REPORT No. 3.

REPORT ON INVESTIGATIONS OF AVIATION WIRES AND CABLES, THEIR FASTENINGS AND TERMINAL CONNECTIONS.

By JOHN A. ROEBLING'S SONS CO., TRENTON, N. J.

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In reference to our investigations of aviation wires and cables, their fastenings and terminal connections for stays, we have failed to find from past practice anything that would allow us to determine the best lines on which to proceed; therefore our study is not limited to any one stay design.

In making our investigation we have aimed to eliminate the use of acid and solder, imperfect bends, flattening of cable on bends, injury to wire, strand, and cord due to unskillful handling of material in the field; and based on our study of present methods of manufacture of aeroplanes we believe it is possible to manufacture the complete stay here at the factory, proof test same to 50 per cent of its ultimate strength, measure same under stress, and therefore eliminate any uncertainty as to strength of terminal connection, length of stay, and workmanship.

On this basis our research covered not only the terminal connection for shop attachment, but also a connection that would allow repairs to be made in the field without requiring the use of blow torch and solder, and from the following tests it will be readily seen that the development eliminates any doubt on this point.

We find present practice considers "the solid wire stay," consisting of one wire of suitable diameter and known to the trade as "aviation wire"; "the strand stay," consisting of either 7 or 19 wires stranded together and known to the trade as "aviator strand"; also "the cord or rope stay," consisting of 7 strands twisted together forming a rope, the strands being either 7 wires or 19 wires; and the rope known to the trade as "aviator cord."

THE SOLID WIRE STAY.

PLATE NO. 1.

Figure 1.

Figure 1 shows the type most generally in use. An eye or loop is formed in tinned aviator wire and a ferrule made by wrapping a thin flat strip around both wires. The free end of the wire is then bent back over the flat ferrule, holding it in place, and the whole terminal dipped in solder. This type of terminal is far from being satisfactory. Its mechanical strength is low and variable. The process of soldering involves the possibility of establishing a source of corrosion, as well as injuring the quality of the wire. The making of such a terminal is almost necessarily a factory proposition and provides no means for quick and efficient field replacements.

Figure 2.

The standard terminal in Europe is shown in figure 2. This consists of an oval spring wire ferrule applied in almost the same manner as the flat wire ferrule in figure 1. Particular emphasis is placed on the method of forming the eye in the stay before applying the ferrule. Radius of curve at "A" and "B," figure 2, must be exactly the same as radius at "C." This is called a perfect eye. No solder is used. The ferrule is made of wire of the same size as wire in stay and is "spring" quality. Nine convolutions constitute the standard length of ferrule. The hole in the ferrule is oval and a snug fit for the two wires forming the eye of stay. Both wire and ferrule are tin coated. The free end of the wire is bent back over the ferrule and is not fastened in any way. This holds the ferrule firmly against the shoulder at "A" and "B."

Tests made on stays having this type of terminal did not show very satisfactory results. Eighty per cent of the tests showed an efficiency of less than 65 per cent, the free end of the wire slipping through the ferrule at failure of the stay. In the remaining 20 per cent of the tests the wire broke at "A," the stays having an average efficiency of 68 per cent of the total strength of the wire.

Figure 3.

Figure 3 shows eye having radii "A" and "B" different from "C," which is not allowed in foreign specifications and practice. Tests made on terminals having an eye formed as in figure 3 always resulted in pulling through the free end of the wire at low efficiency.

Figure 4.

In order to determine whether the direction of pitch of the spiral spring ferrule had any influence in determining the efficiency of the stay, sample terminals having left-hand ferrules as in figure 2 and right-hand ferrules as in figure 4 were made with a perfect eye in both cases, tested, and compared. The left-hand ferrule clearly showed an efficiency of about 5 per cent more than the right-hand ferrule. In testing the latter the free end of the wire slipped in every case.

Figure 5.

In figure 5 an effort was made so secure the free end of the wire against slipping when strain was applied to the stay by wrapping this end around the main stay wire. Tests on this construction showed an average efficiency of 72 per cent, fracture taking place at "B."

Figure 6.

Another method of securing the loose end consisted of tying the end down on the ferrule with fine annealed wire as shown in figure 6. Tests made on this construction showed an average efficiency of 70 per cent, fracture taking place at "A."

CONCLUSIONS BASED ON ABOVE TESTS.

Observations made during tests of terminals 5 and 6 showed clearly that the weak points of this construction existed at "B" and "A," respectively, and that it was necessary to increase the friction between the walls of ferrule and the wire of the stay under strain to increase efficiency. Reliable information at hand showed that the same conclusions had been aimed at by foreign engineers stationed in America and that they had solved the problem by soldering the spring ferrule terminal in the same manner that Americans had adopted with the flat wire terminal.

HORN'S IMPROVED TERMINAL CONNECTION.

In an effort to avoid the use of solder with its many objectionable features types of construction as shown in figures 7 to 15, inclusive, were originated and tested. In every case the spring ferrule with left-hand pitch was adopted. The loose end of wire was secured with a tie or simple wire loop or clip as shown. Numerous tests made at intervals throughout the entire series of tests with wires having strengths of 1,600, 1,800, and 2,300 pounds showed conclusively that there is no difference in efficiency of stays using wire of any of the above strengths.

Figure 7.

Figure 7 shows a wedge between the ferrule and free end of wire so placed that as strain is applied to the stay and the bend in the free end of wire drawn toward the ferrule the wedge is forced in and thus increases the friction between the wall of the ferrule and the main stay wire. Average efficiency secured, 82 per cent; range of efficiency, 80 to 84 per cent. Fracture at "A" in ferrule.

Figure 8.

Figure 8 shows two wedges with a connecting yoke. The wedges enter on each side between the two wires and force them apart and against the wall of the ferrule as strain is applied. The wedges are forced in by pressure on the connecting yoke which passes under the bend of the free end of the wire as this free end is drawn into the ferrule under strain. Average efficiency of terminal in test equals 80 per cent. Range of efficiency in tests made, 79 to 83 per cent. Fracture at "A."

Figure 9.

In construction of figure 9 two wedges were used as in figure 8, but the yoke was replaced by a washer with two holes in it encircling both wires of the stay. Pressure on the wedges was supposed to be secured under strain by the drawing in of the loose end under strain. This result was not realized as the washer became locked on the main wire and broke the loose end at "D." Efficiency secured was only 70 per cent; range, 60 to 75 per cent.

Figure 10.

In figure 10 two wedges were used as in figure 8 and figure 9. The free end of the wire was wrapped around the main stay wire and pushed in the wedge as initial slippage occurred. Average efficiency, 84 per cent; range, 75 to 87 per cent. Fracture at "A" in ferrule.

Figure 11.

Figure 11 shows a double eye with no wedge. Standard straight ferrule with free end tied. This type of eye could only be used on stays when turnbuckles or hooks to be attached had open eye. Average efficiency in test, 80 per cent; range, 74 to 82 per cent. Fracture at "A."

Figure 12.

Figure 12 again shows a double eye in stay with a single wedge between wires on the eye end of the ferrule. As ferrule is drawn down against shoulders "A" and "B" the wedge is forced in. This increases friction of wires against ferrule at "A" and "B," but not at "D" and "E." Average efficiency, 85 per cent; range, 80 to 87 per cent. Fracture at "A."

Figure 13.

Figure 13 shows a construction consisting of a double eye in stay, a single wedge under the eye, and an oval spring wire ferrule tapered at the same angle as the wedge. In this case the pressure of the wedge forces both wires throughout the entire length of the ferrule against the walls of the ferrule and this increases friction on the ferrule uniformly as the strain increases on the stay and reduces the strain at the weak points "A" and "B" proportionately. Fracture always took place at "E." Average efficiency, 94 per cent; range, 92 to 95 per cent.

In figure 13 we have the most efficient terminal tested. It has none of the objections of a soldered terminal. It is simple, parts are inexpensive, strong, and few in number. It is an ideal terminal for emergency use in the field.

Figures 14 and 15.

Figures 14 and 15 show modifications of this type to overcome any objections which might be raised to the double eye. The wedge and a substantial thimble are combined in one piece. To secure more points of contact, and consequently greater friction, and also for greater flexibility, the taper ferrule is made of finer wires and with more convolutions. The wedge thimble may be open or closed, as desired. Fracture took place at "E." Average efficiency, 94 per cent; range, 92 to 96 per cent.

Summary of tests for efficiency.

Terminal.	Average efficiency.	Range of efficiency.	Points of fracture.	Remarks.
	Per cent.	*Per cent.*		
1	80	60–90	"A" or "B"	American, soldered.
2	65	60–75	"A" or slipped.	Foreign, proper eye.
3	62	60–65	Slipped	Foreign, improper eye.
4	60	59–61	do	Right-hand ferrule.
5	72	65–75	"B"	End wrapped around stay.
6	70	68–78	"A"	End tied to ferrule.
7	82	80–84	"A"	Wedge under hook.
8	80	79–83	"A"	Two wedges with yoke.
9	70	60–75	"D"	Two wedges with washer.
10	84	75–87	"A"	Two wedges end wrapped.
11	80	74–82	"A"	Double eye, no wedge.
12	85	80–87	"A"	Double eye, 1 wedge.
13	94	92–95	"E"	Tapered ferrule, double eye, wedge.
14–15	94	92–96	"E"	Thimble wedge T. F. single eye.

NOTE.—These tests were made with wire having a diameter of 0.102 inch and a strength of 1,600, 1,800, and 2,300 pounds. No difference in efficiency of stay was found by using wire of any of these strengths.

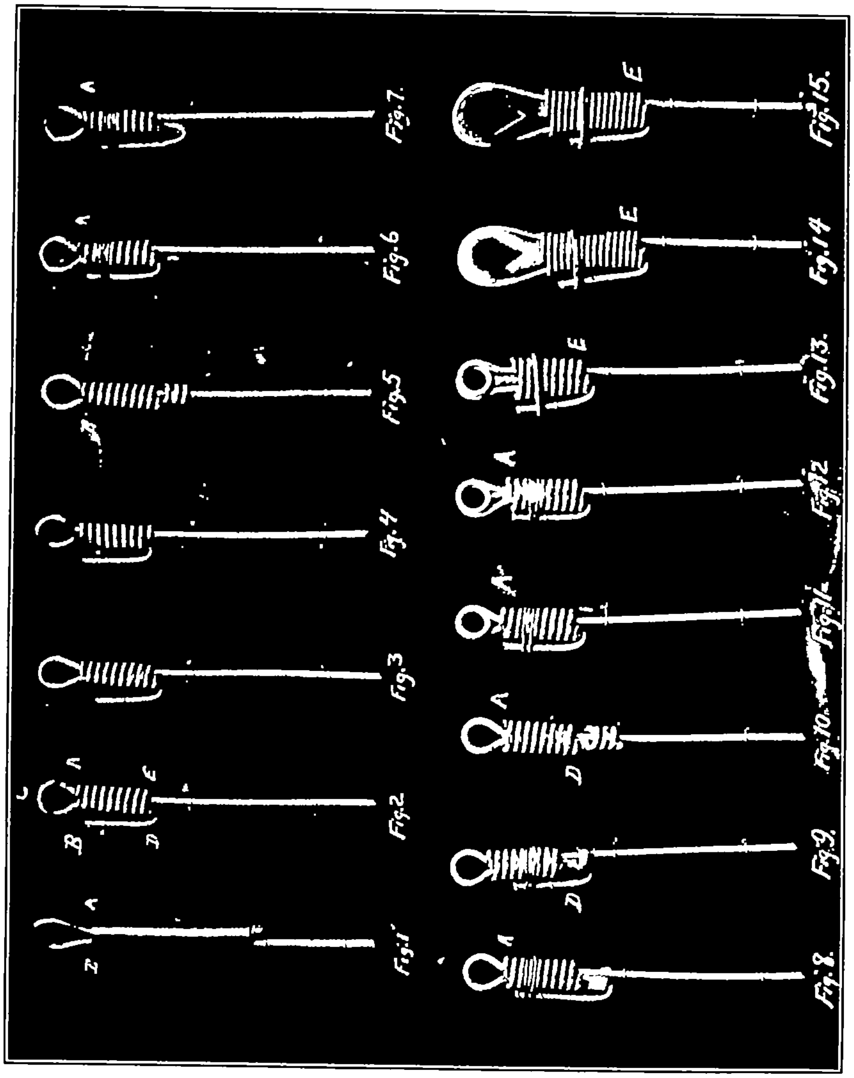


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
Fig. 12
Fig. 13
Fig. 14
Fig. 15

PLATE No. 1.

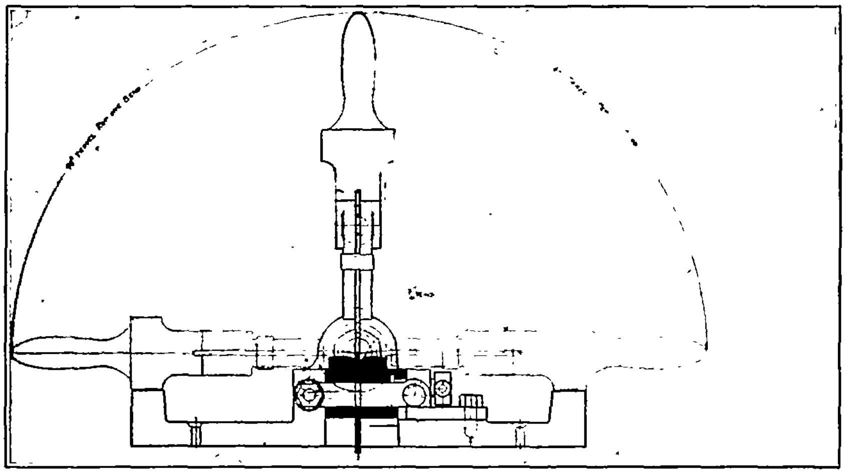


PLATE No. 2.

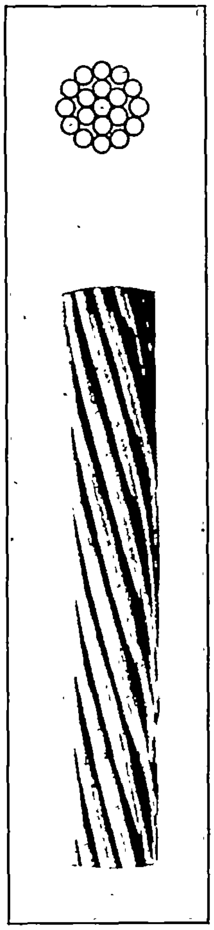


PLATE No. 3.

STANDARD WIRE FOR STAYS FOR AEROPLANES.

The original object in the manufacture of this material was the securing of the wire as strong as possible in order to reduce the weight as much as possible. This resulted eventually in the manufacture of a wire so hard and strong that difficulty was experienced in forming the eye and bend over the ferrule without breaking the wire. The result of this was a lack of confidence in high-strength wire, and in some cases the reaction extended to the use of a wire which could properly be classed as a soft wire. The process of soldering terminals on wire stays undoubtedly helped to a great extent in building up this prejudice. Nevertheless it is still true, as at first, that a strong wire which is serviceable permits the possibility of reducing weight and is therefore desirable. The great number of tests on wire and stays, which were necessary to determine the properties of different types of terminals as described above, afforded a very excellent opportunity to note conclusively the effect of using various grades and strengths of wire. We determined that it was all important that the wire should be tough and ductile as well as strong. All bends should be made without danger of fracture. In addition to requirement for tensile strength, we found it necessary to recommend requirements for torsion and bend. As the per cent efficiency of the stay due to loss of strength at terminal is as great with a strong wire as with a weaker wire, as was clearly demonstrated in our tests, it followed conclusively that as high a strength as can be secured commercially under the conditions of torsion and bend test required was desirable. The following specification is therefore recommended as representing suitable high-grade material for the purpose.

Standard aviator wire (tinned).

Diameter (inches).	American gauge (Brown & Sharpe).	Nearest fraction of inch.	Minimum breaking strain.	Minimum torsion in 6 inches.	Minimum number of bends through 90° over $\frac{1}{16}$ inch radius of jaws.	Weight in pounds per 100 feet.
0.204	4	$\frac{13}{64}$	6,700	9	4	11.15
.182	5	$\frac{3}{16}$	5,500	10	4	8.84
.162	6	$\frac{5}{32}$	4,500	11	5	7.01
.144	7	$\frac{9}{64}$	3,700	12	6	5.56
.128	8	$\frac{1}{8}$	3,000	14	8	4.40
.114	9	$\frac{7}{64}$	2,500	16	9	3.50
.102	10	....	2,000	18	11	2.77
.092	11	$\frac{3}{32}$	1,620	21	14	2.20
.081	12	$\frac{5}{64}$	1,300	24	17	1.744
.072	13	....	1,040	27	21	1.383
.064	14	$\frac{1}{16}$	830	31	25	1.097
.057	15	....	660	34	29	.870
.051	16	....	540	39	34	.690
.045	17	$\frac{3}{64}$	425	44	42	.547
.040	18	....	340	49	52	.434
.036	19	....	280	55	70	.344
.032	20	$\frac{1}{32}$	225	61	85	.273
.028	21	....	175	70	105	.216

PLATE NO. 2.

Breaking strain.—Test sample should be at least 15 inches long, free from nicks or bends. It should measure 10 inches in the clear between the jaws of a standard testing machine. Load should be applied uniformly at a speed not exceeding 1 inch per minute.

Torsion.—Test sample should be gripped by two vises 6 inches apart. One vise is turned uniformly at a speed not exceeding 60 revolutions per minute. On the large size of wire this speed should be reduced sufficiently to avoid undue heating of the wire. The vise which is not turned should have free lateral movement in either direction.

Bend test.—Wire for bending test should be a straight piece. One end is clamped between jaws having their upper edges rounded to 3/16-inch radius. The free end of the wire is held loosely between two guides and bent 90° over one jaw. This is counted one bend. On raising to vertical position the count is two bends. Wire is bent to the other side and so forth, alternating to fracture, each 90° bend counting one.

Diameter of strand.	Breaking strength of strand.	Approximate weight per 100 feet.
$\frac{5}{16}$	12,500	20.65
1/4	8,000	13.50
$\frac{7}{32}$	6,100	10.00
$\frac{3}{16}$	4,600	7.70
$\frac{5}{32}$	3,200	5.50
1/8	2,100	3.50
$\frac{7}{64}$	1,600	2.60
$\frac{3}{32}$	1,100	1.75
$\frac{5}{64}$	780	1.21
$\frac{1}{16}$	500	.78
$\frac{1}{32}$ 7 wire	185	.30

PLATE NO. 3.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Roebling galvanized aviator strand consists of 19 fine wires of great strength stranded together. On account of its small size the $\frac{1}{32}$-inch diameter strand is made of seven wires. This strand is not very flexible and is used for stays. This strand is approximately one and one-third times as elastic as a solid wire of the same material.

Thimble spliced in each end.

Diameter of strand.	Breaking strength of strand.	Breaking strength of stay.	Efficiency (per cent).	Approximate weight per 100 feet.
$\frac{1}{4}$	8,000	7,200	90.0	13.50
$\frac{7}{32}$	6,100	5,500	90.0	10.00
$\frac{3}{16}$	4,600	4,180	91.0	7.70
$\frac{5}{32}$	3,200	3,000	93.7	5.50
$\frac{1}{8}$	2,100	2,060	98.2	3.50
$\frac{7}{64}$	1,600	1,570	98.1	2.60
$\frac{3}{32}$	1,100	1,100	100	1.75
$\frac{5}{64}$	780	780	100	1.21
$\frac{1}{16}$	500	500	100	0.78

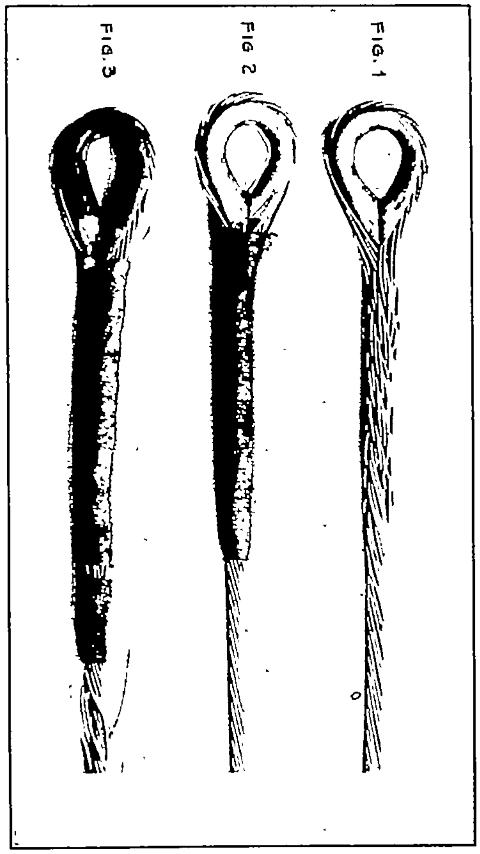


PLATE No. 4.

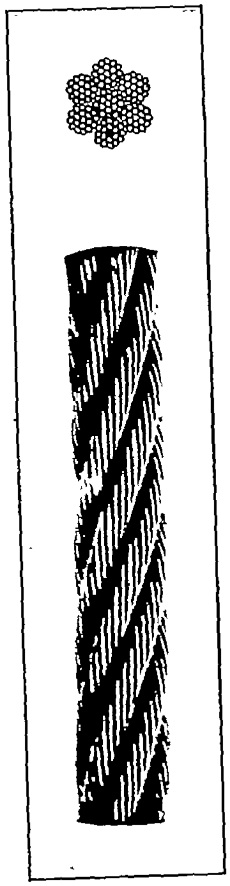
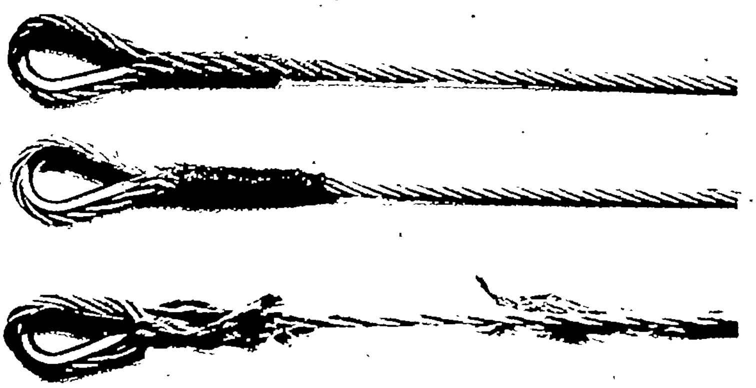


Plate No. 5.

FIG. 1

FIG. 2

FIG 3



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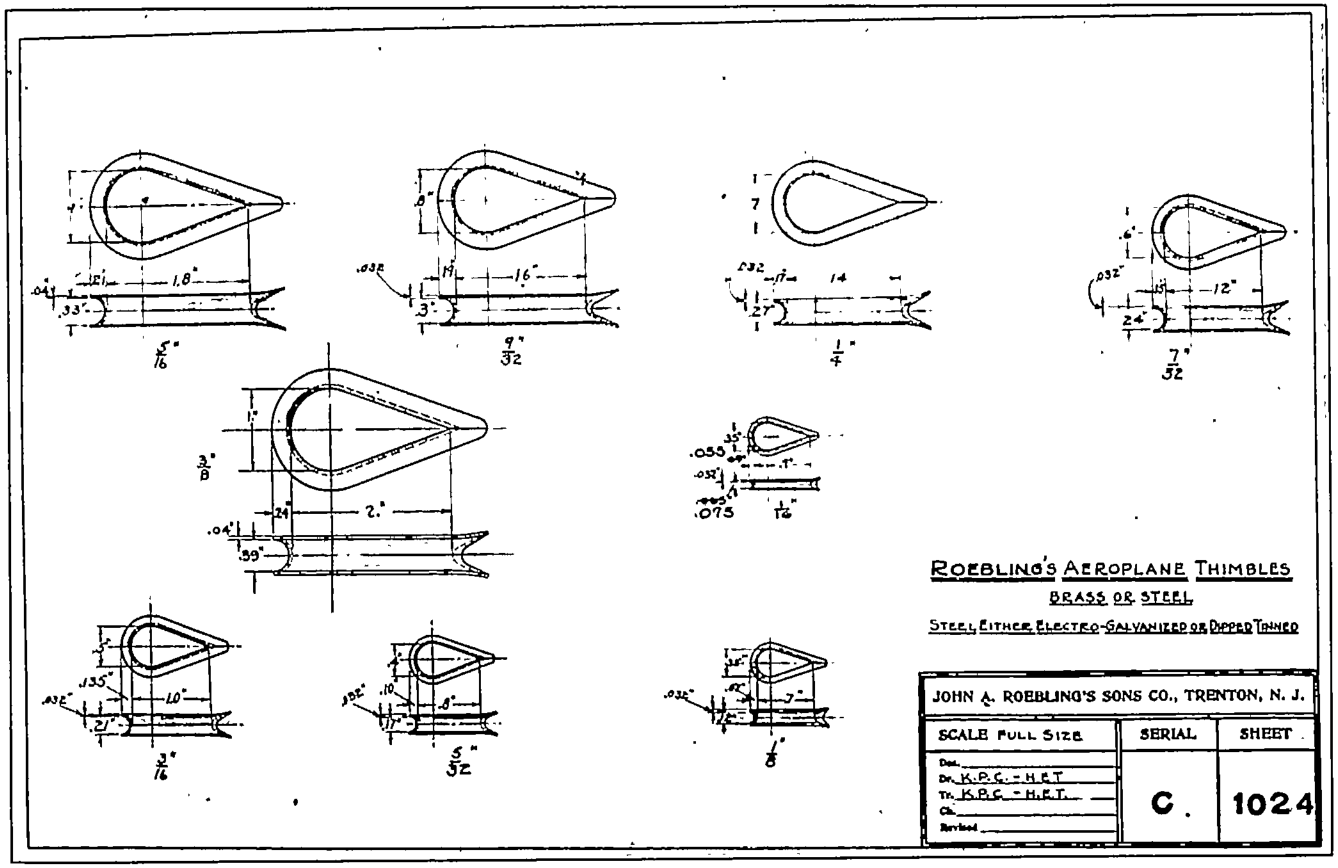
ROEBLING'S AEROPLANE THIMBLES
BRASS OR STEEL
STEEL EITHER ELECTRO-GALVANIZED OR DIPPED TINNED
JOHN A. ROEBLING'S SONS CO., TRENTON, N. J.
SCALE FULL SIZE
SERIAL
SHEET
Dr. K.P.C. - H.E.T
Tr. K.P.C. - H.E.T.
C.
1024

PLATE NO. 7.

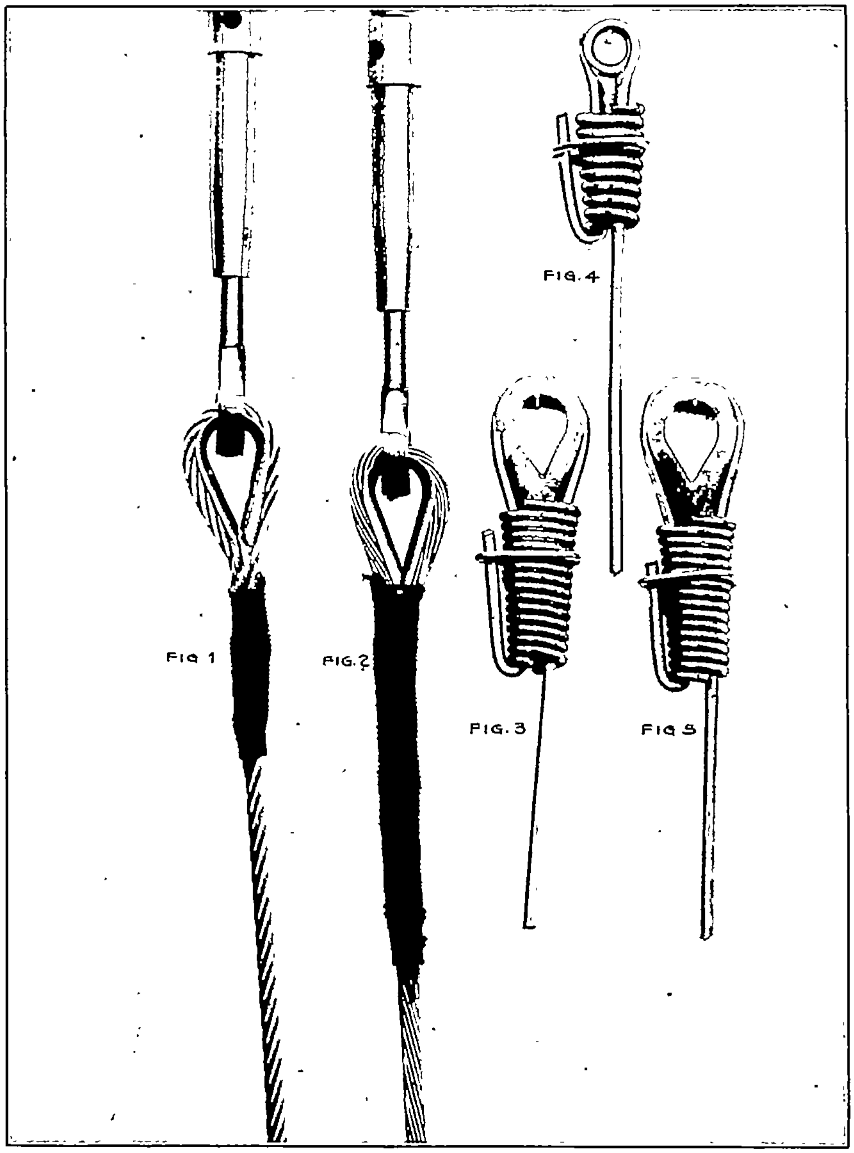

PLATE No. 8.

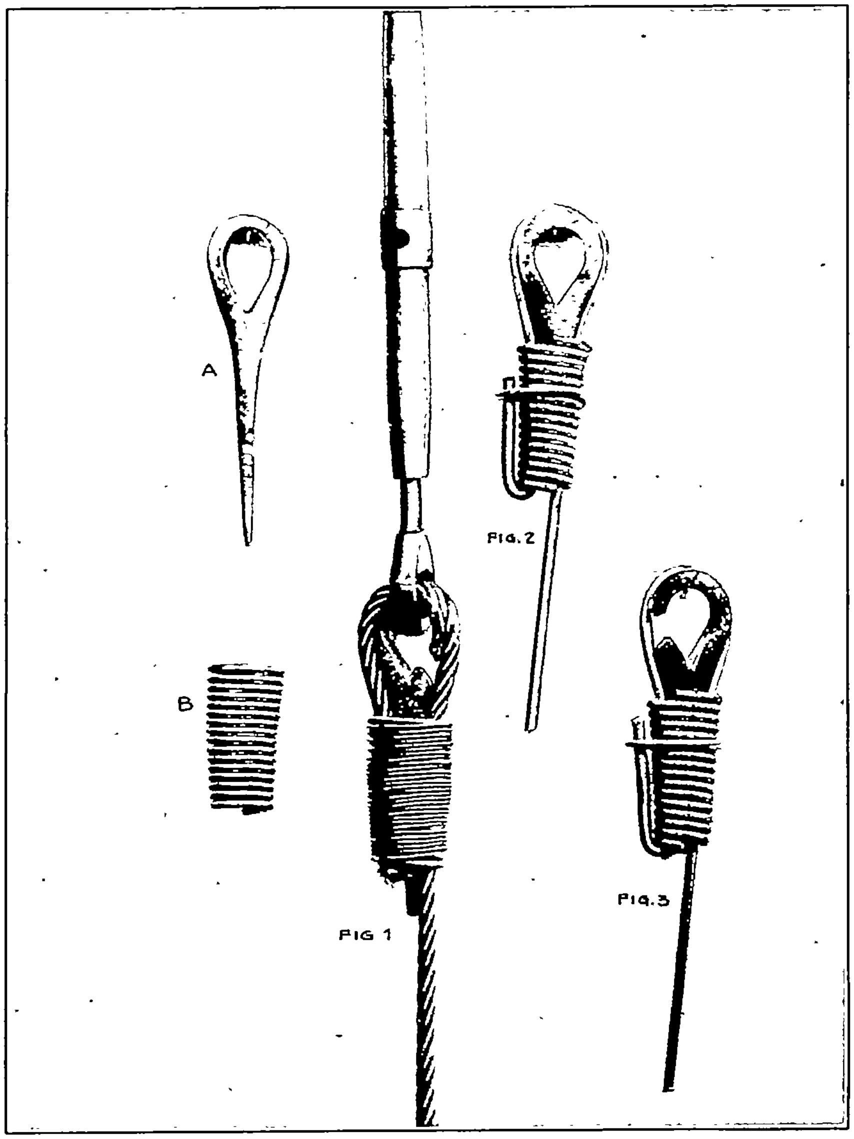

PLATE No. 9.

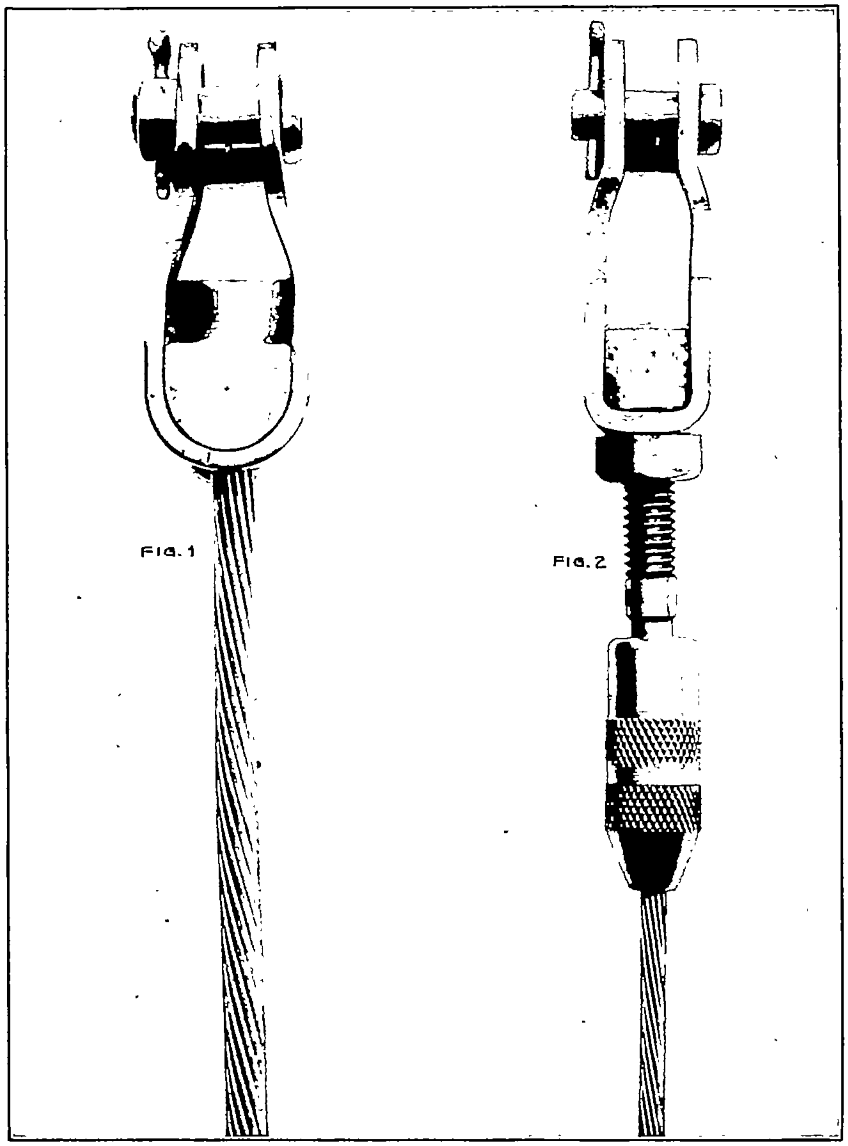

PLATE No. 10.

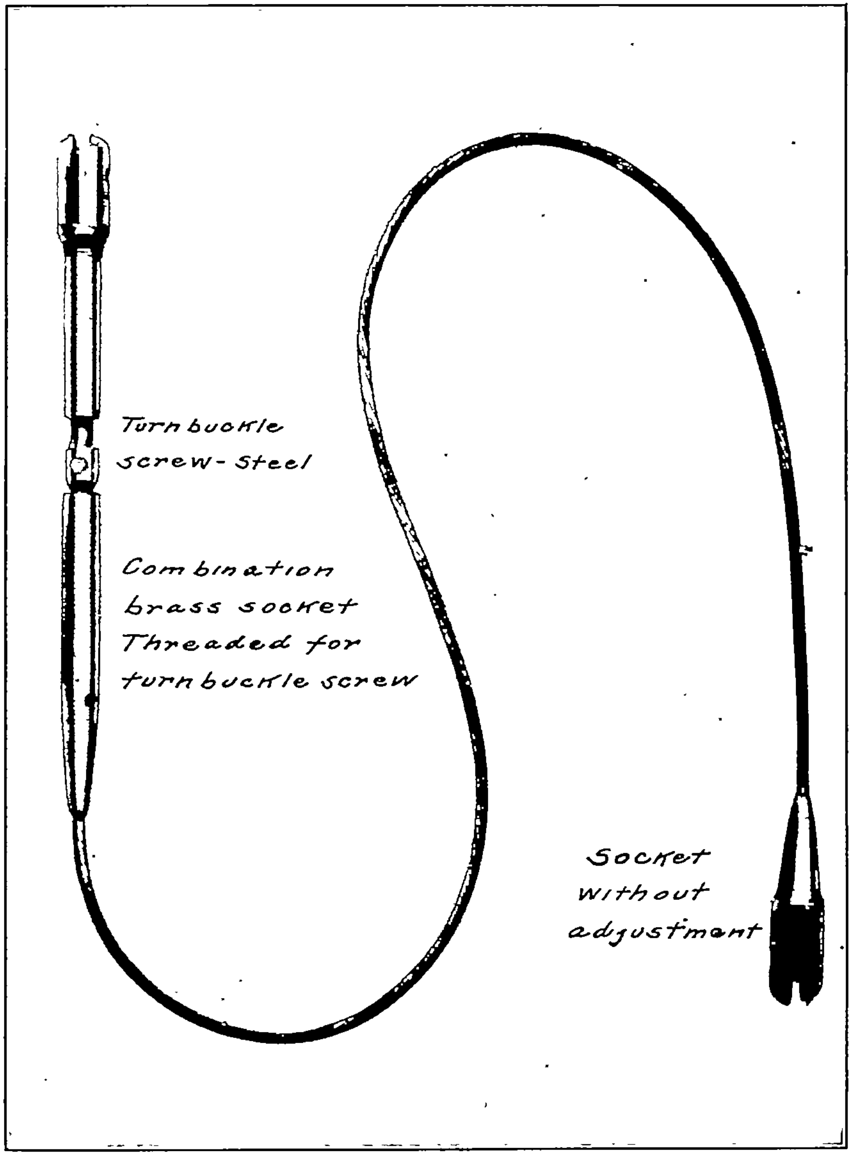
Turnbuckle
screw-Steel
Combination
brass socket
Threaded for
turnbuckle screw
Socket
without
adjustment

PLATE No. 10 A.

PLATE NO. 4.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Figure No. 1 shows thimble spliced in 19-wire galvanized aviator strand.

Figure No. 2 shows the splice after the serving is applied.

Figure No. 3 shows the broken wires after the stay had been tested to destruction in the testing machine. It will be noted there are four broken wires. This break always occurs at the last tuck in the splice and never around the thimble.

Diameter of cord.	Breaking strength cord (pounds).	Approximate weight per 100 feet.
$\frac{1}{8}$	2,000	2.88
$\frac{5}{32}$	2,800	4.44
$\frac{3}{16}$	4,200	6.47
$\frac{7}{32}$	5,600	9.50
$\frac{1}{4}$	7,000	12.00
$\frac{9}{32}$	8,000	14.56
$\frac{5}{16}$	9,800	17.71
$\frac{11}{32}$	12,500	22.53
$\frac{3}{8}$	14,400	26.45

PLATE NO. 5.

ROEBLING 7 BY 19, TINNED AVIATOR CORD.

Roebling tinned aviator cord is composed of 7 strands of 19 wires each. This wire is made from the highest grade of steel and given a heavy plating of tin. It is used principally for stays on foreign machines. This cord is approximately one and three-quarter times as elastic as a solid wire of the same material.

Thimble spliced in each end.

Diameter of cord.	Breaking strength of cord.	Breaking strength of stay.	Efficiency.	Approximate weight per 100 feet.
$\frac{1}{8}$	2,000	1,600	Average of 54 tests 83.6 per cent.	2.88
$\frac{5}{32}$	2,800	2,300		4.44
$\frac{3}{16}$	4,200	3,500		6.47
$\frac{7}{32}$	5,600	4,700		9.50
$\frac{1}{4}$	7,000	6,000		12.00
$\frac{9}{32}$	8,000	6,800		14.56
$\frac{5}{16}$	9,800	8,200		17.71
$\frac{11}{32}$	12,500	10,400		22.53
$\frac{3}{8}$	14,400	12,000		26.45

PLATE NO. 6.

ROEBLING 7 BY 19, TINNED AVIATOR CORD.

Figure No. 1 shows thimble spliced in 7 by 19 tinned aviator cord.

Figure No. 2 shows the splice after the serving is applied.

Figure No. 3 shows the result of a test to destruction in the testing machine. Five strands have been broken at the last tuck in the splice. In all the 54 tests the stay failed at this point and never around the thimble.

PLATE NO. 7.

THIMBLES.

The eye splice in strand and cord should be protected by means of either steel or brass thimble.

The brass thimble can be used for 19-wire strand for diameters of 1/8 inch and smaller. For larger diameters use steel thimbles.

For the 7 by 19 cord use brass thimble for 3/16 inch diameters and smaller, and steel thimbles for larger diameters.

PLATE NO. 8.

SHOP CONNECTIONS.

Figure No. 1.—Based upon tests, believe the eye splice for the 7 by 19 cord is the most satisfactory for all sizes, including $\frac{1}{2}$ inch diameter, unless higher efficiency is required, in which case a socket attachment can be used for the larger diameters.

Figure No. 2.—The eye splice is very satisfactory for 19-wire strand for diameters not exceeding $\frac{5}{16}$ inch. For larger diameters a socket attachment is necessary to get high efficiency.

Figures Nos. 3, 4, and 5.—The tapered ferrule and wedge attachment gives maximum efficiency, and we believe can be used to great advantage for single-wire stays.

PLATE NO. 9.

FIELD CONNECTIONS.

The repairing of stays in the field has been given careful consideration, and *Figure No. 1* on plate No. 9 shows a very simple and efficient device for attachment of either 19-wire strand or 7 by 19 cord. The efficiency is 90 per cent.

The wedge "A" and ferrule "B" are the two important members of the connections. After the strand or cord is placed on wedge and through ferrule, the end of same is bent backward on ferrule and then served with wire.

Figures Nos. 2 and 3 show the same type of connection for wire attachment. The efficiency is 94 per cent.

PLATE NO. 10 AND PLATE NO. 10A.

SOCKET ATTACHMENT.

We believe the socket attachment can be used to advantage in connection with 19-wire strand, especially on the larger diameters.

The efficiency is nearly 100 per cent and the connection is positive and safe.

We find it necessary to use pure zinc for attachment of galvanized strand.

Plate No. 10 shows two types of sockets—

Figure No. 1 not furnished with adjustment and *Figure No. 2* having adjustment.

Plate No. 10A shows the sockets used by the Glenn L. Martin Co., and it is stated their efficiency is 100 per cent.

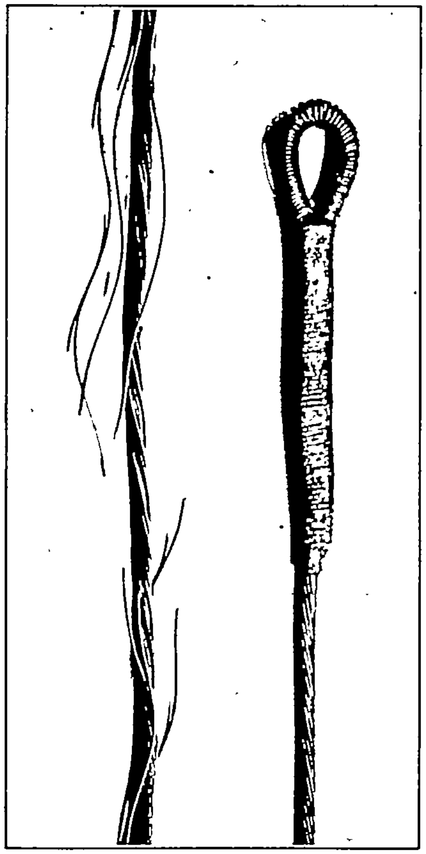

PLATE No. 11.

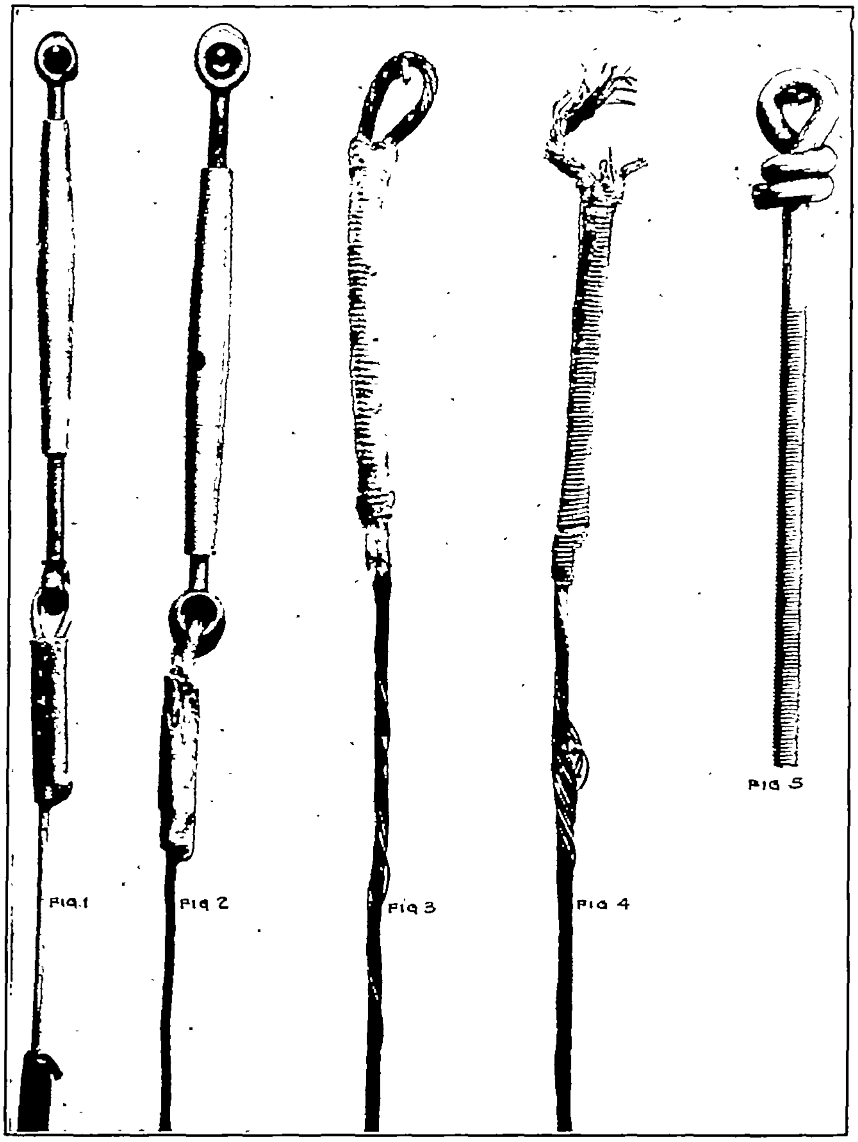

PLATE No. 12.

PLATE NO. 13.

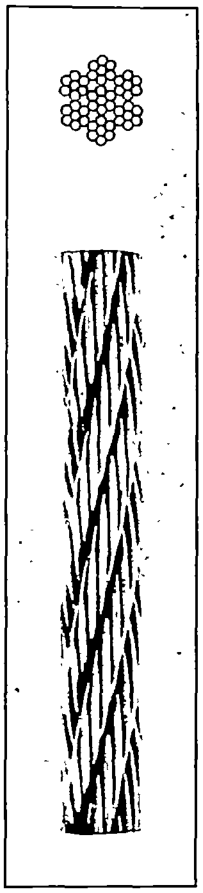

PLATE No. 14.

PLATE NO. 11.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Figure No. 1 shows a 19-wire galvanized aviator strand with end looped and soldered.

Figure No. 2 shows the result of test to destruction in the testing machine. It will be noted that the break of the seven wires occurs at the center of the stay and never at the ends. In the series of tests made this connection showed an efficiency of 100 per cent.

Special attention is called to the protective serving of the loop. In case this is not done a thimble must be used. The principal objections to this connection are the use of acid and solder.

Ends looped and soldered.

Diameter of strand.	Breaking strength of strand.	Breaking strength of stay.	Efficiency (per cent).	Length of lap.	Serving of lap.	Approximate weight per 100 feet.
$\frac{1}{4}$	8,000	8,000	100	20 times diameter of strand.	Diameter of serving wire = $\frac{1}{4}$ diameter of strand.	13.50
$\frac{7}{32}$	6,100	6,100	100			10.00
$\frac{3}{16}$	4,600	4,600	100			7.70
$\frac{5}{32}$	3,200	3,200	100			5.50
$\frac{1}{8}$	2,100	2,100	100			3.50
$\frac{7}{64}$	1,600	1,600	100			2.60
$\frac{3}{32}$	1,100	1,100	100			1.75
$\frac{5}{64}$	780	780	100			1.21
$\frac{1}{16}$	500	500	100			.78

PLATE NO. 12.

EXAMPLES OF PRESENT PRACTICE.

No. 1 shows the solid wire, using a copper tube as a ferrule, and if attached properly will give efficiency of 75 to 80 per cent.

No. 2 shows a 19-wire strand attachment, using a copper tube as a ferrule and bending the strand back and soldering both inside and outside of ferrule. Note that the strand is not protected where it bears on turnbuckle and the strand fails here. The efficiency is low.

No. 3 shows a 19-wire strand attachment where the strand is looped, served, and then soldered. Note the wire displacement in loop.

No. 4 was taken from a wrecked aeroplane and shows point of failure in loop, due to want of protection at this point.

No. 5 shows form of eye for solid wire, which makes it necessary to use medium steel to allow manipulation.

Diameter of cord.	Breaking strength of cord.	Approximate weight per 100 feet.
$\frac{5}{16}$	7,900	15.00
$\frac{1}{4}$	5,000	9.50
$\frac{7}{32}$	4,000	7.43
$\frac{3}{16}$	2,750	5.30
$\frac{5}{32}$	2,200	4.20
$\frac{1}{8}$	1,150	2.20
$\frac{7}{64}$	830	1.50
$\frac{3}{32}$	780	1.30
$\frac{5}{64}$	480	.83
$\frac{1}{16}$	400	.73

PLATE NO. 13.

ROEBLING EXTRA FLEXIBLE AVIATOR CORD 6 BY 7 COTTON CENTER.

Roebling extra flexible aviator cord is composed of six strands of seven galvanized wires each and a cotton center. On account of its flexibility this cord is used for steering gear and controls. This cord is approximately two and one-quarter times as elastic as a solid wire.

Diameter of cord.	Breaking strength of cord.	Approximate weight per 100 feet.
$\frac{5}{16}$	9,200	16.70
$\frac{1}{4}$	5,800	10.50
$\frac{7}{32}$	4,600	8.30
$\frac{3}{16}$	3,200	5.80
$\frac{5}{32}$	2,600	4.67
$\frac{1}{8}$	1,350	2.45
$\frac{7}{64}$	970	1.75
$\frac{3}{32}$	920	1.45
$\frac{5}{64}$	550	.93
$\frac{1}{16}$	485	.81

PLATE NO. 14.

ROEBLING FLEXIBLE AVIATOR CORD 6 BY 7 WIRE CENTER.

Roebling flexible aviator cord is made with seven strands of seven galvanized wire each. This cord is not as flexible as the cotton center cord and is approximately one and three-quarters times as elastic as a solid wire.

PROTECTIVE COATINGS ON STEEL WIRES.

NONFERROUS METALS—ALLOY STEELS.

We manufacture wire and cable in nonferrous metals such as monel metal, german silver, phosphor bronze, aluminum bronze, silicon bronze, brass, copper, etc., but we do not believe that any of these metals will ever prove commercially practicable for the purpose of aeroplane stays or cables. "Maximum strength with minimum weight" appears to be too all-important. In none of these can extreme reliability with high elasticity be so well secured as with steel when it is well protected from mechanical injury and corrosion. For exceptional purposes, the nonmagnetic properties of these metals may outweigh their lack of strength and durability in fatigue, making their use imperative, but in the final design the amount thus used will undoubtedly be the least possible amount permissible under the circumstances. For construction of this kind we would not recommend, without many qualifications, a natural alloy such as monel metal. This material appears to possess excellent noncorrosion properties when used in a relatively large mass, as in a propeller, but there appears to be considerable doubt as to its absolute reliability in uniformly resisting corrosion when rolled into very thin sheets or drawn into wire. To a lesser degree, a lack of confidence must exist in such manufactured alloys as brass, german silver, or bronzes containing relatively large proportions of two or more elementary metals. "Phosphor bronze," "silicon bronze," "aluminum bronze," or similar alloys containing a relatively high per cent of one element (copper) only, are more "fool-proof" and consequently more reliable and desirable.

An attempt to give the elastic limit and tensile strength of each size of wire, strand, and cable used in aeroplane construction, if same were made of all the nonferrous metals mentioned above, would involve the publication of quite an extensive report. Confining ourselves to the most suitable of these metals or alloys, phosphor bronze, aluminum bronze, etc., it is a safe and reliable rule to assume that the ultimate strength of such wire or cable or stay will be 50 per cent of the ultimate strength of the extra high-strength steel listed by us for standard aeroplane use. The elastic limit for nonferrous metals could not safely be assumed at more than 50 per cent of the ultimate breaking strain.

The use of vanadium, titanium, and other special deoxidizers or cleansers in the manufacture of steel has undoubtedly resulted in very much improving homogeneity and density of structure in cast, forged, and other hot-worked masses of the metal especially in the harder alloyed varieties. It is not so certain, however, that the use of these metals has proven necessary or even desirable in making steels of the higher grade for wire manufacture where the enormous amount of cold working and exact heat treatment absolutely inherent to the process of wire manufacture produces eventually a structure finer and more homogeneous than has ever been possible by any other method. The increased resistance to corrosion which the special steels, referred to above, afford, because of their density and uniformity, is more than duplicated by any drawn high-grade wire of the ordinary carbon steels of sufficient degree of manufacture.

Vanadium steels and other steels of their kind have not as yet become established as desirable wire steels. Although strongly urged upon the industry and tried time and again, they have not demonstrated their superiority.

Carefully made high-grade carbon steel affords to-day the most reliable and flexible material for wire, cable, and stays, possessing the "greatest strength for the least weight" known in the wire industry. We know its advantages and we know its disadvantages. The fact that the mechanical properties of steel wire and cable are seriously affected by corrosion is so well known that it must be guarded against. As the damage done is a function of time as well as intensity of chemical or electro-chemical action on the unprotected steel, we have investigated the question of retarding corrosion in the steel itself to as great a degree as possible. We have found that pure iron retards corrosion to a greater degree than the more impure steel—but we have also found that in highly extenuated filaments of these two metals, as in wire, the difference in rate of corrosion is practically negligible, especially when the total life of the wire protected by an external coating such as galvanizing is taken into consideration. We have found the use of special deoxidizers and cleansers questionable and have not adopted them.

The use of protective coatings on steel wire or cable is a very broad subject. Hot galvanized unwiped wire is undoubtedly the best protected wire for the purpose. Very hard wires and very fine sizes of hard wire are likely to become brittle at the temperature of hot galvanizing, and the next best coating available is, therefore, a tin coating. Both of these metal coatings should be further protected by frequent applications of paint. As a protection to the galvanizing, a coat of red-lead paint should be applied after the stay is assembled and the red lead protected by a coat of graphite paint.

The care with which inspections are made from time to time and the efficient maintenance of the paint on the wires really determines the life of the combination. This has been proven absolutely by the very extensive use and treatment of galvanized steel on board ship for many years.

Nickel plating is out of the question for wires to be bent or twisted into cable. Furthermore, nickel is absolutely injurious where the initial purely chemical action on the intact nickel surface ceases and electro-chemical action between steel and nickel begins at such spots when steel is exposed.

We believe, therefore, that tinning and galvanizing are to-day the most satisfactory coatings for steel wire that can be employed. They do not actually represent the final and efficient protection which is necessary in aeroplane construction, as this is secured by the repeated application of paint. These coatings are, however, an efficient guard against corrosion preliminary to service conditions in the plane and also serve to prevent corrosion and consequent damage to the steel cables and stays in service when the paint may have been accidentally rubbed off.

RECAPITULATION.

WIRE STAYS.

As shown by tests, the terminal fastening, figures 13 and 14, on plate No. 1, are efficient, simple, and readily attached, and we believe solve the question.

For shop attachment figure 13 or 14 would be used in connection with shackles and clevises, and for attaching to turnbuckle eye or other closed eyes use figure 15.

For field attachment use either figure 14 or 15.

Plates No. 8 and No. 9 also show these terminal connections.

WIRE SPECIFICATIONS FOR STAY WIRES.

Plate No. 2 and pages 10 and 11 of this report give specifications for wire having the highest possible strength, together with the necessary ductility for manipulation, and is the result of many years of experimenting in cooperation with engineers and manufacturers of aeroplanes.

19-wire strand stays.

Plates No. 3 and No. 4 give the strength of this strand, also the strength of same as stays using the thimble eye splice for terminal connection, and judging from tests as given, this connection is efficient, neat in appearance, and reliable.

Plate No. 11 gives table of stay strength when the ends of the strand are looped and soldered. The efficiency of this connection is a maximum, but the use of acid and solder are objectionable, and we believe the thimble eye splice with slightly lower efficiency is preferable.

We understand ¼-inch diameter strand is the largest diameter used, but judging from present development larger diameter will be required and it will be found that the thimble eye splice, also the ends looped and soldered, will not give the same efficiency as the diameter increases and we believe the use of sockets for ⅜-inch diameter and larger may be desirable.

Plate No. 10 shows two types of sockets.

For making terminal connection of strand in the field, we believe the arrangement shown on plate No. 9 is best, as it gives 90 per cent efficiency and is readily attached by the average man and does not require the use of acid, solder, or blow torch.

7 by 19 cord stays.

Plates No. 5 and No. 6 show the 7 by 19 rope which is flexible, elastic, and lends itself readily to thimble splice, giving very uniform efficiency and has the advantage of higher efficiency for diameters between ⅜ and ½ inch.

We have determined by tests that the socket connection alone gives higher efficiency than the thimble eye splice on 7 by 19 cord, but as a general proposition believe the thimble eye splice is entirely suitable for stay construction.

For a field connection plate No. 9 shows the most suitable type.

CONCLUSIONS.

The tests as given show that it is possible to furnish efficient terminal connections for wire, strand, and 7 by 19 cord, and eliminate the use of acid, solder, and blow torch, and this report as a basis will allow a more thorough investigation on similar lines.

We are unable to determine from aeroplane manufacturers why it is necessary to use the solid wire, 19-wire strand, and the 7 by 19 cord for stays. It is self-evident that the wire stay is less elastic than the 19-wire strand, also that the strand is less elastic than the 7 by 19 cord, also the strength varies considerably, as can be determined by comparison of tables as given before, and to allow a quick comparison we give below:

Comparison of stay strength.

Material.	Diameter.	Strength of material.	Strength of stay.
	Inch.	*Pounds.*	*Pounds.*
Wire	$\frac{3}{16}$	5,500	5,100
Strand	$\frac{3}{16}$	4,600	4,100
7 by 19 cord	$\frac{3}{16}$	4,200	3,500

American practice covers both the wire and 19-wire strand stay and foreign practice requires the use of 7 by 19 cord for stay.

The table above shows how much more efficient the wire and strand stays are for the same diameter and therefore we are led to believe there are other considerations just as important as strength, such as the elastic stretch of stays, flexibility and fatigue values of material which may be governed by the construction of stay, and we believe these points should be investigated under field conditions as well as laboratory tests.

We hoped to give this report stress-strain diagram for the solid wire, 19-wire strand, also 7 by 19 cord, so that the modulus of elasticity could be determined for any desired load and elastic stretch of stay calculated for comparison. We were unable to complete our tests in time, and therefore if you decide this is of value we will be pleased to submit these diagrams and any other data developed. If vibration of stays is a factor, the relative fatigue value of the three constructions would give interesting data.

Respectfully submitted.

JOHN A. ROEBLING'S SONS CO.,
By C. C. SUNDERLAND, *Engineer*.

(Investigations under direction of C. C. Sunderland, H. J. Horn, and D. Green.)