and concentricity did indicate a problem with quality control, but will not affect optical or environmental performance. With properly specified glass bundles, this problem should be eliminated. (See appendix D, Problems with optical Fiber Bundles.)

The failure of the cable to pass the impact test should not present a problem with aircraft installations. The equivalent wire cable for aircraft, according to MIL-W-81381, does not need to pass an impact test. Times Wire performed the same impact test on a 0.150-inch-diameter stainless steel tube with 0.015-inch wall thickness. This tube failed the impact test, which may indicate that the test in DOD-STD-1678 is too severe for fiber optic cable.

The flammability test specification called for a maximum burn time of 5 seconds. with a maximum flame travel of 5.0 cm up the cable. The wire cable specification, MIL-W-81381, requires a 3-second burn time and a maximum flame travel of 7.6 cm. The cable, when tested by Times Wire, had a burn time between 14 and 33 seconds. The cable had a flame travel of between 5 and 7.6 cm. The cable jacket material, Tefzel, is rated VO, which is an Underwriters Laboratory flammability specification for nonflammable materials. The Kevlar strength members are also nonflammable. Further flammability tests were conducted at NOSC. The cable was exposed to a flame for a period of 30 seconds, according to DOD-STD-1678. The average burn times for the Galileo, American Optical, and Valtec cables were 6.3 seconds, 7.3 seconds, and 9.6 seconds, respectively. The burn time is the amount of time the cable continues to burn after removal of the flame source. In many cases, the cable was burned totally in two before the 30 seconds expired. Even though the cable continued to burn, the flame did not travel up the cable length. When the cable was exposed to the flame source for only a 5-second period, the outer jacket melted and the Kevlar strength members were charred but the inner tube was not penetrated. In this case, the burn time was zero. The cable continued to burn only when the inner tube was penetrated. All these facts point to the serving thread and the glass lubricant as the combined reason for the flammability failure. The serving thread and glass lubricant act as a candle wick to maintain the flame. By properly specifying the serving thread and lubricant, this cable should meet the flammability requirement.

COST ANALYSIS

Part of the contract effort was a cost analysis. This analysis contained a breakdown of the various production costs, including costs for manufacturing, materials, production setup, special handling and processing, and quality control. The results of the cost analysis can be found in appendix E. The results can be summarized as follows:

1. It is believed that the production cost of a ruggedized, jacketed, fiber-optic cable will be reliably reduced by 40 to 50 percent.
2. The most significant cost factor in terms of materials is the optical fiber bundle itself, which was a furnished subcontracted item for this contract effort.
3. Costs in this report are based on extrusion lengths of fiber optic bundles of 305 metres. An estimated 30% cost reduction can be achieved with fiber bundle extrusion lengths of 2 kilometres. These greater lengths for production-run schedules reduce material waste and setup labor costs.
4. This effort resulted in a process that can be repeatable by multiple sources, and thus portends a competitive market potential and reduced cost.

APPENDIX A:

MANUFACTURING PROCESS SPECIFICATION

INTRODUCTION

The following Manufacturing Process Specification was a major deliverable in this contract. The main goal of the Manufacturing Technology Program was to establish the necessary expertise in industry to produce ruggedized optical fiber cables on a production basis. This manufacturing technique must be made available to all concerned fiber optics companies. The specification defines the production processes necessary for cable manufacture. It is presented as a guide to any cable manufacturer interested in producing a similar optical fiber cable.

1.0 SCOPE

The object of this specification is to define high-volume manufacturing methods for optical fiber cable capable of performing in the environment encountered during aircraft installation, maintenance, and flight. The intent of this specification is to present techniques that shall be reproducible by multiple suppliers.

2.0 PRODUCTION EQUIPMENT

EXTRUDER

The extruder shall be capable of handling fluorocarbon materials and shall be able to produce results required by the cable design shown in figure A-1 and table A-1 under the processing requirements of tables A-2 and A-3. The extrusion equipment shall be equipped with temperature controllers capable of maintaining the temperatures required in tables A-2 and A-3.

TAKEUP SYSTEM

The takeup system shall provide for constant low-tension spooling onto reel sizes large enough to accommodate run length without damaging fibers. The recommended minimum hub size for the takeup system is 9 inches with 1-pound tension for production runs.

PAYOFF SYSTEM

The payoff system shall be capable of accurately maintaining the tension of the fibers during extrusion at the line speed specified in table A-2. The required tension shall be such that no fiber damage is incurred during the extrusion process. A tension of 20 grams was used in the production run.

LINE PAYOFF SYSTEM

The payoff system shall be capable of maintaining a constant line speed as specified in table A-2. Line speed tolerance shall be such that the requirements of table A-1 are maintained during both extrusion stages.

BRAIDER

The braiding equipment shall be so designed as to satisfy the requirements of table A-1 without damaging the individual strength members during braiding. Carrier back tensions shall be equal and shall be such as to maintain tight, even braid.

COOLING EQUIPMENT

Cooling equipment used during the first processing stage, as defined in table A-1, shall consist of a vacuum chamber with appropriate sizing dies capable of maintaining the diameter tolerances as defined in table A-1.

HOPPER DRYER

A hopper dryer shall be used to precondition material to eliminate moisture problems.

3.0 REQUIRED PROCEDURES AND OPERATION

The intent of this specification is to produce optical fiber cable with the dimensions shown in figure A-1, using the included materials.

PROCESSING PROCEDURE

The processing procedures necessary to produce the desired optical fiber cable are detailed in this section. The procedures cover bundle preparation, first tube production, strength member application, and final jacket production. These procedures are outlined in tables A-1 through A-3.

STEP 1: BUNDLE PREPARATION

Prior to first tube production, the fiber bundle must be prepared for processing. The preparation consists of applying heat-curing epoxy to approximately 1 foot of the leading end of the bundle. The epoxy must bond the bundle together, maintaining a circular cross section, and also achieve a bond to the serving thread (bonding to the serving thread presented a problem with American Optical and Valtec bundles because of the low melt temperature of the material). The epoxied section must be straight and, if necessary, any excess epoxy may be removed with a razor blade prior to insertion into the extruder cross head.

The simplest technique to achieve these results is virtually to suspend the bundle and then apply the epoxy to the bundle 1 foot from the end. When heat is applied, the epoxy will flow down the bundle and then set, yielding a straight, relatively smooth section. If more than one bundle is to be processed, the trailing of the bundles is also prepared as above so that the tube can be maintained when the trailing end passes through the extruder head.

STEP 2: PRODUCTION OF THE FIRST TUBE

The most critical processing stage is the first tube. The extrusion procedure in a straight-line process with payout, extruder, vacuum chamber, line payoff system, and takeup requires an approximately 50-foot line. The process is started by initiating tube extrusion without glass until stability is achieved and all dimensional specifications are satisfied. The procedure requires about 1 hour to reach equilibrium. The process is monitored continuously for outside diameter in two planes and the tube is sampled to measure inside diameter and concentricity. The nominal line specifications are shown in table A-1. Slight variations may be necessary for a particular run because of variations in processing condition. Once the process has obtained stability, the bundle payout is turned on and the back tension adjusted to 20 grams. After the desired tension has been set, the finished bundle end is inserted through the crosshead and into the tube. The tube will attach to the glass and begin the processing. It should be noted that no further adjustments can be made to the process after the glass has begun processing. It is therefore critical that the process be within specifications prior to bundle insertion. Because of the disturbance caused by process initiation, the first 10 feet of cable should be removed from the reel. As the end of the bundle is processed, the disturbance may cause the tube to break and/or cause sealing integrity to be lost. In this event, water will penetrate the bundle; affected areas should be removed from the reel. The worst observed case required removal of 4 feet of cable from the end of the reel.

STEP 3: STRENGTH MEMBER APPLICATION

The strength member is applied to the cable as processed in step 2 above on a sixteen-carrier braider. Back tension on the carriers shall be adjusted to 1 pound and appropriate gears employed to yield a 4.04 pick count. The individual bobbins shall contain enough material to guarantee that no bobbins shall end during processing of any length. Takeup reels with a 9-inch hub shall be used and back tension on the payout reel, although not critical, should be 1 pound. This processing step is not a difficult procedure and the test results indicate that no fiber damage was incurred during this processing stage.

STEP 4: OUTER JACKET

Application of the outer jacket is a straightforward extrusion that utilizes tubing technique. The detailed process parameters are outlined in table A-3. Prior to running, the cable ends shall be epoxied to prevent possible moisture penetration into the cable. A marker identification tape shall be pulled in with the cable. Payout tension shall be adjusted to 10 pounds by the brake-dancer method. Takeup tension is not critical, but 1 pound was used for the production runs. The manufacturing instructions set in table A-1, in conjunction with tables A-2 and A-3, identify the various parameters necessary to produce the cable.

4.0 TEST EQUIPMENT

The test equipment employed shall be as defined in DOD-STD-1678, FED-STD-228, MIL-STD-202E, and MIL-STD-810B.

5.0 TEST METHODS

The test methods employed shall be in accord with MIL-C-85045 in compliance with DOD-STD-1678 except as otherwise specified in the contract or order. The tests which must be performed are listed under the classifications Glass Bundle Inspection, In-Process Inspection, First Article Inspection, and Quality Inspection as follows:

Glass Bundle Inspection

Bundle diameter
Fiber diameter
Number of fibers
Transmitting fibers
Attenuation

In-Process Inspection

Cable diameter
Concentricity
Workmanship
Transmitting fibers
Attenuation
Insulation leak rate
Tensile loading
Ultimate insulation tensile strength

First Article Inspection

Cable diameter
Workmanship
Transmitting fibers
Fiber breakage
Attenuation
Insulation leak rate
Tensile loading
Low temperature flex

Quality Inspection

Cable diameter
Concentricity
Finished cable weight
Continuous length
Workmanship
Transmitting fibers
Fiber breakage
Attenuation
Insulation leak rate
Low temperature flexibility
Accelerated aging
Humidity conditioning
Temperature cycling
Cyclic flexing
Impact test
Compressive strength

Quality Inspection (Cont'd)

Tensile loading
Tensile loading after humidity
Tensile loading after accelerated aging
Insulation abrasion resistance
Blocking
Flammability
Fluid immersion.

6.0 QUALITY ASSURANCE PROVISIONS

RESPONSIBILITY FOR INSPECTION

Unless otherwise specified in the contract or order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except where specified, the quality assurance testing will include those tests listed in appendix C.

MONITORING PROCEDURES FOR EQUIPMENT USED IN PROCESS

Prior to the start of any processing stage, all equipment shall be checked and calibrated to assure performance consistent with the specifications. Where applicable, equipment shall be calibrated in accordance with MIL-C-45662A.

MONITORING PROCEDURES FOR MATERIALS

All materials used in production of the desired cable shall require a Certificate of Compliance from the material supplier. All material used shall be stored and handled in such a manner as to not alter its characteristics.

7.0 MATERIALS

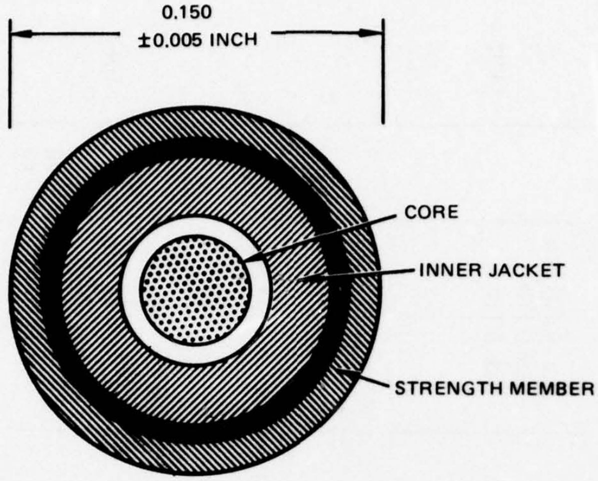
TEFZEL

The material used for the inner tube and outer jacket of the cable shall be Tefzel 280. The material properties shall correspond to those listed in figure A-1.

STRENGTH MEMBER

The strength member shall be a 380-denier aramid material with the properties as specified in figure A-1. The strength member shall be the lubricated type normally employed in braiding applications.

All materials used shall be virgin material. For purposes of this specification, virgin material shall be 100-percent new material which has been through only the processes essential to its manufacture and its application to the optical fiber cable and has been through these essential processes one time only. Any material which has been processed previously in any other manner is considered nonvirgin material. This requirement shall apply to the manufacture of all ingredients and components used.



I.	CONSTRUCTION		
	CORE: FIBER BUNDLE (GFM)		0.046 INCH
	INNER JACKET: TEFZEL 280 TUBE	ID.	0.062 INCH
		OD.	0.110 INCH
	STRENGTH MEMBER: ARAMID BRAID		0.125 INCH
	FINAL JACKET: TEFZEL 280		0.150 ±0.005 INCH
II.	PHYSICAL PROPERTIES		
	WEIGHT (PER KILOMETRE)		15.1 kg/km
	BEND RADIUS: RECOMMENDED MINIMUM		0.385 INCH
	BREAKING STRENGTH		400 lb
III.	PARAMETERS		
	INNER AND OUTER JACKETS		
	TEMPERATURE		-55°C TO 150°C
	COEFFICIENT OF FRICTION		0.4
	HARDNESS		DUROMETER D75
	WATER ABSORPTION		0.029%
	FLAMMABILITY		UL94 SE-O
	TENSILE STRENGTH		6500 psi
	VOLUME RESISTIVITY		10^{16} ohm-cm
	COMPRESSIVE STRENGTH		7100 psi
	FLEXURAL MODULUS		200000 psi
	TENSILE MODULUS		120000 psi
	DEFORMATION UNDER LOAD		2000 psi, 122°F: 4.1%
	STRENGTH MEMBERS		
	TENSILE STRENGTH		430000 psi
	TENSILE MODULUS		19×10^6 psi
	DENSITY		0.053 lb/m^3
	ELONGATION TO BREAK		2.3%

Figure A-1. NOSC optical fiber cable design.

TABLE A-1. OPTICAL FIBER TUBULAR BRAID DESIGN.

Operation	Department	Description	Diameter	Kft of Finished Cable: Std Hrs Used	Kft of Finished Cable: Material Used, lb
01 Extrusion	11	Core: GFM glass OD: 0.046 +0.000 inch -0.001 Extrude: 74012 Tefzel 280 tube ID: Min 0.059 inch Nom 0.060 Max 0.062	Min 0.108 inch Nom 0.110 Max 0.112		4.92
02 In-process test	23	Cable diameter: 06003A/0.110 ±0.002 inch Cable concentricity: 06001A/0.9 Workmanship: 06002A/no jacket damage Transmitting fibers: 06005A/contact project manager Attenuation: 06004A/NA Insulation leak rate: 06006B Insulation leak rate: 03003R revision D; $\leq 3.2 \times 10^{-4}$ cc/s/m			
03 Braid	14	Material: Kevlar 49, 380-denier Carriers: 16; ends: 2; LF: 3.67 Gears: 12/30; for: 4.04 picks Bobbin wind: 0.10; braid labor hours: 0.10 MRT	Nom 0.120	0.20 1.52	0.96
04 In-process test	23	Cable diameter: 06003A/0.120 inch Cable concentricity: 06001A/0.9 Workmanship: 06002A/no jacket damage Transmitting fibers: 06005A/contact project manager Attenuation: 06004A/NA Insulation leak rate: 03003R revision D; $\leq 3.2 \times 10^{-4}$ cc/s/m			

TABLE A-1. (CONTINUED)

Operation	Department	Description	Diameter	Kft of Finished Cable: Std Hrs Used	Kft of Finished Cable: Material Used, lb
05 Extrusion	11	Pull in marker tape (as specified in job strip) Extrude: 74012 Tefzel 280 Nominal wall thickness: 0.010 inch 1st article test: Cable diameter: 06003A/0.150 ±0.005 Workmanship: 06002A/no jacket damage Transmitting fibers: 06005A/NA Fiber breakage: (refer to) 06005A/⩾0.91 remaining Attenuation: 06004A/NA Insulation leak rate: 03003R revision D/⩽3.2×10^{-4} cc/s/m Tensile loading: 06007A/⩽10%/1.5% elongation Low-temperature flex: 06008A/no insulation cracking; transmitting power: ⩾0.9	Min 0.145 inch Nom 0.150 Max 0.155		3.24
06 Prod Test	23	Cable diameter: 06003A/0.150 ±0.005 Cable concentricity: 06001A/0.9 Workmanship: 06002A/no jacket damage Transmitting fibers: 06005A/contact project manager Attenuation: 06004A/NA Insulation leak rate: 03003R revision D/⩽3.2×10^{-4} cc/s/m Tensile loading: 06007A/⩽10%/1.5% elongation Ultimate insulation tensile: 06007B/⩽1.5% elongation			

TABLE A-2. EXTRUSION PROCESS PROCEDURE FOR GLASS BUNDLE WITH BINDER

Incoming Material	**Construction Description**
Dia (inch): MI 0.046 Act: 0.046	Dia (inch): min 0.108; nom 0.110; max 0.112
Desc: glass bundle with binder	Min Wall (inch): see note 1 Run To: nom

Compound Information

Type: Tefzel 280 Color: Natural

Setup and Run Conditions

Screw Type: FEP	Screens: Stainless 60 mesh	Line Speed: 28 fpm
Temp In: Neutral	Hopper Dryer: 150°F	Cat/Cap Set: 2.2
Temp Out: --°F	Trough POS: 3 inches	Screw Speed: 4.8 rpm
Heats 1: 540°F	Temps 1: see note 3	Screw Set: 105
2: 550°F	2: --	Mat'l Use: 8.3 lb/hr
3: 560°F	3: --	Motor Amperage: 2.7
4: 580°F	Marker Position: none	Melt Temp: 590°F
H: 600°F	Cat/Cap Gear: none	Pressure: -- psig
D: 640°F	Takeup Gear: none	Takeup Set: on
Tip ID: see note 2	Payoff: see note 4	Preheat Type: none
OD: 0.180 inch	Straightener: none	Temp: -°F
Die ID: 0.360 inch	Back Tension: see note 4	Sparker Type: none
Type: Tefzel	Vacuum: see note 3	
Space: flush		

Special Instructions:

1. Run 0.110 nom OD, 0.062 nom ID.
2. Vespel insert in tip; ID = 0.100
3. Use vacuum chamber sizing plate diameter = 0.116
4. Use special glass payoff; set tension control to 20 grams.

TABLE A-3. EXTRUSION PROCESS PROCEDURE FOR BRAIDED KEVLAR CORE

Incoming Material

Dia (inch): MI 0.120 Act: 0.125
Desc: braided Kevlar core

Construction Description

Dia (inch): min 0.145; nom 0.150; max 0.155
Min Wall (inch): 0.010 Run To: 0.150

Compound Information

Type: Tefzel 280 Color: Natural
Supplier: Dupont

Setup and Run Conditions

Screw Type: Fep	Screens: stainless 60 mesh	Line Speed: 36 fpm
Temp In: neutral	Hopper Dryer: 150°F	Cat/Cap Set: 2.6
Temp Out: --°F	Trough POS: 2½ inches	Screw Speed: 5 rpm
Heats 1: 540°F	Temps 1: cold	Screw Set: 110
2: 560°F	2: --	Mat'l Use: 8.7 lb/hr
3: 580°F	3: --	Motor Amperage: 3.0
4: 600°F	Marker Position: see note 1	Melt Temp: 595°F
H: 600°F	Cat/Cap Gear: none	Pressure: --psig
D: 630°F	Takeup Gear: none	Takeup Set: on
Tip ID: 0.140 inch	Payoff: small	Preheat Type: none
OD: 0.375 inch	Straightener: none	Temp: --°F
Die ID: 0.450 inch	Back Tension: payoff brake	Sparker Type: none
Type: Tefzel	and dancer, 10 lb total	
Space: flush	Vacuum: 5 inches, 1-inch core	

Special Instructions:

1. Pull in marker tape - Kapton - "07145-1977."

APPENDIX B:

CABLE SPECIFICATION

INTRODUCTION

This Cable Specification defines the optical, mechanical, and environmental requirements established at the beginning of this program for an airborne, optical fiber cable. The majority of the requirements was met by the final Times Wire cable.

1.0 SCOPE

1.1 SCOPE

This specification covers step index fiber bundles, insulated, which will serve as optical transmission lines in military aircraft.

1.2 TEMPERATURE RANGE

The operating temperature range of the cable shall be –55°C to 150°C.

2.0 PHYSICAL CABLE REQUIREMENTS

2.1 GENERAL DESCRIPTION

The cables are optical fiber (O/F) bundles sheathed in a jacketing configuration designed to terminate in the ferrule hardware depicted in figure B-1. The materials selected for the cable and the manufacturing process employed to fabricate it shall be such as to minimize fiber breakage and to retain the optical characteristics of the O/F bundle during fabrication, testing, and normal avionics usage.

2.2 INSULATION MATERIAL

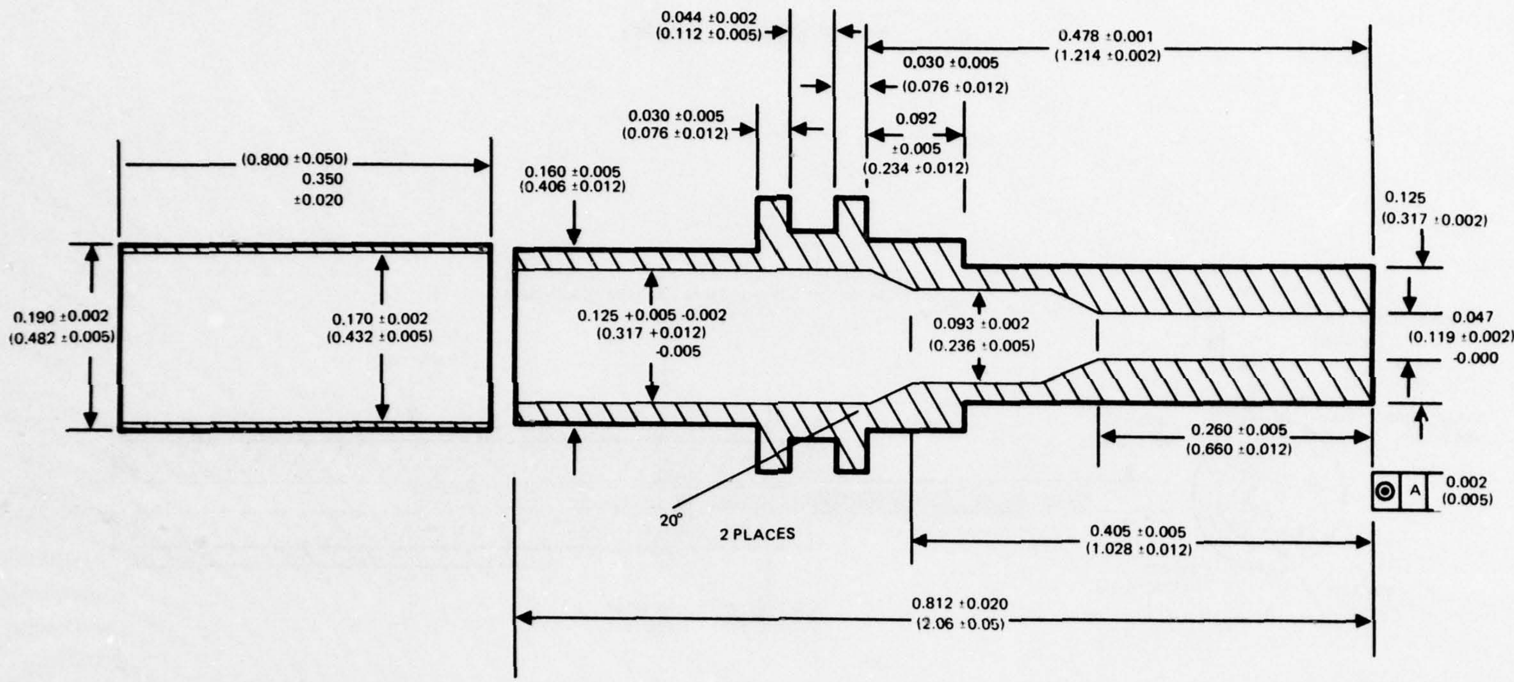
The insulation materials shall be virgin material and shall be dielectric, nonconductive, nonmetallic, and non-nutrient to fungus. The insulation shall be free of splits, cracks, irregularities, and embedded foreign materials.

2.3 VIRGIN MATERIAL

For purposes of this specification, virgin material shall be 100-percent new material which has been through only the processes essential to its manufacture and its application to the fiber optics cable and has been through these essential processes one time only. Any material which has previously been processed in any other manner is considered nonvirgin material. This requirement shall apply to the manufacture of all ingredients and components used.

2.4 STRENGTH MEMBER MATERIAL

The strength members shall be dielectric, nonconductive, nonmetallic, and non-nutrient to fungus. The strength members shall be longitudinally laid in the cable, as required by figure B-2.



DIMENSIONS WITHOUT PARENTHESES ARE INCHES;
DIMENSIONS IN PARENTHESES ARE CENTIMETRES

Figure B-1. Connector detail.

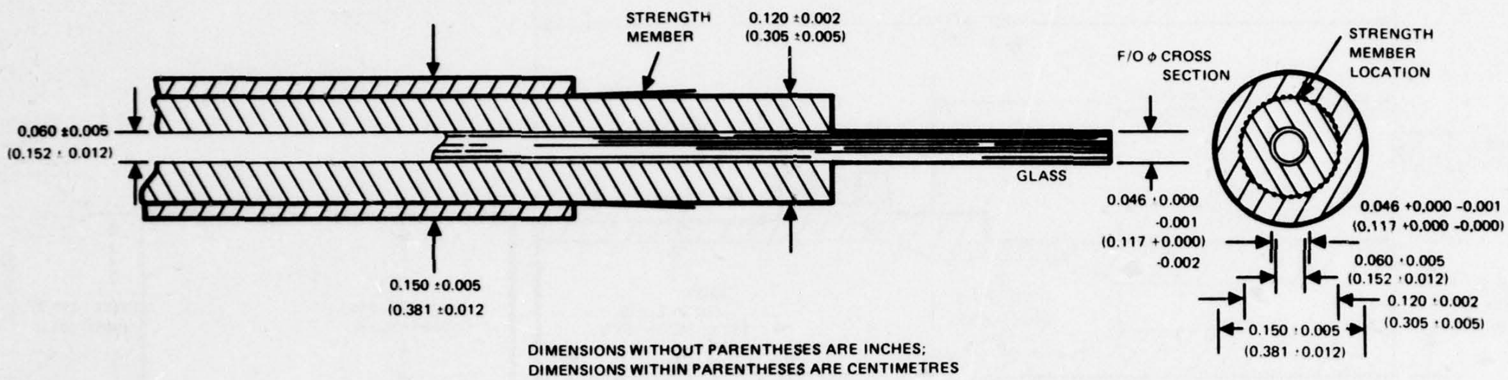


Figure B-2. Cable structure.

2.5 CONSTRUCTION

The design, construction, and physical dimensions of the cable shall be as specified in figure B-2.

2.6 INSULATION THICKNESS

The overall thickness of the insulation or of any primary insulation, insulation coating, or jacket shall be as specified in figure B-2. The thickness shall be determined according to method 1018 of FED-STD-228.

2.7 CONCENTRICITY

The concentricity of the overall insulation or of any primary insulation, insulation coating, or jacket shall be equal to or greater than 0.9. The concentricity shall be determined by locating and recording the minimum and maximum wall thickness of the same cross section. This shall apply to all layers of insulation.

2.8 CABLE DIAMETER

The finished cable diameter shall be as required in figure 2. The diameter shall be computed from the circumference measurement determined in accordance with method 1441 of FED-STD-228.

2.9 IDENTIFICATION OF PRODUCT

The O/F cable shall be identified by characteristic markings and color. The finished cable shall be identified by a printed marking applied to the outer surface of the cable or visible through the outer surface. The marking shall consist of the following at suitable intervals:

1. Manufacturer's code number
2. Date of manufacture.

The printing shall be in accordance with MIL-STD-104, class 1.

2.10 CABLE COLOR

The preferred color of insulation is white or natural. Any color used shall be in accordance with MIL-STD-104, class 1.

2.11 FINISHED CABLE WEIGHT

The finished cable weight shall not exceed 28 grams per metre.

2.12 WORKMANSHIP

The finished cables shall be free of manufacturing flaws that would degrade performance after installation, that would inhibit future processing, and that would otherwise yield an inferior product. The following shall be a minimal level of visual examination to be performed and is not intended to restrict other pertinent workmanship examinations deemed necessary by the manufacturer:

1. Outer jacket: free of cuts, burnt areas, abrasions, holes, roughened areas, bulges, thin spots, and discontinuities.
2. Inner layers: free of cuts, holes, discontinuities, bulges, and thin spots.
3. Strength members: uniformly laid with no interruptions.

3.0 FIBER BUNDLE REQUIREMENTS

3.1 GENERAL DESCRIPTION

The bundles shall consist of multiple strands of randomly laid, step index fibers.

3.2 TRANSMITTED POWER MEASUREMENTS

Radiated power measurements shall be made in accordance with method 6010 of DOD-STD-1678. The radiation source used shall emit radiation of peak emission wavelength ($\lambda\rho$) and emission bandwidth with the following characteristics:

1. $850 \text{ nm} \leqslant \lambda\rho < 950 \text{ nm}$
2. $BW \leqslant 50$ nm.

3.3 ATTENUATION

The attenuation of the fiber bundle shall be determined in accordance with method 6020 of DOD-STD-1678. A reference length (L_2 in the method) shall be taken from each bundle lot. The reference length shall be removed from a bundle designated for use in manufacturing setup and shall be preserved for all attenuation tests to be performed upon the lot. The length of each reference length shall be 1 metre.

3.4 FIBER DIAMETER

Fiber diameter measurements shall be made in accordance with method 1010 of DOD-STD-1678.

3.5 NUMBER OF FIBERS

The number of fibers shall be determined in accordance with method 1030 of DOD-STD-1678. The number shall be sufficient to satisfy the fiber bundle size requirements of figure B-2.

3.6 BUNDLE DIAMETER

The bundle diameter shall be as required in figure B-2. The bundle diameter shall be determined in accordance with method 1020 of DOD-STD-1678.

3.7 NUMBER OF TRANSMITTING FIBERS

The number of transmitting fibers shall be determined in accordance with method 1040 of DOD-STD-1678. The ratio of the number of transmitting fibers in the finished cable to the total number of fibers (both transmitting and broken) in the original fiber bundle before cable production shall not be less than 0.91.

4.0 TEST REQUIREMENTS

4.1 INSULATION FLAWS TEST

The optical fiber cable shall be inspected for flaws in the insulation after the application of the final insulation layer, and the cable jacket leak rate determined according to method 112 of MIL-STD-202, test condition C, procedure I or II. The leak rate shall be equal to or less than 3.2×10^{-4} cc/s/m. One end of the cable shall be sealed with a connector. If the tested length fails, the end seal shall be examined to ensure a proper seal. If the seal is improper, the test length shall be reterminated and retested.

4.2 LOW-TEMPERATURE FLEXIBILITY

Finished cable shall be tested in accordance with method 2020 of DOD-STD-1678. The test samples shall be conditioned for 4 hours at −54°C. The mandrel diameter shall be 2.5 cm. The weight shall be 4.5 kg. There shall be no cracking of the insulation. The transmitted power shall not degrade by more than 10%.

4.3 ACCELERATED AGING

Finished cable shall be tested in accordance with method 4010 of DOD-STD-1678. The test samples shall be conditioned for 96 hours at 150°C. There shall be no melting of the insulation, or shrinkage of more than 1.25 cm per metre. The transmitted power shall not degrade by more than 10%.

4.4 HUMIDITY CONDITIONING

Finished cable shall be tested in accordance with method 4030 of DOD-STD-1678. There shall be no softening or swelling of the insulation. The transmitted power shall not degrade by more than 10%.

4.5 TEMPERATURE CYCLING

Finished cable shall be tested in accordance with method 4020 of DOD-STD-1678. There shall be no softening of the insulation, or shrinkage of more than 1.25 cm per metre. The transmitted power shall not degrade by more than 10%.

4.6 CYCLIC FLEXING

Finished cable shall be tested in accordance with method 2010, procedure 1, of DOD-STD-1678. The mandrel diameter shall be 2.5 cm. The weight shall be 0.9 kg. The number of cycles shall be 200. There shall be no cracking or splitting of the insulation. The percentage of broken fibers shall not exceed 10%.

4.7 IMPACT TEST

Finished cable shall be tested in accordance with method 2030, procedure 1, of DOD-STD-1678. The weight shall be 2.25 kg. The number of cycles shall be 200. There shall be no cracking or splitting of the insulation. The percentage of broken fibers shall not exceed 10%.

4.8 COMPRESSIVE TEST

Finished cable shall be tested in accordance with method 2040, procedure I, of DOD-STD-1678. Incremental loads of 45, 90, 136, and 180 kg shall be applied for 20 minutes each. There shall be no cracking or splitting of the insulation. The percentage of broken fibers shall not exceed 10% total throughout the entire test.

4.9 TENSILE LOADING

Finished cable shall be tested in accordance with method 3010, procedure II, of DOD-STD-1678. There shall be no cracking or splitting of the insulation. Strength members shall not break or elongate more than 1.5%. The transmitted power shall not degrade by more than 10% throughout the entire test. The connector shall not separate from the cable end during the test. The tensile loading shall begin at 4.5 kg and shall be stepped by 4.5-kg increments to 45 kg. The tensile load shall be applied between one end of a cable which shall be terminated with a connector, and the midpoint of the cable which shall be held by a mandrel.

4.10 TENSILE LOADING AFTER HUMIDITY

Finished cable shall be conditioned in accordance with method 106 of MIL-STD-202 except that step 7b shall be omitted. This is the same requirement as in section 4.4 of this document. After completion of the tenth cycle, the specimen shall be removed from the test chamber and within 15 minutes subjected to the tensile loading test required in section 4.9. The cable shall meet the same requirements of section 4.9

4.11 TENSILE LOADING AFTER ACCELERATED AGING

Finished cable shall be conditioned in accordance with method 4010 of DOD-STD-1678. The entire specimen shall be conditioned for 96 hours at 150°C. After removal from the conditioning chamber and cooling to room temperature, the specimens shall be subjected to the tensile loading test required in section 4.9. The cable shall meet the same requirements of section 4.9

4.12 INSULATION ABRASION RESISTANCE

Finished cable shall be tested in accordance with method 2211 of FED-STD-228. A length of 50 cm (±1.25 cm) of #400 grit paper shall be used. The abrasion shall not extend into the strength members.

4.13 BLOCKING

Finished cable shall be tested in accordance with method 8010 of DOD-STD-1678. The cable shall not adhere to itself or to the metal spool.

4.14 FLAMMABILITY

Finished cable shall be tested in accordance with method 5010 of DOD-STD-1678. The cable shall have a 5-second maximum flammability "after burn" and a 5.0-cm maximum flame travel.

4.15 FLUID IMMERSION

Finished cable shall be tested in accordance with method 8030 of DOD-STD-1678. The cable shall be immersed in hydraulic fluid (MIL-H-5606) at 25°C for a period of 168 hours. The cable diameter shall not change by more than 10%. After removal from the test fluid, the cable shall meet the weight requirement of section 2.12. The cable shall then be subjected to the low-temperature flexibility test of section 4.2. There shall be no cracks, splits, or voids in the insulation after the tests.

4.16 ULTIMATE INSULATION TENSILE STRENGTH

Using methods 3021 and 3031 of FED-STD-228 as a guide, the finished cable shall be tested for ultimate tensile strength and elongation of the cable jacket without an enclosed fiber optical bundle. The cable jacket shall meet the requirements of section 4.9.

4.17 TOXICITY

Organic materials used in the cable construction shall not give off toxic fumes when exposed to flame.

5.0 PREPARATION FOR DELIVERY

5.1 PACKAGING

Packaging shall be in accordance with the level A requirements of MIL-C-12000. Cable shall be wound on spools of a nonreturnable type. Each spool shall have a minimum diameter of 25 cm. The cable shall be terminated on both ends, in such a manner that the optical properties of the cable (section 3.2 through section 3.7) can be evaluated.

5.2 PACKING

Packing shall be in accordance with the level C requirements of MIL-C-12000.

APPENDIX C:

TEST REPORT

INTRODUCTION

The following report documents the tests performed on the Times Wire optical fiber cables. The test methods used depended heavily upon DOD-STD-1678, Fiber Optic Test Methods and Instrumentation, and the related documents referenced in that standard. NOSC performed tests 1 through 10. Times Wire performed tests 11 through 24.

1. CABLE DIAMETER, METHOD 1441 OF FED-STD-228

The specified cable jacket diameter was 0.150 ±0.005 inch. The measured cable diameters of the three samples were as follows:

Glass Manufacturer	Outside Jacket Diameter (inch)
American Optical	0.159
Galileo	0.154
Valtec	0.149.

One cable was out of specification by 3 percent. The other cables met the specification.

2. CONCENTRICITY

The specified concentricity for both inner and outer jackets was 0.90 or greater. The measured concentricity was as follows:

	American Optical	Galileo	Valtec
Inner Jacket	0.928	0.735	0.839
Outer Jacket	0.619	0.729	0.648.

The concentricity requirement was not met by the majority of the cable jackets. This is not a major problem, since the optical fiber connectors do not depend upon the jacket for alignment. By tighter specification of the glass bundle diameter, this problem should be eliminated.

3. FINISHED CABLE WEIGHT

The specified cable weight was not to exceed 28 grams per metre. All cables met the weight requirement. The measured weights were as follows:

American Optical	17.5 g/m
Galileo	16.7 g/m
Valtec	16.6 g/m.

4. TRANSMITTING FIBERS, METHOD 1040 OF DOD-STD-1678

This was the most important parameter to be monitored during the contract. Times Wire had to handle and jacket the glass fiber bundles, supplied as GFM, and maintain breakage at less than 9 percent. The number of transmitting fibers was counted in the GFM glass before shipment to Times Wire for cabling. The finished cables were then rechecked after jacketing. The number of fibers broken during the handling and jacketing process was then determined. The breakage of continuous fibers during cabling was as follows:

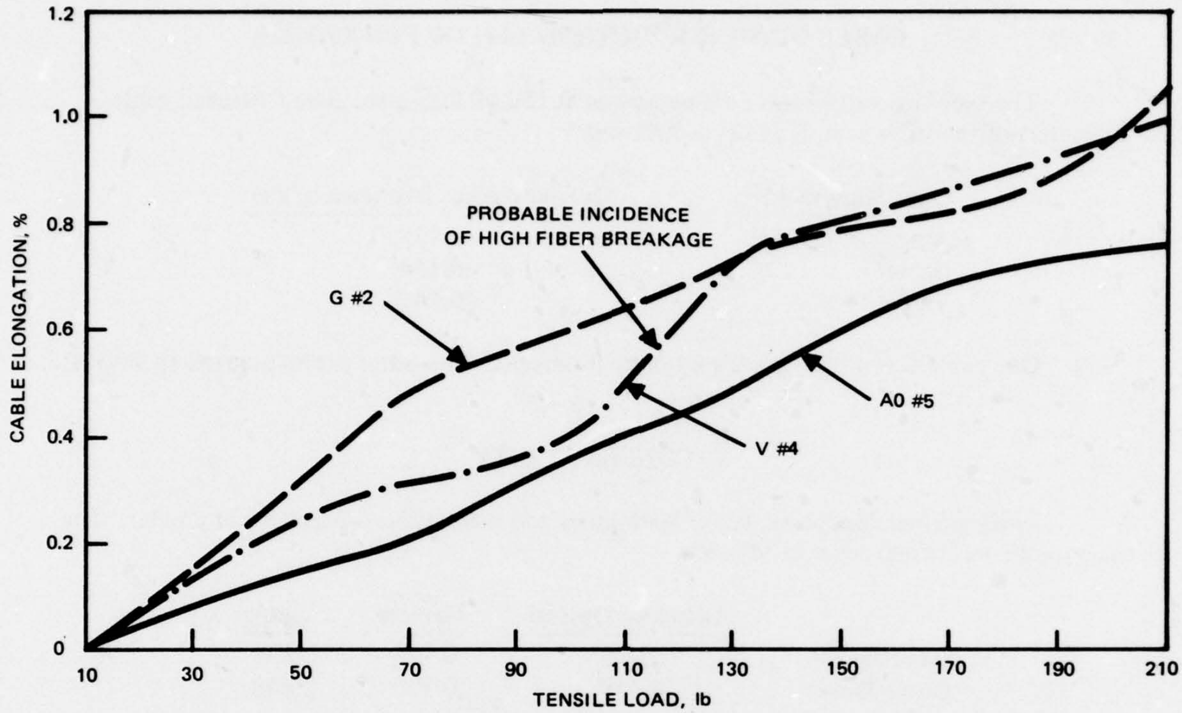


Figure C-1. Cable elongation under tensile load.

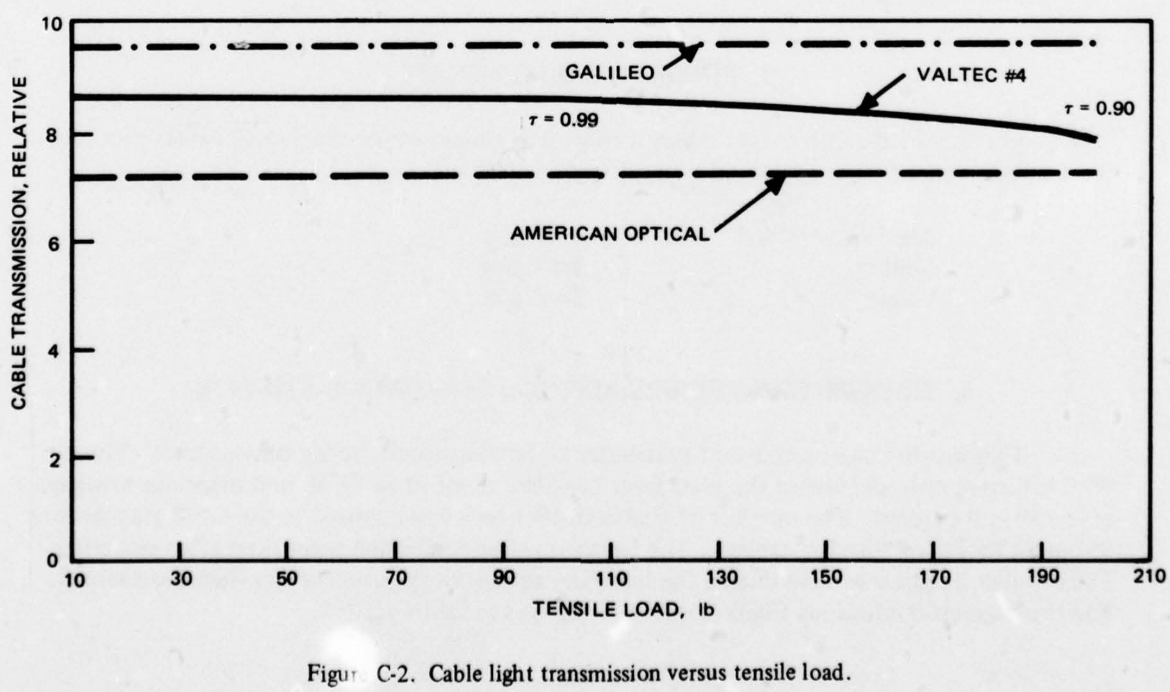


Figure C-2. Cable light transmission versus tensile load.

		Breakage During Cabling
American Optical cable	#1	7.7%
	#2	19.1%
	#3	3.8%
	#4	1.0%
Valtec cable	#1	1.8%
	#2	19.5%
	#3	8.0%
	#4	5.6%

The average fiber breakage was 8 percent. Galileo cable data were not included. The fiber breakage, as delivered from Galileo before any cabling was done, was so excessive that an accurate count of breakage during cabling could not be made. The American Optical and Valtec cables had negligible breakage before the cabling process.

5. ATTENUATION, METHOD 6020 OF DOD-STD-1678

The attenuation of a sample of American Optical cable was measured before and after the cabling process. The attenuation before cabling was 412 ±9 dB/km. The attenuation after cabling was 431 dB/km. The attenuation increased by 4.6 percent. The increase was not caused by the increased breakage, because the added breakage was accounted for in the attenuation calculation.

6. HUMIDITY CONDITIONING

The test procedure followed was method 106D of MIL-STD-202, except for elimination of the vibration exposure. The conditioning consisted of high humidity (>90%), combined with temperature cycling from –10° to 65°C, for a 10-day period. After humidity conditioning, no degradation or additional fiber breakage occurred.

7. TENSILE LOADING, METHOD 3010 OF DOD-STD-1678

The cable specification required that the percent increase in broken fibers not be greater than 10 percent, and the elongation be less than 1.5 percent, when loaded with 45 kg. The cable greatly exceeded this requirement. Less than 1-percent degradation and 0.6-percent elongation occurred at 45 kg. The degradation was 10 percent and the elongation reached 0.96 percent at 91 kg for the Valtec cable. No optical degradation occurred for the Galileo and American Optical cables at 91 kg. The data are shown in figures C-1 and C-2. The tensile load was applied between the jacket and the connector. No separation of jacket or glass from the connector occurred for the three cables tested.

8. TENSILE LOAD AFTER HUMIDITY

After being exposed to the humidity conditioning stated above, the same cables again underwent the tensile loading test. No measurable degradation of any cables occurred during the test. Loads exceeding 80 kg were applied to the cables and connectors. No fiber breakage or connector-cable separation occurred. The cable elongation was under the 1.5 percent specified. The elongation for the cables at 45 kg was as follows:

	Elongation at 45 kg
American Optical	0.82%
Galileo	0.54%
Valtec	0.78%.

There was no measurable degradation of tensile strength or optical properties after the exposure to humidity conditioning.

9. TENSILE LOADING AFTER ACCELERATED AGING

The same tensile loading test was performed on the cables after exposure to accelerated aging. This consisted of 96 hours of exposure to 150°C temperatures. No optical degradation or fiber breakage occurred on any of the cables up to a maximum tensile load of 91 kg. At 45 kg, the cable elongation was as follows:

	Elongation at 45 kg
American Optical	1.0%
Galileo	1.3%
Valtec	1.4%.

10. BEND RADIUS

The cable was wrapped five times around mandrels of various sizes. The number of broken fibers was counted after unwrapping the cable. There were no broken fibers with a 0.375-inch-diameter mandrel. Small amounts of breakage began to occur with a 0.250-inch-diameter mandrel. The cable also tended to kink slightly at 0.250 inch. Since the cable is only 0.150 inch in diameter, it has far better bend properties than regular copper coaxial cable, which must be limited in bend to 10 times the outside cable diameter.

11. WORKMANSHIP

All cables were visually inspected for flaws in construction. No holes or rough spots were observed in insulation.

12. INSULATION LEAK RATE, METHOD 112 OF MIL-STD-202

The insulation leak rate was measured for all cables. The specification required 3.2×10^{-4} cc/s/m. All cables passed specification with the maximum leak rate being 5.04×10^{-5} cc/s/m.

13. LOW-TEMPERATURE FLEXIBILITY, METHOD 2020 OF DOD-STD-1678

The low-temperature flex test was performed by means of a 2.54-cm mandrel and a 4.5-kg weight. The test required a transmitted power degradation of less than 10%. Of 11 cables tested, all passed with the exception of one American Optical and two Galileo cables. The three cables showed power degradations of 14%, 47%, and 14%, respectively. Since eight of the remaining cables showed no change whatsoever, no explanation can be given for these failures. No cracking or splitting of the insulation was observed.

14. ULTIMATE INSULATION TENSILE STRENGTH, METHODS 3021 AND 3031 OF FED-STD-228

All cables were subjected to the ultimate tensile test, redefined to mean the point at which the cable stops transmitting. In no case did the cable fail before 102 kg loading with a maximum elongation of 1 percent.

15. ACCELERATED AGING, METHOD 4010 OF DOD-STD-1678

The cables were subjected to 96 hours at 150°C temperature. The changes in radiant power are shown below:

American Optical 0.00%
Galileo . . . . +2.5%
Valtec . . . . 0.00% .

Shrinkage was less than the specified 1.25 cm per metre, or 1.25%. The measured shrinkage was as follows:

American Optical 0.00%
Galileo . . . . +0.5%
Valtec . . . . +0.25% .

16. HUMIDITY CONDITIONING, METHOD 4030 OF DOD-STD-1678

No melting or cracking of the insulation was noted. Diameter changes were as follows:

Valtec . . . . −1.4%
Galileo . . . . −0.7%
American Optical . . . . +0.36% .

Changes in radiant power are shown below:

Valtec	+20%	(increase)
Galileo	0.0%	
American Optical	0.0% .	

Humidity testing was conducted after preconditioning at 90% ±5% relative humidity at 150° for a period of 164 hours.

17. TEMPERATURE CYCLING, METHOD 4020 OF DOD-STD-1678

The test was conducted on 50-inch samples. In all cases, no change was observed in radiated power. The changes in diameter and length are shown below:

	Diameter Change	Length Change
Galileo #2004	0.68%	1.2%
American Optical #6 . . .	0.63%	1.5%
Valtec #8	0.0%	1.0% .

18. CYCLIC FLEXING, METHOD 2010 OF DOD-STD-1678

The test was performed by means of a 2.5-cm mandrel, 200 cycles, with a weight of 0.9 kg. In all cases, no change in radiated power was observed.

19. IMPACT TEST, METHOD 2030 OF DOD-STD-1678

This test was also performed by means of a 2.5-cm-diameter mandrel, 200 cycles, with a weight of 0.9 kg. All samples failed original specification. The transmitted power went to zero after 24, 42, and nine impacts for Galileo, American Optical, and Valtec cables, respectively. As a benchmark comparison, a 0.150-inch stainless tube with a 0.015-inch wall was subjected to the same test. The tube closed after 15 impacts. The cable did not meet the specification.

20. COMPRESSIVE STRENGTH, METHOD 2040 OF DOD-STD-1678

Samples were subjected to incremental loading from 45 kg to 180 kg. No cracking of insulation was observed on any of the samples. Changes in radiant power were as follows:

Valtec	−19%	(reel failed)
Valtec at 135 kg	−5%	
Galileo	−4%	
American Optical	−6.25% .	

No explanation for the failure of the Valtec reel at a load of 180 kg can be given.

21. INSULATION ABRASION RESISTANCE, METHOD 2211 OF FED-STD-228

A 50-cm length (±1.25 cm) of #400 grit paper was pulled across the cable sample. An 11-lb weight was employed. All three cables passed the test. The jacket was not penetrated to expose the strength member.

22. BLOCKING, METHOD 8010 OF DOD-STD-1678

The blocking test was performed after a conditioning period of 24 hours at 93°C. The test was conducted on a 6-inch mandrel with three turns and three layers. All specimens passed the test.

23. FLAMMABILITY, METHOD 5010 OF DOD-STD-1678

The results were as follows:

	Times Wire Results	NOSC Results
American Optical. . .	33-s burn, 7.0-cm travel	7.3 s
Valtec	14-s burn, 5.1-cm travel	9.6 s
Galileo	25-s burn, 7.6-cm travel	6.3 s.

The specified burn time was 5 seconds. The specified travel distance was 5.0 cm. The cable did not meet the specification. The NOSC results indicated that the specified burn time was exceeded only when the inner tube was penetrated, exposing the serving thread and glass bundle.

24. FLUID IMMERSION, METHOD 8030 OF DOD-STD-1678

Samples were immersed in hydraulic fluid wrapped on a 1-inch mandrel with a weight of 10 lb for a period of 168 hours. No change in diameter was observed. After performance of the fluid immersion test, the samples were subjected to the cold bend test and transmitted power was measured before and after the test. Changes in radiant power were as follows:

	Degradation
Galileo	-2%
Valtec	-4%
American Optical	-9%.

APPENDIX D:

PROBLEMS WITH OPTICAL FIBER BUNDLES

INTRODUCTION

The manufacture of optical fiber cable in production quantities makes use of standard wire cabling processes. However, the handling and processing of the glass bundle during the cabling process presents special problems. The identification and solution of these problems are a major accomplishment of this program. The following report identifies the problems encountered during the cable manufacturing process. All of the problems are associated with the optical fiber bundles. By properly specifying the optical fiber bundle, these problems are eliminated.

The production of optical fiber cables required very precise processing in the first stage of manufacture. The process required very tight tolerances on the first tube. Perturbations in the fiber bundle greatly affected the process.

BUNDLE SIZE VARIATION

The bundles supplied by Galileo and American Optical were not consistent in cross section. It appears that individual fiber tension controls were not adequate to maintain a tight bundle. As a result, the fibers with lower tensions tended to move away from the bundle axis. The extreme case was a loop of approximately 50 fibers, which extended nearly 2 inches from the bundle axis. When the loop entered the extrusion head, the bundle broke. Average perturbation of the fiber axis was approximated at 0.25 inch for the Galileo and 0.125 inch for the American Optical product. The perturbations caused an apparent variation in the outer diameter of the first tube. The Valtec bundles did not exhibit such variations. It is apparent that proper tension control and proper application of the serving thread will yield a consistent bundle cross section. The serving thread lay (between 0.75 and 1 inch) of the American Optical cables would produce a very consistent bundle cross section.

SERVING THREAD

The original cable specification required an inner diameter of 0.060 inch. The glass bundle had a maximum outer diameter of 0.046 inch, leaving a 0.007-inch clearance. For all three bundle types, a serving thread was employed to hold the bundle together. The thickness of the serving thread varied to such a degree that the 0.007-inch clearance was not enough, and this caused small diameter variations in the first tube outer diameter. This was particularly true for the American Optical bundles, which employed a double serving thread wound in opposite directions. As a result, the inner diameter of the first tube had to be increased to 0.065 inch to allow adequate clearance for the serving thread.

For the Galileo glass bundles, the lay of the serving thread showed tremendous variations (from 0.125 inch to 2 inches). The lay variations also caused variations of the outer diameter of the first tube. The lay of the serving thread for both American Optical and Valtec bundles showed no appreciable variation and did not affect processing. Besides not allowing adequate clearance for the serving thread and no specification of the lay of the serving thread, the type of serving thread also was not specified.

Both American Optical and Valtec used a serving thread with a very low melt temperature. During the initial process for manufacturing setup, the serving thread melted when it passed through the extruder head. The Valtec bundles did not suffer damage. The black serving thread melted and smeared on the bundle but did not cause breakage.

The melting problem with the American Optical product was compounded by the use of a double serving thread and did cause two cases of bundle breakage during processing.

In a first attempt to eliminate the problem, the supplied serving threads were removed and replaced by a higher-temperature material. As the American Optical product represented the worst case, the initial work was on a sample of their bundle. It became immediately apparent that, as a result of the unequal fiber tension, the process was length-limited (approximately 20 feet); further attempts to reserve the glass were terminated.

A second approach utilized a nonmetallic insert in the extrusion tip, which isolated the bundle from the heat in the extrusion head. This procedure eliminated the melting problem of the serving thread. The serving thread on the Galileo glass bundles was apparently cotton and was not affected by extrusion heat.

REEL SIZE

The reels supplied by American Optical and Galileo were small plastic reels with a 4-inch hub diameter. Multiple layers of the glass bundles were wound on each reel with low tension. The bundles had free movement on the reels and caused binding during payout. Constant attention had to be paid to the reels during payout to eliminate binding. The possibility of fiber damage during processing is greatly increased with the small reel sizes.

SOLUTIONS

After the experience gained by processing 27 reels of bundles, it is felt that a specification must be developed to cover the bundles to be employed in the manufacture of this type of cable. The specification should require that the individual fiber tension be controlled so that all fibers in the bundle have the same tension (and therefore length), so as to maintain the desired bundle diameter.

The serving thread should be high-temperature material, such as that employed by Galileo, or an equivalent. A 380-denier aramid fiber would be an ideal candidate, and the initial attempt at reserving the bundles used such a material successfully.

The lay length of the serve should be between 0.75 to 1 inch. A standard reel size for the bundles should be specified and it should be large enough that the bundles do not have multiple layers on the reels. The reels supplied by Valtec caused no problem during processing.

APPENDIX E:

COST ANALYSIS

INTRODUCTION

The following cost information is documented for further comparative cost-analysis efforts. The data presented only report details of costs that a potential supplier may expect in the fabrication of this ruggedized optical fiber cable. Information presented in this appendix will include actual cost data as well as projected trends and possible methods of cost reduction based on lessons learned from this contract effort.

COST BREAKDOWN

MATERIAL COSTS

The material costs do not include the fiber bundle because it was a subcontracted item. Total raw-material costs for the entire contract included procurements of 700 lb of Tefzel at $8.09 per lb, as well as Kevlar, Epotek 331 epoxy,* and Dupont Mylar and Kapton tapes, for a total raw material cost of approximately $6200. The material cost for a 305-metre length of cable (excluding the cost of the glass bundle) was $86.50. The breakdown is shown in the table E-1 below.

TABLE E-1. MATERIAL COSTS FOR 305 METRES OF CABLE.

Mylar Marker Tape	Tefzel Inner Tube	Tefzel Jacket	Kevlar Strength Member
$1.50	$36.00	$24.00	$25.00

PRODUCTION SETUP

The production setup costs include the tooling, test fixtures, instrumentation, assembly line, and facilities necessary to produce a given production run of ruggedized optical fiber cable. This cost element also includes the engineering labor hours necessary to translate the technical data package into a production line startup. This engineering labor cost is minimal at $42.35.

A. TOOLING COSTS

Several process jigs and fixtures were procured for this contract effort, which include:

1. Extrusion dies (1 spline, 4 circular) $1620
2. Extrusion tips (1 spline, 1 tube, a jacket Vespel tip, and insert) $1775
3. Sizing plates . . . . $ 950
4. Illuminator . . . . $ 200

Total: $4545.

*Epoxy Technology Corp.

Total man-hours for tooling the dies, tips, and sizing plates include some miscellaneous engineering hours and maintenance work for a sum of 370.5 hours. At a $7.00-per-hour labor rate, the total tooling labor cost is more than $2590.

B. EQUIPMENT SETUP COSTS

The setup costs include the inner tube extrusion, the Kevlar strength member braid, and the extrusion of the outer Tefzel jacket. These costs are as follows:

1. First pass extrusion setup	$120
2. Braided setup	$ 10
3. Second pass extrusion setup	$ 80
Total:	$210.

SPECIAL HANDLING AND PROCESSING

Automated equipment was utilized in the monitoring of the handling and fabrication of these ruggedized cables. During the initial development of production techniques, all phases of each process also were under constant supervision. The costs reflect the labor hours of these special personnel for the following process steps:

1. Extrusion of Tefzel inner tube	$42
2. Braiding of Kevlar strength members	$13
3. Extrusion of Tefzel jacket	$31
Total:	$86.

QUALITY CONTROL

The quality control effort comprises the necessary tests and methods, and thus the associated costs, required to ensure high yield and satisfactory performance. Quality control is that function of management relative to all procedures, inspections, examinations, and tests required during procurement, production, and storage that are necessary to provide the user with an item of required quality.

Total man-hours for inspection, test, and quality assurance are consumed by test machinists, draftsmen, factory technicians, and test engineers. The man-hours and dollar costs are shown in table E-2.

TABLE E-2. QUALITY CONTROL MAN-HOURS AND COST.

Labor Source	Man-Hours	Cost
Machinists	100	$ 678
Draftsmen	82	512
Technicians	579	3215
Engineers	375	2770
Total	1136	$7175

Prior to a breakdown of each individual test and its associated costs, some special equipment was necessary for testing. A glass polisher for $470 was procured to polish the connectors after termination. In addition, man-hours and costs for these terminations were separated from the testing information. The connector assembly process, which is not part of the cable production, is only required for inspection and testing. This required approximately 15 minutes per connector at a cost of $1.40 per termination. The individual test and evaluation costs are given in the tables below. Table E-3 reflects the cost and time required for each inspection stop of the subcontracted procurement of the glass bundles. Table E-4 reflects the cost and time required for in-process testing. Table E-5 reflects the cost and time required for first-article testing. The values represented in these tables are based on one length of cable, which is 305 metres. Quality assurance testing or after-production testing is based on a flat $1200 rate per sample tested. The test list for quality assurance is shown in table E-6.

TABLE E-3. GLASS BUNDLE INSPECTION MAN-HOURS AND COSTS.

Test	Time Required, h*	Cost*
Bundle diameter	0.3	$ 1.50
Fiber diameter	0.5	2.50
Transmitting fibers	1.5	7.50
Fiber count	1.0	5.00
Attenuation	0.25	1.25
Total	3.55 h	$17.75

*Values represent time and cost for one length of cable.

TABLE E-4. IN-PROCESS TESTING MAN-HOURS AND COSTS.

Test	Time Required, h	Cost*
Diameter	0.5	$ 2.50
Concentricity	0.5	2.50
Workmanship	0.15	.75
Transmitting fiber	1.5	7.50
Insulation leak rate	1.0	3.00
Argon leak	0.25	1.25
Tensile loading	0.3	1.50
Ultimate tensile	0.3	1.50
Total	4.5 h	$20.50

TABLE E-5. FIRST ARTICLE TESTING MAN-HOURS AND COSTS.

Test	Time Required, h	Cost*
Diameter	0.2	$ 1.00
Workmanship	0.15	.75
Transmitting fiber	1.5	7.50
Attenuation	0.25	1.25
Insulation leak rate	1.0	5.00
Tensile loading	0.3	1.50
Low-temperature flex	1.0	5.00
Total	4.4 h	$22.00

*Values represent time and cost for one length of cable.

TABLE E-6. QUALITY ASSURANCE TESTING MAN-HOURS AND COSTS.

Test	Cost
Transmitting fibers, fiber breakage Attenuation Humidity conditioning Tensile loading, elongation Tensile loading, humidity Tensile loading, accelerated aging Bend radius Finished cable weight	$1200/sample

MANUFACTURING

The manufacturing effort includes the direct labor incurred during the fabrication, processing, subassembly, final assembly, reworking, modification, and installation of parts to an end item of equipment. Processing labor for this contract includes 386 hours of engineering and 80 hours of production extruding and cabling at a cost of $2830. Project engineering and management consists of 596 hours at a cost of $5455. Assuming a full production capability, the purchase price of the finished product includes all associated company costs, profits, overhead, and other amortized costs. The quantity buys were given as 1000; 10 000; and 50 000 feet. Table E-7 presents these cost estimates as of May 1978. Delivery at these costs is expected to require 14–16 weeks from inquiry.

TABLE E-7. RUGGEDIZED FIBER OPTIC CABLE PROCUREMENT COSTS.

Quantity	Cost
1000 ft (305 m)	$3.23/ft
10 000 ft (3050 m)	$2.94/ft
50 000 ft (15 250 m)	$2.69/ft

CONTRACT COST RESULTS

Presented as a summary of the total contracting effort are the projected and actual cost summaries (table E-8). The contract resulted in a process that should be repeatable by multiple sources for a production cable that satisfies the majority of the specifications outlined in the original statement of work.

TABLE E-8. SUMMARY OF TOTAL CONTRACT COSTS.

	Projected Cost	Actual Cost	Sub Totals
Subcontracted items			
Process jig and fixtures	$6000.00		
Dies – 1 spline		$695.00	
4 circular		925.00	
Tips – 1 spline		310.00	
1 tube		310.00	
1 jacket – Vespel tip		460.00	
1 jacket – Vespel insert		695.00	
Sizing plates			
1 Gatto		425.00	
1 in house		527.53	
Illuminator		196.90	
Glass polisher		469.95	
		$5014.38	
Modification items	2500.00	2749.24	
Totals:	8500.00	7763.62	7763.62
Raw Materials	5773.00		
Tefzel 700 lb @8.09/lb		5663.00	
Kevlar		364.12	
Mylar tape		16.30	
Kapton tape		71.50	
Epotek 331 epoxy		58.80	
Totals:		6173.72	6173.72
Engineering – Labor	13573.13	$15463.28	15463.28
– Burden @ 54%	7329.49		8350.17
Totals:	35175.62		37750.79
G & A @ 30.5%	10728.31		11513.99
Totals:	45728.31		49264.78
Profit @ 10%	4572.83		4926.48
Projected Total	50301.14		
Contract Modification	1000.00		
Totals:	$51301.14		$54191.26

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