FIBERGLAS REINFORCEMENT
FOR SAILPLANES

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INTRODUCTION

This paper discusses glass fibers, how they are manufactured, and their properties. The glass fibers of interest are most generally used as the reinforcement component of a composite system.

The composite system is fiberglass reinforced plastics or FRP. This system is a family of engineering materials. The performance of this material is dependent on and achieved by the selection and combination of three components; resin type, glass reinforcement, and processing technique. Resins are categorized into two main types: thermosets and thermoplastics. There are at least eight different thermoset resins in use today for producing FRP parts. For the strength required in sailplanes, epoxies are the usual choice. Thermoplastic resins currently being used in Fiberglas* reinforced plastic applications include polystyrene, nylon, ABS, polycarbonate, SAN, polypropylene, polyethylene, polysulfone and acetal. Versatility is a prime characteristic of plastics. The choice of resin determine such properties as chemical resistance, weatherability, electrical characteristics, thermal properties and, to some extent, appearance.

The second component of the FRP family of materials is the glass fiber. Its function is to increase these properties of the plastic resin:

- Mechanical strength
- Resistance to impact
- Stiffness
- Dimensional stability.

The strength properties of FRP parts are a product of the form, arrangement, and amount of glass used. Glass fibers reinforce plastics much as steel reinforces concrete and may be directional to resist specific loads or patterned randomly for multidirectional strengths. The usual forms of fiberglass used to reinforce plastics are fabric, roving, woven roving, mat, chopped strands, and milled fibers. Within practical limits, the strength properties of FRP composites increase in proportion to the volume of glass used. (Figure 1) The lowest glass content is achieved with randomly oriented chopped strands. Increasing glass contents can be achieved by more orientation from biaxially oriented fabrics to totally unidirectional continuous strand rovings such as those used in the construction of some sailplane spars.

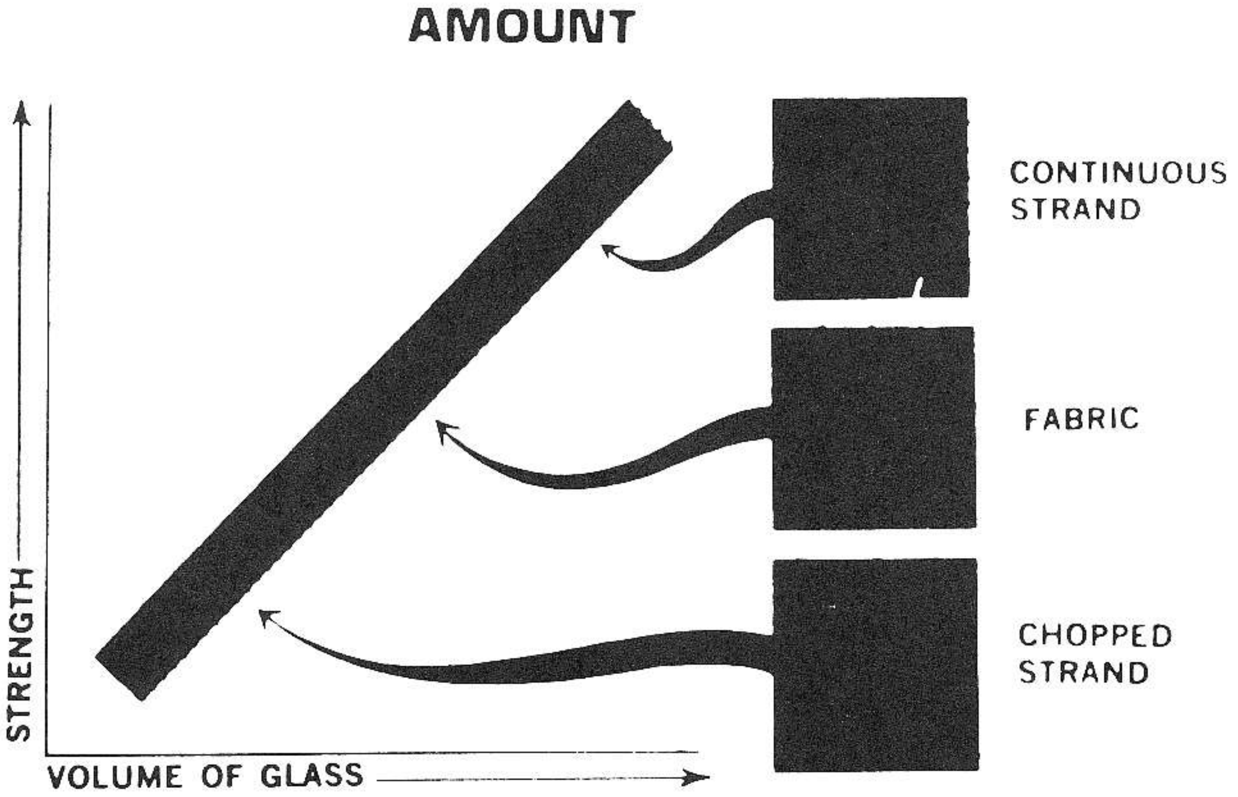

FIGURE 1

The third component of the FRP family is the manufacturing process which ranges from simple hand lay up methods, through intermediate techniques such as cold molding to fully automated methods such as match metal die molding. The final composite properites are dependent upon all three system components--the resin, the glass, and the process.

GLASS FIBERS

Glass is one of the oldest manufactured materials used by man today, dating back as far as 2500 B.C. It is most familiar to the general public in the various forms and shapes of bulk glass--windows, drinking glasses, dishes and lenses. Bulk glass is not thought of as a structural material even though it is very strong in compression because its tensile strength is not as great as other structural materials. It is primarily brittle and subject to easy fracture resulting from minute surface flaws. It does possess extremely high chemical durability and weatherability. Prior to 1938, glass in fiber form was only a laboratory curiosity. Today glass in fiber form is being successfully used as the strength-giving material in various composite structures.

The commonly accepted American definition of glass is that it is an inorganic product of fusion which has cooled to a rigid condition without crystallizing. Chemical, electrical, physical, and mechanical properties of glass are controlled largely by composition. It is possible to draw many different glass compositions into fibers.

Depending upon the drawing media, the resultant fiber will be either a short, noncontinuous fiber called a staple fiber, or a long, continuous fiber. This discussion will be concerned only with the continuous type fiber.

The properties of glass fibers can be better appreciated if you have some knowledge of the process by which they are manufactured. (Figure 2). A glass batch is compounded and mixed with great care to ensure consistent glass composition. The incoming ingredients are checked against quality control standards. The composition is important not only from the standpoint of the properties of the glass fibers, but also from the economic efficiency with which they can be produced which then affects their ultimate price.

In Fig. 3, the standard fiberglass composition is known as E or electrical grade glass. It is an alumina borosilicate glass and is used as the standard reinforcing media for such diverse products as aircraft wing-to-body fairings, electrical high-pressure laminates, and various spacecraft components. S -Glass is a higher tensile strength material that also possesses superior modulus values, higher temperature resistance, and a lower density. It is used in high performance applications such as rocket motor cases and other aerospace applications where high strength-to-weight ratios are important. C glass stands for chemical resistant glass. E and S glass are also resistant to most chemicals but C glass is specifically designed for this purpose. Its reinforcing properties are generally lower than E glass or S glass.

Table 1 shows the comparative virgin fiber properties of E glass, S glass, S-2 glass, which is a more economical version of S glass and C glass. The virgin fiber is that glass tested immediately after leaving the bushing or fiberizing device and before any sizing is applied. The glass composition controls the modulus values but the processing conditions, particularly thermal history, including dwell times at various temperatures, control tensile strength.

The batch is introduced into a melting furnace or tank where it becomes molten glass. The batch can be melted directly or first made into marbles and then remelted. The molten glass then follows from the tank or furnace in to the fiberizing device which is called a bushing. This is made out of a platinum alloy to ensure even heat distribution which in turn aids in maintaining uniform filament diameters. The older standard bushings have 204 holes and produce simultaneously 204 individual glass filaments.

The 204 fibers are brought down past a sizing applicator. A size is a three constituent chemical coating applied to each individual fiber to protect it during further processing and to couple the glass chemically to the matrix resin. Below the sizing applicator the filaments are gathered together into a bundle called a strand by means of a gathering shoe. The strand then passes down to a winder where it is wound onto a forming tube, which is also referred to as a forming cake. The melting temperature of the E-glass bushing is around 2200°F. S glass is higher. A few inches below the bushing the temperature of the filament has dropped to around 500°F. This rapid quenching of the glass, which results from its being wound through still air at speeds over 6,000 ft/min, is one reason for its high tensile strength.

When the cake has been built up to the desired size or weight, the forming tube with the cake is removed from the winder and dried in an oven to remove the solvent associated with the size application. The forming cake is then further processed into roving or yarn.

ROVING

A roving consists of a number of ends or strands of glass gathered together without purposely induced twist, into a flat ribbon-like strand. Each strand or end has a number of filaments in it equal to the number of holes in the bushing from which it was pulled. Thus a 20-end roving made from a 204 hole bushing has 20 x 204 or 4080 individual filaments. Conventional rovings normally come in 12, 20, 30, 60, or

FIBERGLAS MANUFACTURING PROCESS

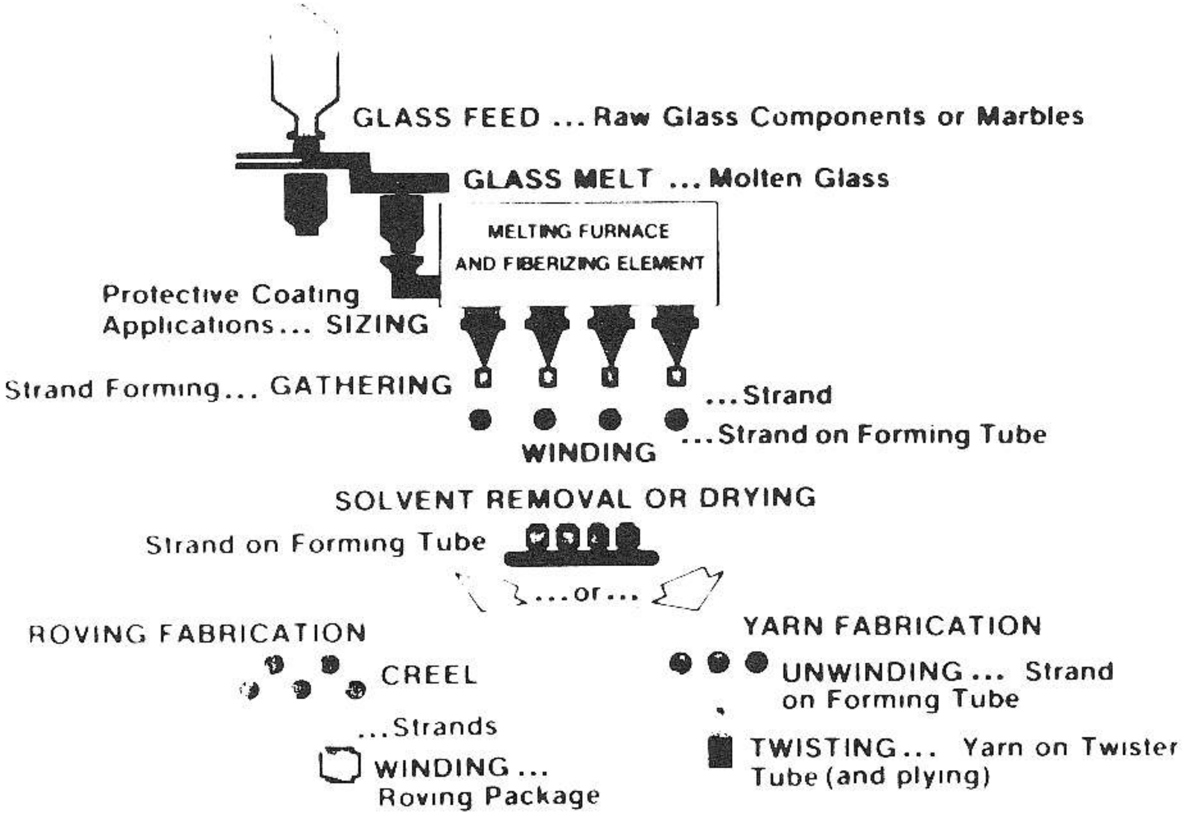

FIGURE 2

COMPARATIVE GLASS COMPOSITIONS

(by weight)

	E Glass	S & S-2 Glass	C Glass
SiO_2	53%	64%	65%
Al_2O_3	13%	25%	4%
CaO	19%	--	14%
MgO	3%	10%	3%
B_2O_3	10%	--	6%
Na_2O	--	--	8%
Others	2%	1%	--

FIGURE 3

PROPERTIES OF GLASS FIBERS

	E	S & S-2	C
Specific Gravity, g/cc	2.54	2.49	2.49
Virgin Tensile Strength, psi	500M	665M	480M
Modulus of Elasticity, psi	10.5M	12.6MM	10.0MM
Elongation, %	4.8	5.4	4.8
Coefficient of Expansion, in./in. °F	2.8	3.1	4.0
Dielectric Constant, 1MHz	6.33	5.34	---

TABLE 1

120 ends. As forming technology advances the 204 hole bushing is being replaced by larger bushings with 408 and 816 holes. More recently a new concept in roving called Type 30 has been introduced. It has only a single end containing in excess of 2,000 filaments. Rovings are primarily used in the filament winding process and for unidirectional laminates. The nomenclature of a roving contains a designation for the glass composition, the type of fiber, the filament diameter, the yards per pound or yield of the roving and a number designating the sizing. Thus, a typical roving would be called out as: (Glass--E); (Type Fiber--C); (Filament--G 135); (Yield--225); and (Sizing--801). This is an E Glass, continuous filament with a G diameter and has 13,500 yards of glass per pound of the basic forming strand and 225 yards of glass per pound of the finished roving. The chemical sizing is designated as 801. The 13,500 yards per pound is arrived at by taking the G 135 strand designation and adding two zeros. The same principle would apply if the basic forming strand were a G 68 with 6,800 yards per pound. The 13,500 is then divided by the 225 yield to determine that you have a 60 end roving. Conversely, if you know you have a 60 end roving you can arrive at the 225 yards per pound figure.

In recent years, economic reasons have forced an increase in filament diameters from the older G filament to larger K and M diameters. Table 2 shows the decimal equivalents of the letter designations.

The sizing of a roving product is a three constituent chemical composition consisting of a lubricant to help reduce abrasion as the strand is processed over guide eyes and tension bars; a film former to give the fiber additional protection and impart strand integrity; and a coupling agent such as a silane to chemically bond the glass fibers to the matrix resin.

We saw earlier the properties of the virgin fiber before any sizing has been applied and before the strand has been processed into a roving ball. Table 3. In roving form, the virgin filament tensile strength of E glass reduces from 500,000 psi to 280,000 to 350,000 psi depending upon the end count and the particular polyester or epoxy sizing used. The virgin tensile of epoxy compatible S glass is reduced only from 665,000 psi to about 550,000 psi. We guarantee a minimum individual package value of 530,000 psi. These values are measured by ASTM 2343-65T.

TYPICAL ROVING
FILAMENT DIAMETERS

G	.00035 - .000399 inches
K	.00050 - .000549 inches
M	.00060 - .000649 inches

TABLE 2

ROVING STRAND TENSILE AND
SHORT BEAM SHEAR STRENGTHS

(psi)

	E Glass	S-2 Glass	S Glass
Virgin Filament Strength	500M	665M	665M
Roving Strand Strength	280M-350M	530M	550M
Short Beam Shear Strength	6M-8M	8M-10M	10M-12M

TABLE 3

The shear strengths of epoxy rovings as measured by the NOL short beam shear test generally run around 6,000 to 8,000 psi for commercial E glass sizings and 10,000 to 12,000 psi for S glass. These results are obtained on a 1/4-in. thick, 1/4-in. wide, 3/4-in. chord length ring, wound in air, with about 2 percent voids and a bisphenol-A diepoxide and MMA resins system. Higher values close to the ultimate can be achieved with vacuum winding. Shear values for polyester rings are usually not specified.

YARN

Another form into which strand from a forming cake is processed is yarn. Yarn may be defined as a twisted strand or an assemblage of twisted and plied strands forming a continuous structure suitable for use in weaving textile materials. The system for identifying fiberglass textile yarns is similar to that of roving. A typical example is ECG 150 2/2, 3.8S, where the letters describe the strand as we saw in roving. The second number which looks like a fraction, indicates the number of strands used to construct the yarn. The first digit indicates the number of forming packages or single strands twisted and the second digit the number of twisted strands that are then plied together. The product of the two is the number of ends of yarn on the package or bobbin. The 3.8S refers to 3.8 Turns Per Inch in the S direction. Commonly utilized yarn filament diameters are B, DE, E and G. Table 4 shows their decimal equivalents.

TYPICAL YARN FILAMENT
DIAMETERS

B	.00012 inches
DE	.00025 inches
E	.00029 inches
G	.00037 inches

TABLE 4

The sizing on yarn as opposed to that on roving usually has no coupling agent. It is merely a starch-oil base to serve as a lubricant during the weaving operation. After weaving, the fabric is usually heat cleaned and a variety of proprietary finishes can be applied by the weaver. Volan A is one usually used. Some yarns do have a direct compatible size applied at the bushing as is done with roving. The fabrics woven from these yarns do not need to be heat cleaned and thus, generally, can have somewhat higher physical properties.

FABRICS

Fabrics and tapes are woven by a weaver from fiberglass yarns. They are available in a large variety of widths, constructions, and weights. The basic weave patterns available commercially are plain, leno, and satin. Table 5 describes the construction and properties of some of the common fabrics. The plain weave is the most stable, gives the best cover and is best suited to flat laminates. It has the lowest strength in a composite. The leno weave has better drape characteristics and higher composite properties than the plain weave. The satin weave is the most pliable and drapeable and gives the highest strength properties of the three types of basic weaves. Typical fabric styles utilized in reinforced plastic laminates are 181, 1581, and 7781, which have approximately equal strength in the warp and fill directions; 143, which is essentially a unidirectional fabric with the greatest strength in the warp direction and 34 style fabric with most of its strength in the fill direction. These fabrics have the satin weave.

There are several variables within a glass yarn system which will control the physical and mechanical properties of a glass fiber reinforced plastic fabric laminate other than the type of weave. These variables are the glass composition; the filament diameter; the number of filaments in a yarn strand; the twist and ply of the yarn; the finish applied to the yarn or fabric.

Table 6 illustrates the effect of composition. These test panels were reinforced with 14 plies of 1581 fabric, woven from ECG 150 1/2 3.8S and SCG 150 1/2 3.8S yarns, fabricated with an Epon 828 and CL hardener epoxy resin system. The S glass generally shows superior properties. In addition to building up solid fabric laminates, fabrics are also used as skins over various honeycomb materials. This yeilds a lightweight structure which is thick and thus possesses a higher section modulus. This enables the glass to carry higher tensile loads without buckling before its yield point.

DOMESTIC FABRIC CHARACTERISTICS

Style	W x F	Yarn W x F	Thickness (Inches)	Weight (oz./sq. yd.)	Tensile W x F (Pounds)
120	60 x 58	D450 1/2 D450 1/2	.0040	3.16	135 x 125
143	49 x 30	E225 3/2 D450 1/2	.0090	8.78	650 x 60
181	57 x 54	E225 1/3 E225 1/3	.0090	8.90	350 x 340
1581	57 x 54	ECG 150 1/2 ECG 150 1/2	.0090	9.00	375 x 335
7781	57 x 54	DE75 1/0 DE75 1/0	.0090	8.95	590 x 396

TABLE 5

AVERAGE PROPERTIES OF EPOXY LAMINATES
REINFORCED WITH 1581 FABRIC AND
VOLAN A FINISH

	Strength (PSI)		Modulus (PSI x 10^6)	
Property	S Glass	E Glass	S Glass	E Glass
Tensile	74,700	55,800	3.29	3.16
Compressive	58,800	59,200	4.67	4.22

TABLE 6

Glass fibers are commercially available in a variety of filament diameters as was previously seen. Generally, speaking, the smaller the diameter, the more flexible the yarn. Table 7 illustrates the effect of the filament diameter. These yarns have basically the same weight of glass, only the yarn diameters were changed. The yarn which did not require plying reported, generally, the best properties. The twist and ply of a yarn will have an effect on the mechanical properties of a laminate. When a yarn is just twisted, there are economic and property advantages over twisting and plying the yarn. The reason for the property difference has never been fully understood, although the parallel alignment of filaments in the non-plied yarn exposes more surface area for improved glass to resin bonding. The effect of each of the variables is very difficult to separate.

To this point, we have illustrated the differences in mechanical properties through the fabric weave, glass composition, and yarn construction. There are also certain advantages to be gained through the selection of the finish applied to the fabric. As an example, Table 8 shows S glass with Volan A versus S glass with 901 direct sizing and E glass with Volan A versus E glass with UM 550 finish. Table 9. The finish applied to the fabric has a very definite effect on the properties achievable in the laminate. Most finishes like most sizings are based on silane type chemicals, which are compatible with the various resin systems.

As you know, the glass fiber sailplane has been developed in European countries, primarily in Germany. The fabric styles utilized in Europe are shown on Table 10. Unfortunately, with the exception of domestic style number 1557 which corresponds pretty closely to the Interglas number 91-125, there are no standard domestic equivalent fabrics. However, any of the major U.S. weavers have the capability of making equivalent fabrics.

CONCLUSION

In recent years, the combined efforts of the glass fiber producers and the weavers have lead to developments in fabric reinforcements, as well as in roving materials, which have opened new potentials for composite materials. New glass compositions such as S glass to improve mechanical, electrical, and chemical properties have been developed to advance the state of the art. Improvements in fabric design, weaving technology and finishing technology have increased composite design limitations. Remember that Fiberglas reinforced plastics is a family of engineering materials. As such the key variables to consider are: (1) the type of glass with all its associated characteristics such as composition, form, filament diameter and sizing; (2) the resin system, and (3) the process such as lay up, vacuum bagging or matched die molding. Keep in mind that although there are a number of variables to be considered, their proper choice can pay off in a composite structure with definite performance advantages.

14. Lee, H. and Neville, K., Handbook of Epoxy Resins, McGraw Hill, 1967.

15. Semjonow, V. and Wurtinger, H., "Strahlungsaufneizung von Glasfaser/Kunststoffen," Kunststoffe, 54, p. 17, 1964, 1.

REFS. CONTINUED FROM P. 7

AVERAGE PROPERTIES OF EPOXY LAMINATES
REINFORCED WITH 181 FABRIC
VOLAN A FINISH
E-GLASS COMPOSITION

	Strength (PSI)			Modulus (PSI x 10^6)		
Property	ECE 225 1/3 Yarns	ECG 150 1/3 Yarns	ECDE 75 1/0 Yarns	ECE 225 1/3 Yarns	ECG 150 1/3 Yarns	ECDE 75 1/0 Yarns
Tensile	53,400	51,500	56,100	2.63	2.77	2.70
Compressive	47,500	49,900	44,100	4.25	4.05	4.94
Flexural	80,500	80,800	88,100	3.84	4.15	4.03
Interlaminar Shear	2,770	2,780	2,790	--	--	--

TABLE 7

AVERAGE PROPERTIES OF EPOXY LAMINATES
REINFORCED WITH 181 FABRIC
S-GLASS COMPOSITION

	Strength (PSI)		Modulus (PSI x 10^6)	
Property	Volan A	901	Volan A	901
Tensile	74,700	97,700	3.29	3.15
Compressive	58,800	67,400	4.67	4.60
Interlaminar Shear	2,405	3,040	--	--

TABLE 8

AVERAGE PROPERTIES OF EPOXY LAMINATES REINFORCED WITH 181 FABRIC E-GLASS COMPOSITION

	Strength (PSI)		Modulus (PSI x 10^6)	
Property	Volan A	UM 550	Volan A	UM 550
Tensile	56,100	69,800	2.70	2.91
Compressive	44,100	57,600	4.94	5.13
Flexural	88,100	94,800	4.03	4.41
Interlaminar Shear	2,790	2,870	--	--

TABLE 9

EUROPEAN INTERGLAS FABRIC STYLES

Style	Use	Warp Yarn	Fill Yarn
91-100	Overlay finisn on wings	EC9 68 (ECG 75½)	EC9 136 (ECG 37½)
91-125	Fuselage skin	EC9 34 x 2 (ECG 150½)	EC5 11/2 (ECD 450½)
92-110	Torque shell on wings and fuselage	EC9 68 (ECG 75½)	EC9 68 (ECG 75½)
92-140	Reinforcement of spars and bulkheads	EC9 68 (ECG 75½)	EC9 136 x 4 (ECG 37¼)
92-146	Spars	EC9 136 (ECG 37½)	EC9 68 (ECG 75½)

TABLE 10