NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

—

REPORT No. 348   c. 3

STRENGTH OF WELDED JOINTS IN TUBULAR MEMBERS FOR AIRCRAFT

By H. L. WHITTEMORE and W. C. BRUEGGEMAN

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length_____	l	meter_____	m	foot (or mile)_____	ft. (or mi.)
Time_____	t	second_____	s	second (or hour)_____	sec. (or hr.)
Force_____	F	weight of one kilogram_____	kg	weight of one pound___	lb.
Power_____	P	kg/m/s_____	_____	horsepower_____	hp
Speed_____	_____	{km/hr_____	k. p. h.	mi./hr. _____	m. p. h.
		{m/s_____	m. p. s.	ft./sec. _____	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 $= 32.1740$ ft./sec.^{2}

m, Mass, $= \dfrac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $= 0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $= 0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $= \dfrac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \dfrac{L}{qS}$

D, Drag, absolute coefficient $C_D = \dfrac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \dfrac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\dfrac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $= (i_t - i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Bureau of Standards

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I. INTRODUCTION

This investigation was made by the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics for the Aeronautics Branch of the Department of Commerce. The object of the investigation is to make available to the aircraft industry authoritative information on the strength, weight, and cost of a number of types of welded joints. This information will, also, assist the Aeronautics Branch in its work of licensing planes by providing data from which the strength of a given joint may be estimated. As very little material on the strength of aircraft welds has been published,[1] it is believed that such tests made by a disinterested governmental laboratory should be of considerable value to the aircraft industry.

Following the program prepared from information supplied by manufacturers, 40 joints were welded under procedure specifications and tested to determine their strengths. The weight and time required to fabricate were also measured for each joint.

II. ACKNOWLEDGMENTS

Acknowledgment is made to the naval air station, Anacostia, D. C., for welding some preliminary test specimens; to the Linde Air Products Co., the Air Reduction Sales Co., the Bastian-Blessing Co., and the Torchweld Equipment Co. for lending the torches and equipment used; to the Fokker Airplane Co. for assistance in obtaining a welder; to the Air Reduction Sales Co. for the welding supervisor; and to Dr. Lennart Andren, Mr. W. H. Parker, Mr. W. G. Rinehart, and Mr. Robert Patterson, of the Research Department of the American Chain Co., for making flame and weldability tests of the material.

III. MATERIAL

1. PHYSICAL PROPERTIES

Chromium-molybdenum seamless steel tubing was used to make all the test specimens. Chromium-molybdenum sheet steel of the same chemical analysis as the tubing was used in making reinforced joints. The tubes complied with United States Army Specification No. 57–180–2A and the sheet steel with Navy Department Specification No. 47S14. The specified physical properties of the steel are given in Table I and the specified chemical composition in Table II.

[1] See Bibliography for a list of publications on this subject.

TABLE I.—PROPERTIES OF CHROMIUM-MOLYBDENUM STEEL

Material	Specification No.	Tensile strength, minimum	Yield point, minimum	Elongation in 2 inches, minimum
		Lbs./in.²	*Lbs./in.²*	*Per cent*
Tubes	57–180–2A	95,000	60,000	10
Plate	47–S–14	78,000	55,000	22

TABLE II.—CHEMICAL COMPOSITION OF CHROMIUM-MOLYBDENUM STEEL

Material	Specification No.	Carbon	Manganese	Phosphorus (maximum)	Sulphur (maximum)	Chromium	Molybdenum
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Tubes	57–180–2A	0.25–0.35	0.40–0.60	0.040	0.045	0.80–1.10	0.15–0.25
Plate	47S14	.25– .33	.40– .60	.040	.045	.80–1.10	.15– .25

Welding wire conforming to American Welding Society Specification for Gas Welding Rods G–No. 1A[2] was used.

The essential requirements of this specification are given below.

AMERICAN WELDING SOCIETY SPECIFICATIONS FOR GAS WELDING RODS G–No. 1A

MATERIAL.—Material made by the puddling process is not permitted.

PHYSICAL PROPERTIES.—Welding rods shall be made of annealed commercially straight wire of uniform homogeneous structure free from irregularities in surface hardness, segregation, oxides, pipe, seams, etc. Diameter shall not vary more than plus or minus 3 per cent from diameter specified.

CHEMICAL COMPOSITION.—The chemical composition shall be within the following limits:

G–No. 1A

Carbon _____ Not over 0.06 of 1 per cent.
Manganese _____ Not over 0.15 of 1 per cent.
Phosphorus _____ Not over 0.04 of 1 per cent.
Sulphur _____ Not over 0.04 of 1 per cent.
Silicon _____ Not over 0.08 of 1 per cent.

RECOMMENDED SIZES.—1/16, 3/32, 1/8, 5/32, 3/16, 1/4, 5/16, 3/8 inch diameters.

USES.[3]—For welding mild steel, structural shapes, plates, bars, or low carbon steel forgings and castings.

[2] This specification is identical in its essential requirements with U. S. Ordnance Department Metal Specification No. 57–203–A, grade E.

[3] Although no reference is made to aircraft welding, the Committee on Welding Procedure of the American Bureau of Welding recommended this grade of welding rod as being the most suitable for this investigation.

SURFACE FINISH.—The surface shall be smooth and free from scale, rust, oil, or grease, and may be plain or copper coated.

TESTS.—In the hands of an experienced welder, welding rods shall demonstrate good weldability and shall flow smoothly and evenly without any unusual characteristics.

Tubing of the following sizes was used for specimens:

TABLE III.—TUBING SIZES

Outside diameter	Wall thickness
Inches	Inch
¾	0.028
1	.035
1⅛	.049
1½	.058
2	.065

TABLE IV.—TYPICAL PHYSICAL PROPERTIES OF TUBING

Size	Tube No.	Tension					Compression		
		Proportional limit	Yield point	Ultimate strength	Modulus of elasticity	Elongation in 2 inches	Proportional limit	Ultimate strength	Modulus of elasticity
		Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Per cent	Lbs./in.²	Lbs./in.²	Lbs./in.²
¾×0.028	287	45,000	116,800	125,100	27,000,000	10	68,700	119,300	29,300,000
			118,700	125,400		12		119,400	
	290	44,000	75,800	86,500	28,300,000	18	56,000	87,000	28,800,000
			84,400	88,200		15		86,600	
1×0.035	182	41,000	86,700	97,500	27,200,000	10	62,100	95,200	30,000,000
			90,200	94,300		16		95,600	
	196	62,500	115,400	122,000	28,400,000	11	93,900	115,200	28,700,000
			115,100	121,500		14		117,900	
1⅛×0.049	253	41,300	94,200	109,000	28,300,000	18	46,700	94,800	29,600,000
			92,000	104,000		19		96,800	
	256	57,300	109,000	109,000	28,700,000	18	67,400	94,700	28,800,000
			102,800	107,100		21		108,400	
1½×0.058	42	53,500	91,200	100,400	28,300,000	27	60,300	89,700	28,600,000
			88,200	96,800		31		84,000	
	102	44,700	79,800	98,700	28,300,000	25	50,200	89,400	27,100,000
			88,800	101,600		27		97,600	
2×0.065	152	56,500	108,300	111,800	29,800,000	26	103,900	105,100	30,600,000
			93,800	94,900		22		107,900	
	151	60,200	112,600	113,100	29,200,000	19	42,200	97,300	29,800,000
			95,900	96,000		23		101,800	
Average		50,600	98,000	105,100	28,400,000	19	65,100	100,200	29,100,000

Typical physical properties of the material in tension and in compression are given in Table IV. One tensile and one compressive specimen were cut from each end of each tube used. The strengths of the tubes were used to determine compliance with the specifications and in calculating the efficiencies of the joints. Stress-strain diagrams were made from extensometer runs on tensile and compressive specimens taken from ten tubes. The physical properties of these specimens are given in Table IV. Some of the properties of specimens cut from opposite ends of the same tubes are listed for comparison.

Tensile specimens were taken from the tubing in full section, and the ends plugged with round-ended plugs. An Amsler testing machine was used for testing all specimens. The yield point was determined by the "drop of the beam" method. The compressive specimens were made with a slenderness ratio $\left(\dfrac{l}{r}\right)$ equal to 15 and were tested in a special fixture for ensuring round-end conditions. The extensometers used were the Ewing, used on a 2-inch gage length and the Huggenberger with a 1-inch gage length. Typical stress-strain curves in tension and in compression are shown in Figures 1 and 2.

[4] See Discussion by L. B. Tuckerman of The Determination and Significance of the Proportional Limit in the Testing of Metals, by R. L. Templin, presented at the Thirty-second Meeting of the American Society for Testing Materials, June 25, 1929.

The proportional limit was determined by the method proposed by Dr. L. B. Tuckerman,[4] in which the deviation of the stress-strain curve from a straight line was determined by using the least count of the extensometer as a criterion. A trial modulus was assumed and the deviation from this line was plotted for each point. Three parallel lines spaced a distance equal to half the least count of the extensometer (0.00001 inch/inch for both Huggenberger and Ewing instruments) were then moved to include as many as possible of the points in the lower portion of the curve. The trial modulus was then corrected for the slope of these lines and the proportional limit was taken to be the stress at which a straight line connecting two consecutive points cuts the right-hand outer line.

The average variation of strength in specimens cut from opposite ends of tubes of lengths varying from 8 to 15 feet was approximately 3 per cent. In several tubes there was as much as 15 per cent difference.

One sheet of 0.063-inch plate 18 inches wide was used in making all reinforcements requiring material of this thickness. Four tensile specimens in the form of coupons with a 2-inch gage length and a parallel section ½ inch wide by 3 inches long were cut from this sheet.

Results of the test of these specimens are given in Table V.

TABLE V.—STRENGTH OF COUPONS FROM 0.063-INCH CHROMIUM-MOLYBDENUM STEEL PLATE

Specimen No.	Yield point	Ultimate strength	Elongation in 2 inches
	Lbs./in.²	Lbs./in.²	Per cent
1	59,120	76,900	21
2	59,400	81,900	22
3	57,600	75,800	22
4	60,000	81,200	21
Average	59,000	79,000	21.5

TABLE VI.—CHEMICAL ANALYSIS OF TUBING

	No. 155, 2 in.× 0.065 in.	No. 251, 1⅛ in.× 0.049 in.	No. 287, ¾ in.× 0.028 in.
	Per cent	Per cent	Per cent
Carbon	0.31	0.30	0.31
Manganese	.49	.49	.46
Silicon	.13	.17	.15
Chromium	.99	.97	.96
Nickel	.09	.12	.14
Molybdenum	.24	.22	.23
Vanadium	.03	.01	.01
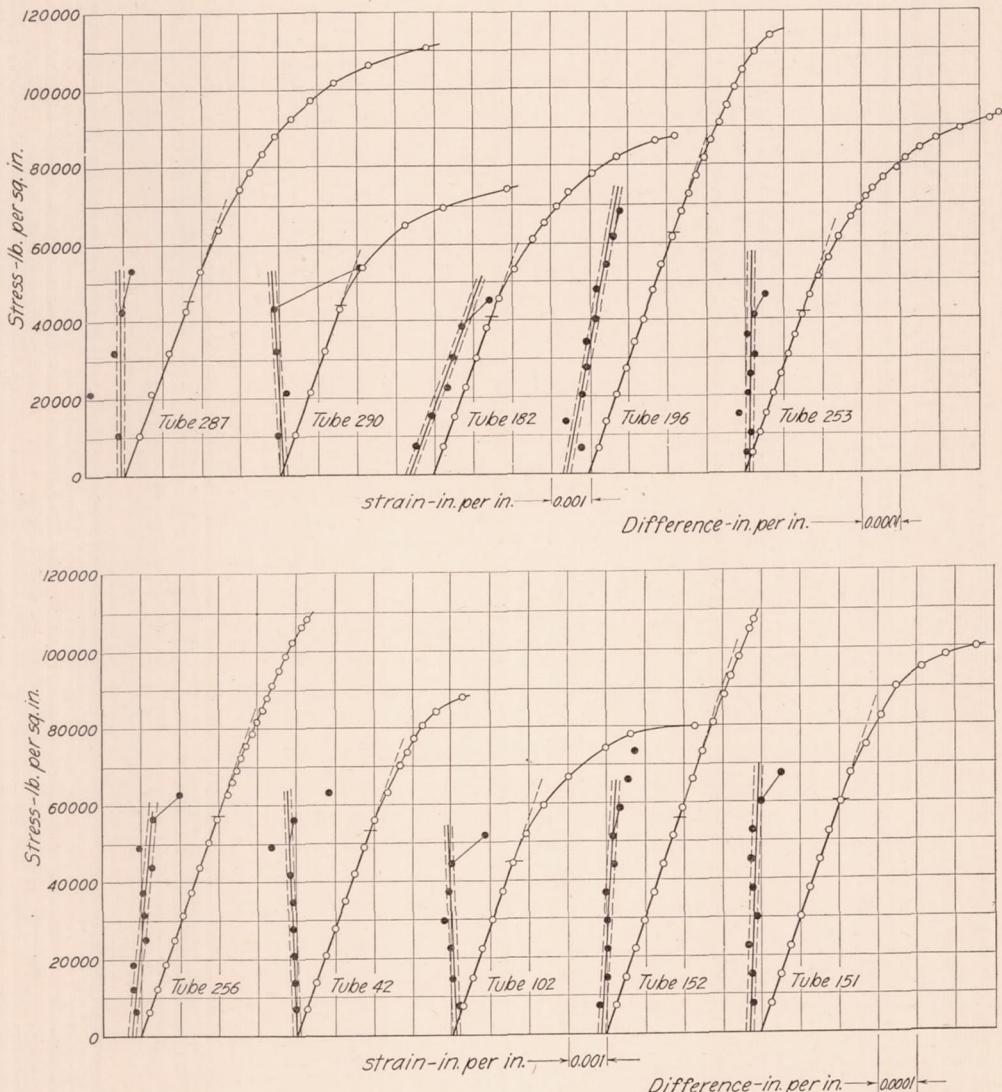
FIGURE 1.—Typical tensile stress-strain curves for tubing, showing method of determining proportional limit by using the least count of the extensometer as a criterion

2. CHEMICAL COMPOSITION [5]

a. Tubing

Results of chemical analyses of one sample of each of three tubes are given in Table VI.

[5] Chemical analyses, flame, and weldability tests of the tubing and welding wire were made by the Research Department of the American Chain Co. The following report of these tests is taken from their Test No. 91, Welding Wire and Chrome-Molybdenum Tubing for Aircraft, Bureau of Standards.

b. Welding Wire

Wire of three sizes supplied in four lots was donated by the Page Steel & Wire Co., for use in this investigation. All wires were copper coated with bright finish. Each lot was analyzed for carbon and manganese with the results given in Table VII.

TABLE VII.—CHEMICAL ANALYSIS OF WELDING WIRE

Lot	Diameter	Carbon	Manganese
	Inch	Per cent	Per cent
1	1/16	0.02	0.01
2	1/16	.02	.02
3	1/8	.02	.02
4	3/32	.01	.02

1/16, 1/16, and 1/32 inch size, respectively, were of too small a diameter for a proper interpretation of this test, as no boiling action could occur even if the conditions which would produce such boiling were present. Lot No. 3 of 1/8-inch size showed slight amounts of impurities under the copper coating but not in amounts great enough to interfere with the welding qualities of this lot. The impurities were
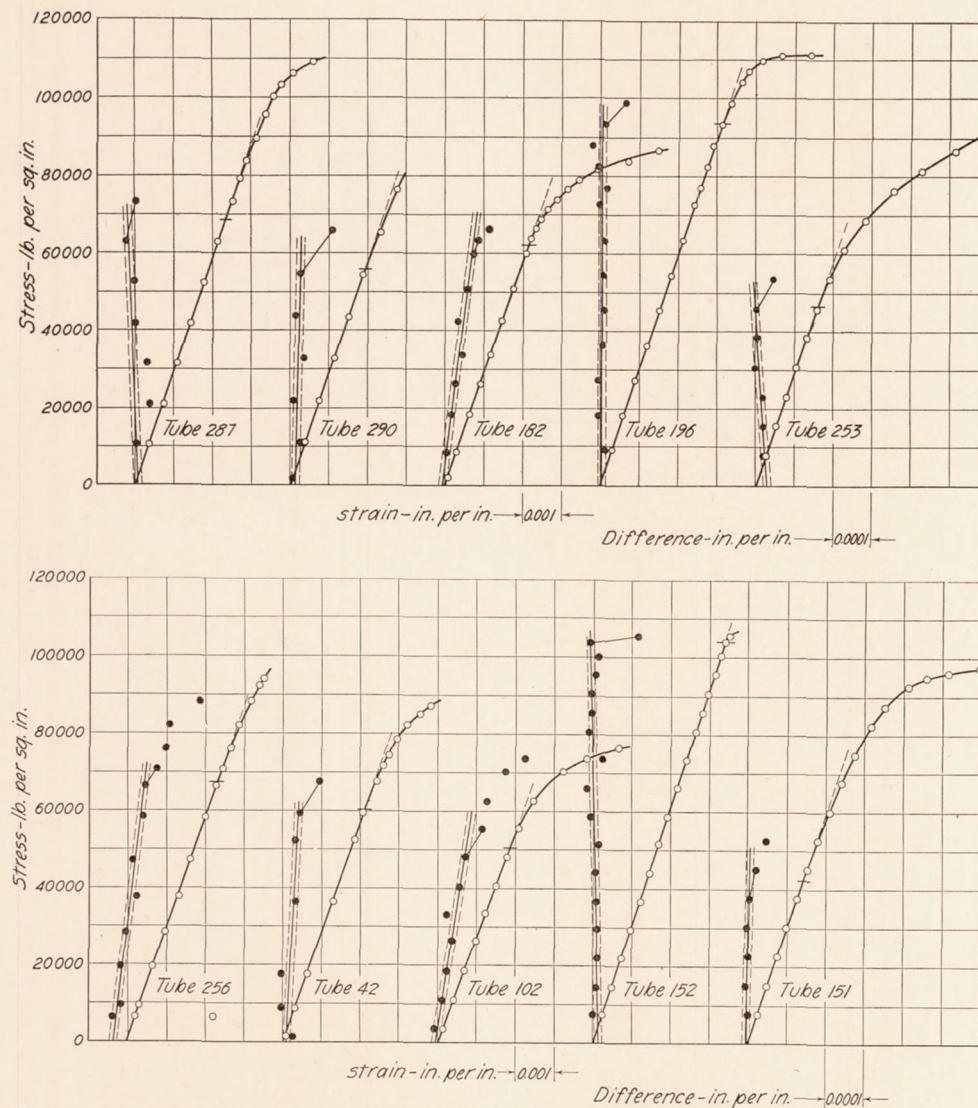
FIGURE 2.—Typical compressive stress-strain curves for tubing

3. WELDING PROPERTIES
a. Tubing

Samples of the tubing were subjected to a flame test [6] applied to the end of the sample and to the wall surface. Figure 3 shows the appearance of samples after the flame test. The indications were that the metal behaved as a clean, quiet material under the torch.

b. Welding Wire

The samples of the welding wire were also subjected to this test. (Fig. 4.) Lots Nos. 1, 2, and 4 of the

only noticeable in the flame test. All the samples showed good welding properties when used on the tubing. Due to the alloy content in the base metal some scale was formed on the welds, but when tried out in actual welding on Armco sheets nothing objectionable could be found in any of the lots submitted.

Six butt joints were made with each one of the four lots of wire submitted. Wire from each end of each coil was used to weld the samples of tubing together. (See fig. 5.) No difficulty whatsoever was encountered in these tests.

[6] See sec. B of procedure specifications for a further description of the flame and weldability tests.

IV. SPECIMENS

1. DESCRIPTION

The joints may be grouped into butt joints, T joints, and lattice joints. Drawings of the joints are shown in Figures 16, 20, 21, 22, 26, 27, and 29. It is believed that most types of joints used in aircraft structures are represented and that a close estimate of the strength
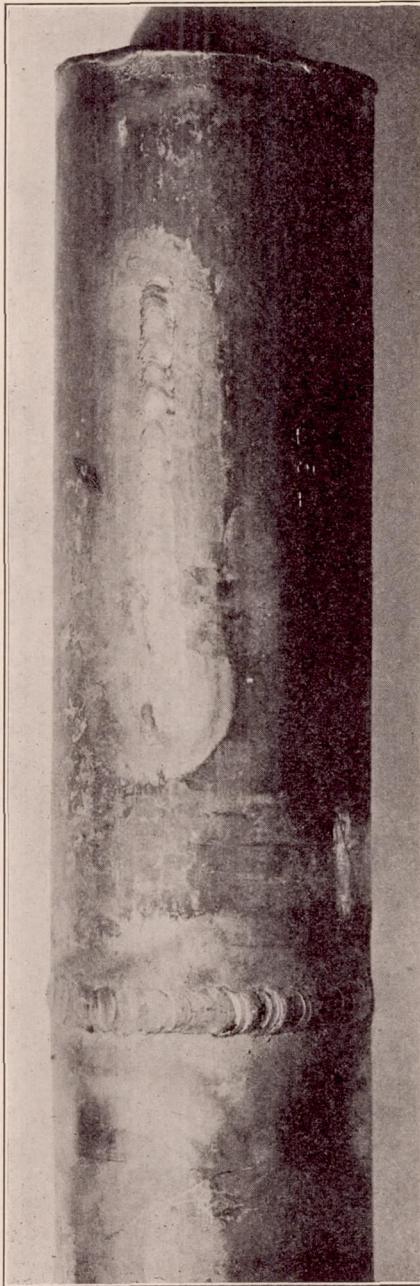
Three specimens were made of each joint. Each specimen was given a number, the first digit referring to the type of joint, the second to the size, and the last to the number 1, 2, or 3 arbitrarily assigned to specimens of the same type and size. Thus, specimen 243 is the third of the triplicate inserted-gusset T joints of type 2 and size 4. When reference is made to the triplicate specimens, the type and size number is used followed by a cipher. Thus, joint 240 is all of the joints of type 2 and size 4.

Specimens of the butt joints were made for both tensile and compressive tests. A slenderness ratio $\left(\dfrac{l}{r}\right)$ equal to 15 was used for the compressive specimens. In addition to determining the strength and efficiency of the butt joints, hardness explorations and stress strain measurements were made of several joints in order to study the properties of the metal in the region in which failure occurred.

In the T joints, tubes A and B meet at an angle of 90°. In all the lattice joints except No. 680 the angle between intersecting tubes is 60°. In joint No. 680 an angle of 45° is used. Both T and lattice joints were made without reinforcement by machining the ends of tubes B and C to fit around the wall of tube A, then welding. Tubes ranging in size from ¾ inch outside diameter by 0.028 inch in wall thickness (hereafter abbreviated ¾ in. ×0.028) to 2 in.×0.065 were used. In some joints all tubes were the same size and in others the secondary or "lattice" tubes (B or B and C) were made three-fourths the diameter of tube A. Three specimens of each joint were tested.
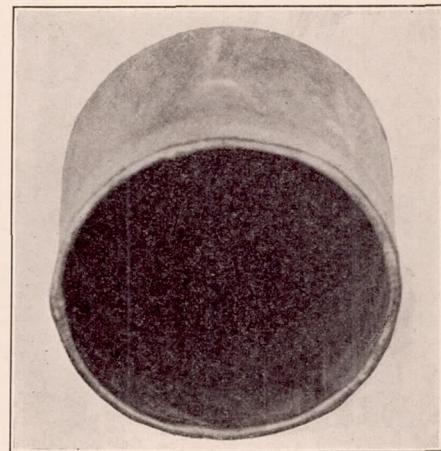

FIGURE 3.—Samples of tubing after the flame and weldability tests have been applied. In the flame test the base metal is melted on the surface and end with the torch. Weldable metal melts evenly and freely without boiling or giving evidence of gases and is relatively free of oxides, dirt, or laminations. The welding rod, when tested for weldability by using it in a welding operation, should also exhibit these characteristics

of any joint can be made by referring to the test results of one or more of the specimens. Although butt joints are seldom used to carry direct tension or compression in aircraft structures, they were included in the program to determine the properties of the metal near the weld.

In addition, joints were made with reinforcement such as plates, straps, etc., welded to the tubes at the joint to determine if reinforcing increased the strength. To avoid too great a number of specimens, all reinforced joints were made in one size of tubing 1½ in. × 0.058.
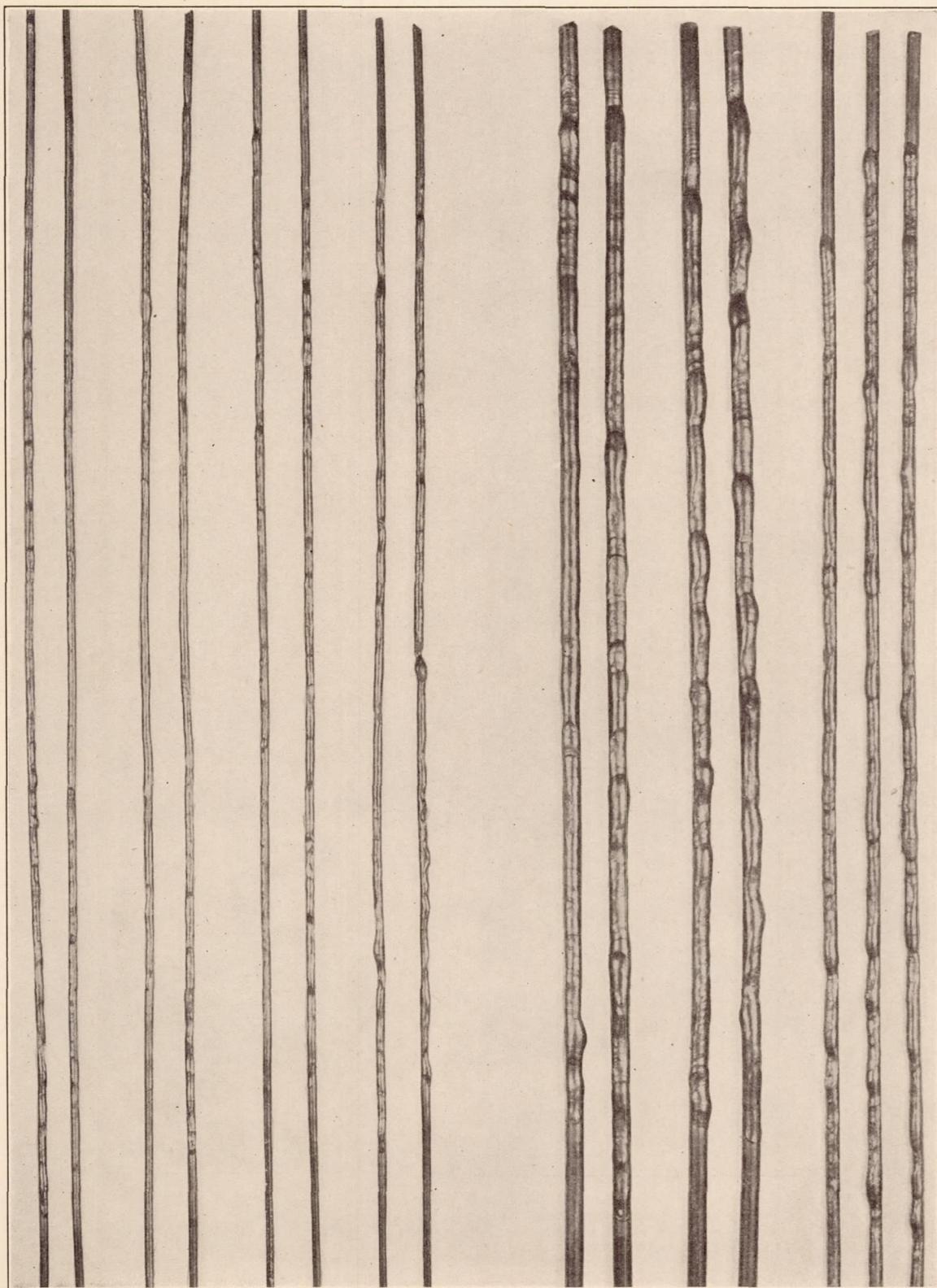
FIGURE 4.—Welding wire after the flame test. The samples were melted with the torch and their behavior observed in the same manner as for the base metal
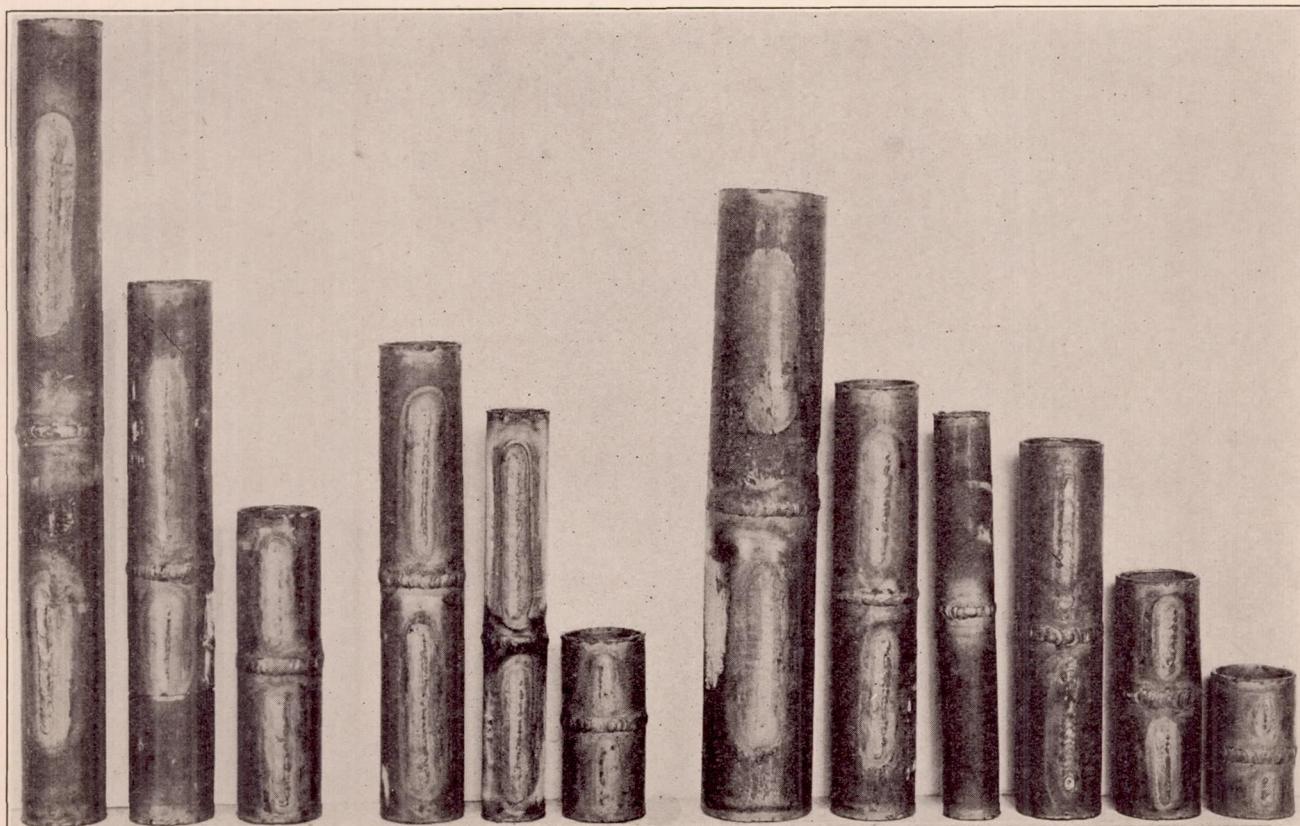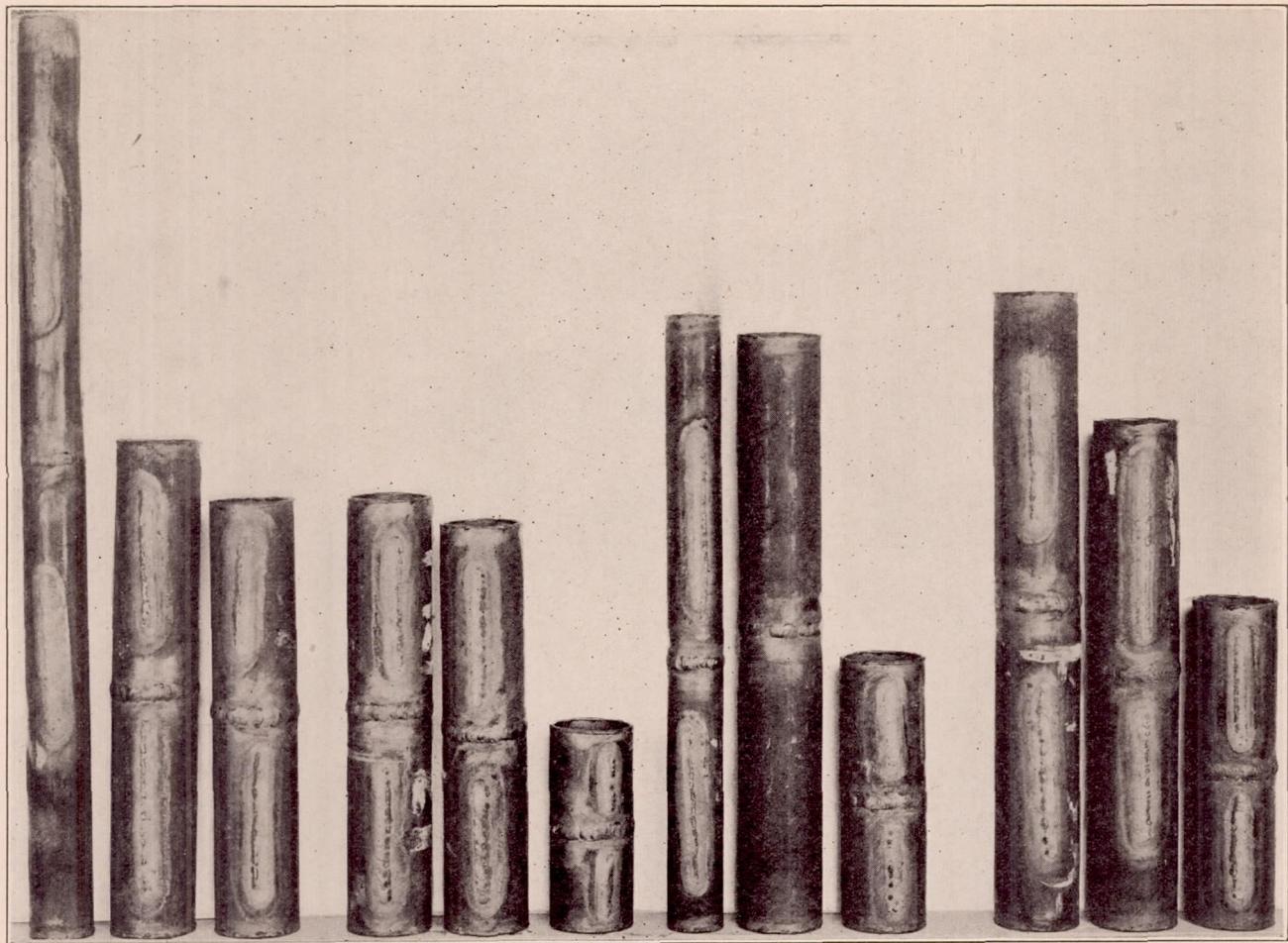
FIGURE 5.—Butt joints made to determine the weldability of the rod
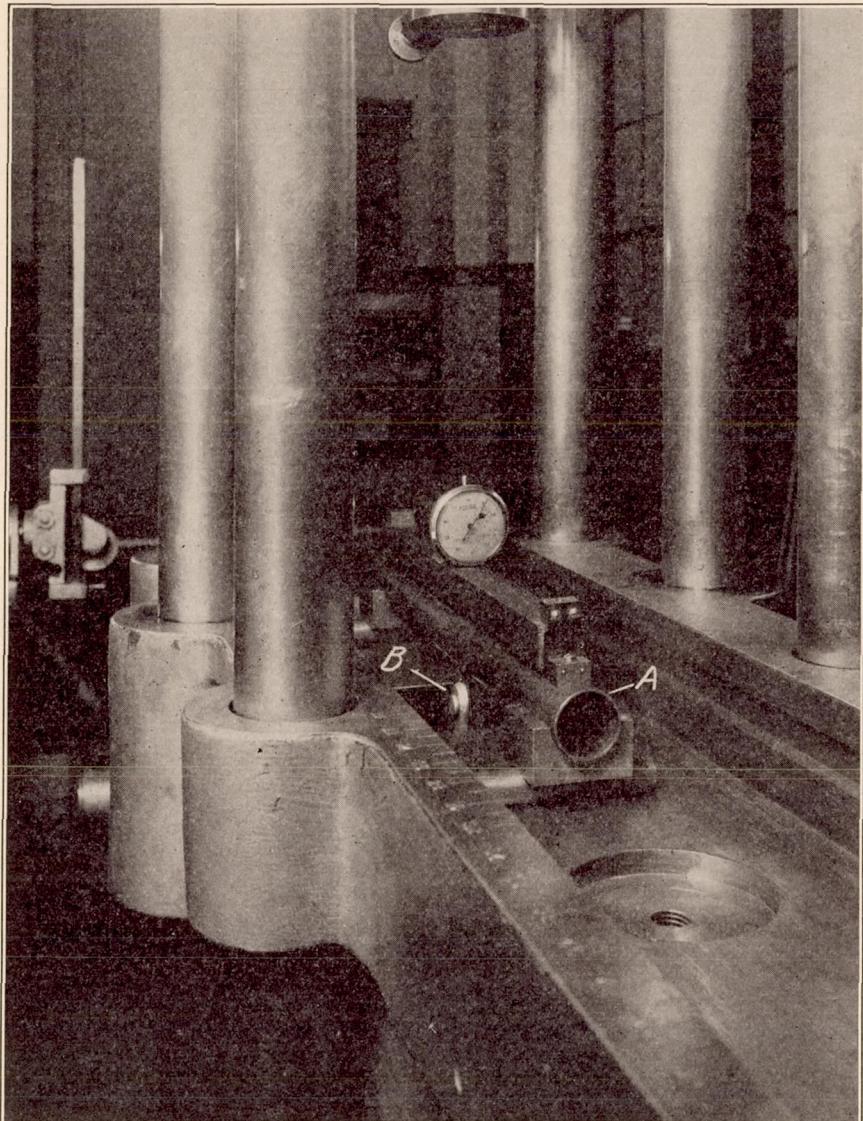
FIGURE 6.—Fixture for testing T joints in Amsler machine, loading I. The vertical member B is loaded in tension until the required permanent deflection at midspan is reached
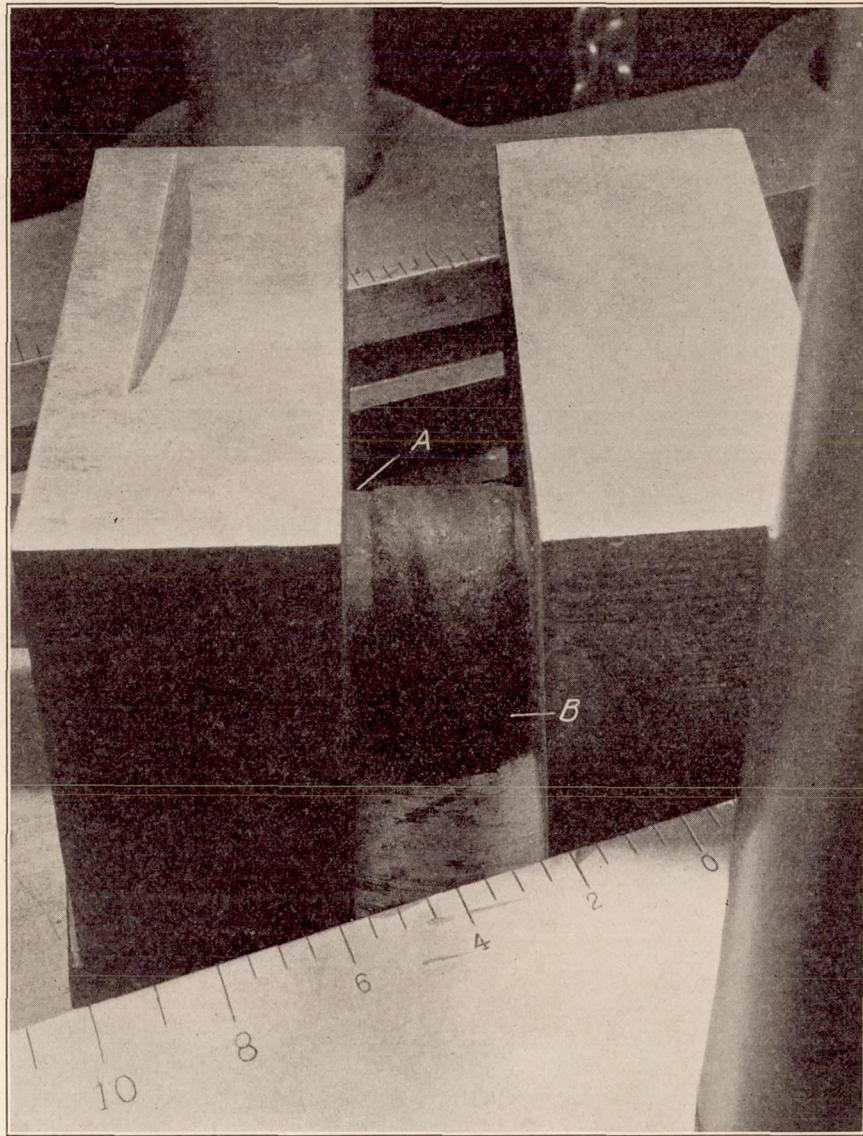

FIGURE 7.—Fixture for testing T joints in Amsler machine, loading II. The steel blocks are slipped over the ends of tube A. Split collars are used to adapt it to varying sizes of tube A, and the blocks are made with slots in the bottom to clear the gusset plates when used. The other end of tube B is gripped in the fixed jaws of the machine, and tube B is loaded in tension until failure occurs

2. METHOD OF TESTING

An Amsler testing machine with load capacities of 0–10,000, 0–20,000, 0–50,000, and 0–100,000 pounds was used for all tests.

T joints were given two tests designated as loading I and II. Loading I is a transverse test of tube A (see drawings) in which this tube was supported on rollers at the ends of a span equal to 10 diameters with the joint in the middle. (Fig. 6.) The deflection was measured

was considered of greater importance than loading II, as it is believed that tube A would seldom be supported on a span less than 10 diameters in an aircraft structure.

For testing the lattice joints the fixture shown in Figure 8 was used. It was designed to support the ends of tubes A and C on pin bearings while tube B is loaded in tension. The fixture was placed on the movable head of the testing machine as shown in Figures 8 and 9.
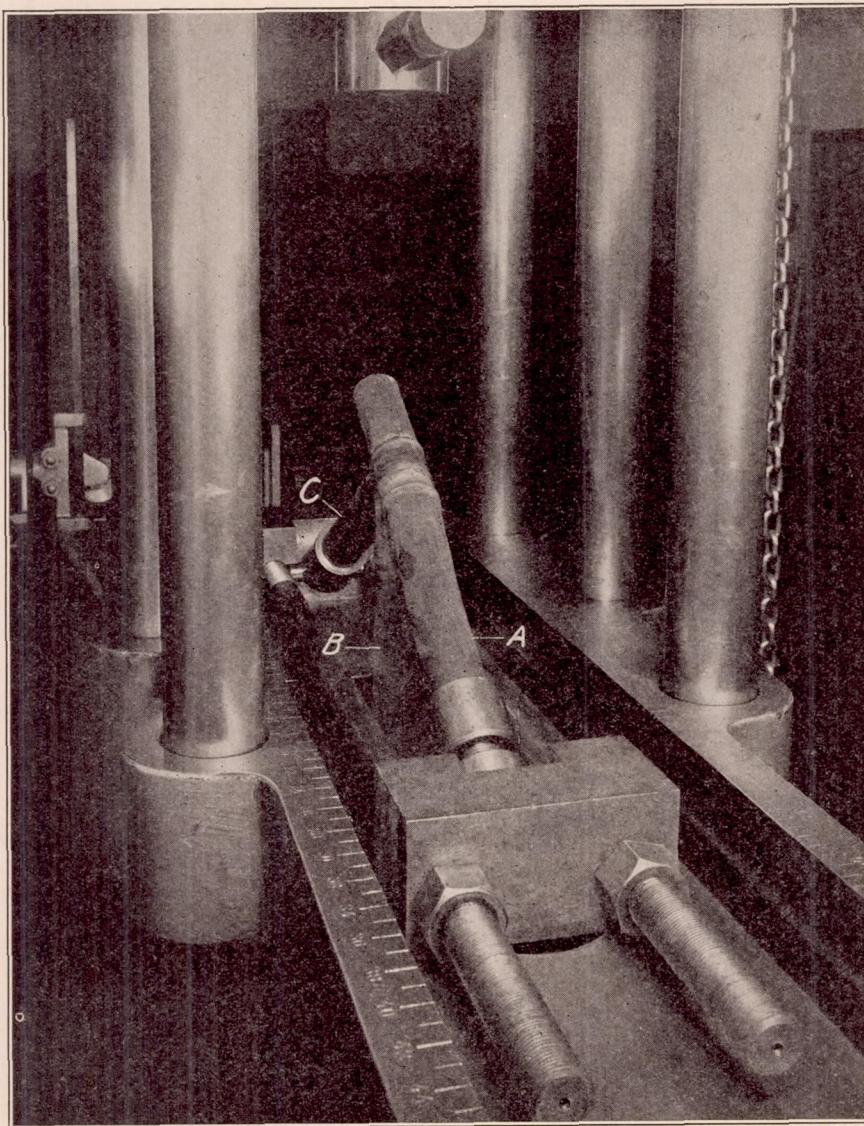

FIGURE 8.—Fixture for testing lattice joints. Tubes A and C are supported on pin bearings while tube B is loaded in tension until failure occurs

by a dial micrometer fastened to an angle bar which was attached to tube A above the supports through flexure plates. Tube B was plugged and loaded in tension until either the specimen failed or a well-defined permanent deflection was reached. The specimen was then given loading II, designed to determine the ultimate strength of the joint when loaded on a short span. Two blocks (see fig. 7) were placed as close to the joint as possible. Tube B was again loaded in tension until failure occurred. Loading I

3. MACHINING

The pieces for corresponding members of the triplicate specimens of each type were cut from the same tube. The cross-sectional area of each tube was computed by dividing the weight by the product of length times density. It was also computed from the measured diameter and wall thickness for a number of tubes as a check. The average difference in the computed areas of 14 tubes measured by both methods was less than 0.5 per cent.

The ends of tubes B and C were shaped in the milling machine to fit tube A closely by using spiral end mills of the same diameter as tube A. Sharp edges were afterwards removed. In joints having inserted plates such as 230 and 750, slots were cut in the tubes using screw-slotting cutters in the milling machine. The time required to machine each joint was observed.

that the test results would be of little value unless the physical properties of the welds as well as the properties of the base metal and the designs of the joints were fixed and reproducible. As procedure specifications are receiving considerable attention as a means for ensuring high-grade welding, it was decided t hat the welding be done under speci-
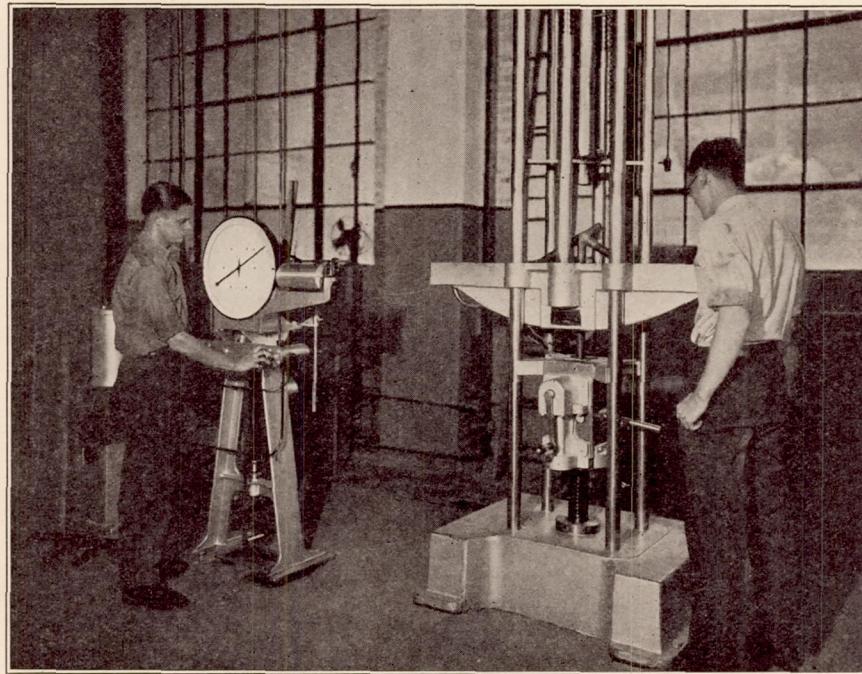

FIGURE 9.—A lattice joint being tested
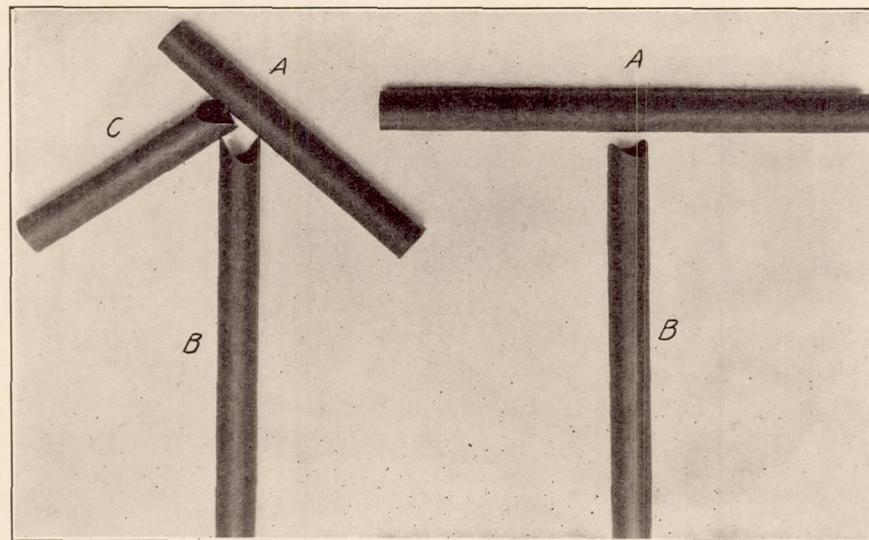
FIGURE 10.—Tubes composing a T and a lattice joint showing tube ends machined by spiral end mills

The pieces for a T and a lattice joint are shown in Figure 10 ready for welding.

4. WELDING

It was considered of the utmost importance that all the welding done in this investigation should be uniform and of good commercial quality. It was realized

fications especially prepared for aircraft structures. The American Bureau of Welding was requested to supply procedure specifications and appointed a Committee on Welding Procedure which prepared the following specifications for oxyacetylene welding. The specifications for electric welding have not yet been prepared.

PROCEDURE CONTROL FOR GAS WELDING [7]

A. Material and Apparatus

Oxygen.—Shall be commercially pure, obtainable from any reputable manufacturer.

Acetylene.—Shall be commercially pure, either dissolved or generated, obtainable from any reputable manufacturer.

Regulators.—Regulators shall be selected that will provide for reducing the initial gas pressures to the working pressure recommended by the manufacturer, and shall be capable of retaining the working pressure constantly until the initial pressure closely approaches the working pressure. The difference between the gauge working pressure with torch valve open and closed should be small. The required oxygen and acetylene pressures for proper welding flames, as illustrated in Figure K, shall be obtained by adjustment of the regulator valves as nearly as possible, thereby necessitating only minor secondary adjustment of the torch valves to obtain the correct flame characteristics.

Pressure gauges.—Pressure gauges having the following pressure ranges shall be used for welding and cutting purposes:

Oxygen	High pressure	0–3,000 lbs./in.²
	Working pressure	0–30, 50, or 100 lbs./in.²
Acetylene	High pressure	0–350 lbs./in.²
	Working pressure	0–30 lbs./in.²

All gauges shall be tested against and shall coincide with a standard testing gauge over the complete pressure range before acceptance for the work to be undertaken in the investigation, standard gauge tolerances to govern.

Welding torches.—The essential requirements of a welding torch for the purpose herein are that it shall properly mix the gases, be light in weight and balanced to the hand, and be provided with proper valve mechanism to enable the operator to obtain secondary gas-pressure adjustments and shut off during the welding operation. Valve-stem packing and hose connections shall at all times be gas tight.

Welding tips.—Tips shall be maintained in a condition that will produce the character of welding flame recommended in Figure K herein. A pointed welding flame should be avoided. When the blowpipe becomes obstructed in any way, use a soft copper or brass wire or hardwood reamer to clean it out. Do not use any hard, sharp tool, as same will enlarge the size of the orifice. The end of the copper or brass wires should be rounded off so that there are no sharp edges to scratch the passageways. Torch tips should be inspected at intervals, by gauging, for drill size. Reasonable tolerances shall be allowed; but if exceed-

ing one-half drill size, shall be marked the next larger size. The joint formed by the tip where it connects to the torch shall be gas tight at all times. For recommended drill size of tip for different thicknesses of metal, reference is made to apparatus manufacturer's published data.

Torch hose.—Rubber and fabric hose shall be used which shall be of a size and quality suitable for the services involved. Hose connections to regulators and torches shall be securely fastened and gas tight. Long length of hose should be avoided; but where this is not possible, heavy duty ¼-inch to ⅜-inch diameter hose should be used except for the last 10 to 15 feet connecting to the torch. A ³⁄₁₆-inch service hose is recommended at this point as an aid to the welder. No joint compounds should be used to aid in joint tightness. Regular hose clean-out and inspection for leaks is recommended. Hose should at all times be prevented from laying on the floor or under workmen's feet.

Goggles.—At all times during welding operations the operator's eyes should be protected by properly designed goggles or spectacles. Lenses are made of amber-colored optical glass that minimizes the effect of glare, which lenses can be obtained from any reputable manufacturer of welding supplies.

Note.—For use and handling of oxygen and acetylene cylinders and/or apparatus, refer to Bulletin No. 23, National Safety Council Safe Practices.

B. Base-Metal Inspection

Physical properties.—Check tests: Base metal as received shall be check tested for physical properties to determine the conformity of the same with the military specifications under which it was procured.

Weldability properties.—All base material shall be subjected to a weldability test, first to an end or cross-section test, and second to a surface flame test—these tests to be applied to every stock length of tubing in each grade of steel used. This is undoubtedly excessive for production work, but, it is felt, should be done in this investigation. Before applying this test the part to be subjected to the flame inspection shall be thoroughly cleaned of mill scale or surface oxides, or foreign matter, such as oil, grease, paint, etc., oxide to be removed by a wire brush, file, or emery paper, as may be required to expose clean metal, or by pickling in suitable solutions. A 10 per cent solution of sulphuric acid in water will be satisfactory.

The end or cross-section test consists of melting the end of the tube around its entire periphery by advancing a neutral oxyacetylene flame produced by a welding tip of 70 to 55 drill size, depending upon the thickness of the metal, regularly as the base metal becomes fluid.

The surface test consists of applying a similar flame over small sections of the tube or plate surface until the base metal becomes fluid. Weldable base metal shall be that which melts evenly and freely without

boiling or giving evidence of gases, and is relatively free of oxides, dirt, or laminations. This testing should be done under the direction of an experienced welding supervisor or metallurgist.

C. Welding-rod Inspection

A manufacturer's report of average chemical analysis of the rod supplied by him shall be furnished investigators. Inspection of the quality of the welding rods to be used shall be made of each lot or package of rods
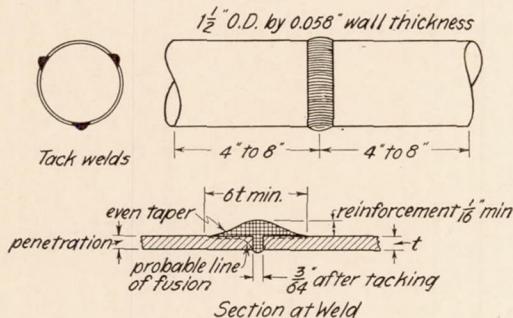

FIGURE A.—SPECIFICATIONS

Type "A" Open Butt Weld Test.

Preparation of ends.—Cut square, clean inside and out past width to be welded.
Tacking.—Tack welds 3/16 inch to 1/4 inch long at three equidistant points.
Method of welding.—Tubes rotated while welding.
Reinforcement.—1/16 inch minimum, 1/8 inch maximum.
Penetration.—Full, to inside wall.
Width of finished weld.—Not less than six times tube wall thickness.
Contour of weld.—Tapered gradually to base metal either side of weld, as shown in detail.

supplied. Rods shall be carefully cleaned of all oxide or foreign matter before test is applied.

Due to the small diameter of the welding rods, a surface flame test or a welding test of the rod is recommended. The flame test is similar to that described in the foregoing (chapter B) for the tubular and plate material. The welding test consists of observing the characteristics of the rod during a welding operation. Scrap pieces of tubing, having the same properties as the base metal selected for this investigation, can be used, upon which the rod is deposited by aid of a suitable oxyacetylene welding flame (neutral), the weld being either in the form of a joint weld or upon the surface of the tubing. Under this test, which should also be made under the direction of an experienced welding supervisor or metallurgist, the rod shall flow freely and show evidence of being free from dirt or oxides.

D. Qualification of Welders

The welders before being permitted to weld any of the specimens in this investigation shall be required to pass the following qualification test:

Each welder shall be given a designating number or letter which shall prevail throughout this investigation. Form No. 1 has been prepared, upon which shall be entered the welder's identification, years of experience

in welding, class of work employed on, and similar data. Welders not having experience in welding materials similar in character to those to be used in this investigation should be referred to a training school before being subjected to the test. On the reverse side of this form there is provided space for the result of the welder's qualification test. (See Form No. 2.) The forms shall be properly filled in for each welder and be submitted as a record for the final report of this investigation.

Preliminary test.—(Essentially an observation test to determine an unrated applicant's ability, intended for the purpose of economically eliminating operators unskilled in this type of welding.)

Scrap materials of like properties to that to be used in the investigation can be used.

1. *Rotative butt welds.*—Welder to make an open butt weld joining two short sections of tubing for each of
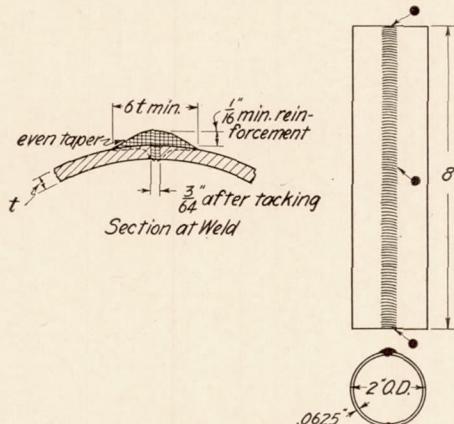
FIGURE B.—SPECIFICATIONS

Type "B" Position Butt Weld Test.

Preparation of edges.—Cut square, surface of edges to be ground or filed off if cut with oxyacetylene torch. Surfaces of tube to be welded to be thoroughly cleaned of oxides and any foreign matter as heretofore specified.
Tacking.—Tack welds 3/16 inch to 1/4 inch long where marked ●→.
Method of welding.—Tube secured in a vertical position. Weld vertical, starting at bottom of specimen.
Reinforcement.—1/16 inch minimum, 1/8 inch maximum.
Penetration.—Full, to inside wall.
Width of finished weld.—Not less than six times tube wall thickness.
Contour of weld.—Tapered gradually to base metal either side of weld, as shown in detail.

the two grades of steel specified herein. The designs and specifications for this test specimen are given in Figure A.

2. *Position butt welds.*—Welder to make an open butt vertical weld joining two sections of 2-inch tubing in either of the two grades of steel specified herein. The designs and specifications for this test are given in Figure B.

3. *Horizontal fillet welds.*—Welder to make a fillet-welded specimen, joining a 3/16-inch plate to a 1 1/2-inch tube section in either one of the two grades of steel specified herein. The design and specifications for this test specimen are given in Figure C.

The material shall be thoroughly cleaned before welding in the regions of welding of all oxides or any foreign matter. Cleaning can be done either with a stiff wire brush, a file, or emery paper, or by grinding if necessary.

Welder to select tip and determine gas pressures.

Welder to weld one fillet forward and one backward.

Welder to select wire size.

The welding inspector or supervisor shall, during the welding operations, look for the following factors of manual skill (*a* to *l*, inclusive) of the welder, and shall determine whether he has sufficient skill to proceed with the final qualification tests:

(*a*) A clean welding tip.

(*b*) Soft neutral welding flame, neither pointed nor irregular.

(*c*) Penetration to inside wall of tube, or to points "X," and to see if welder permits excessive weld metal to protrude into the tube.

(*d*) "Floating out" of oxides or any dirt in the weld puddle.

(*e*) Even fusion into the base metal.

(*f*) Regular movement of the welding torch.
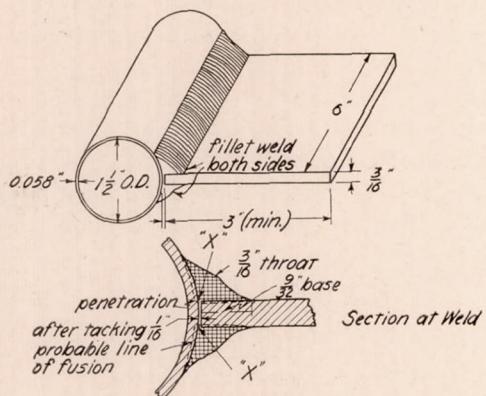
FIGURE C.—SPECIFICATIONS

TYPE "C" FILLET WELD TEST.

Preparation.—Edge of plate abutting tube to have square cut. Surface of edge to be ground or filed off if cut with oxyacetylene torch. Surfaces of tube and plate to be thoroughly cleaned of oxides and any foreign matter as heretofore specified.

Tacking.—Tack welds ³/₁₆ inch to ¼ inch long, both sides, near ends of plate.

Method of welding.—Tube clamped to table so welds can be made in a horizontal position.

Dimensions of weld.—As shown in detail. Fillet contour to taper gradually at either side of weld.

Penetration.—To the root of the fillet or to point "X."

(*g*) Occasional check for neutral flame, by throttling back to neutral indication, a momentary excess of acetylene.

(*h*) Uniform incorporation of filler material with the progressing weld puddle.

(*i*) Production of a regular weld contour and proper tapering of the weld along the sides in accordance with the sketches in Figures A and/or B.

(*j*) Maintenance of clean molten metal at all times during the welding operation.

(*k*) Proper incorporation of the weld tacks into the final weld, particularly the fusion at such points.

(*l*) Proper "closing out" of weld at finish where the progressing weld engages the start of the weld, where care should be exercised on the part of the welder to see that the finish of the weld is thoroughly penetrated into the previously made weld.

The fillet welds in specimen type C are to be remelted by aid of a suitable welding flame, to expose the char-
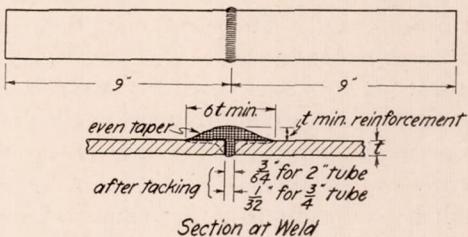
FIGURE D.—SPECIFICATIONS

OPEN BUTT TENSILE TEST.

Preparation of ends.—Cut square. Surfaces of tubes to be welded, including surfaces inside joint, to be thoroughly cleaned of oxides and any foreign matter as heretofore specified.

Tacking.—Tack welds ⅛ inch to ¼ inch long at three or more equidistant points.

Method of welding.—Four specimens to be rotated during welding, tube to be horizontal. Two specimens to be welded in a vertical, fixed position. Welding to be done forward or backward. Backward is recommended

Welding tip size.—See Section A. Material and Apparatus.

Oxygen pressures.—See Section A. Material and Apparatus.

Acetylene pressures.—See Section A. Material and Apparatus.

Reinforcement.—Wall thickness minimum, ⅛ inch maximum.

Penetration.—Full, to inside wall.

Width of finished weld.—Not less than six times tube wall thickness.

Contour of weld.—Tapered gradually to base metal either side of weld.

acter of the weld such as its fusion, penetration, and the general density of the deposited metal.

Final qualification test.—If the welder has satisfactorily passed the preliminary tests set out above, he shall next be required to pass the following final qualification test:

Material:

Tubing, ¾ inch O. D. ✕ 0.028, Spec. No. 57–180–1–A.

Tubing, 2 inches O. D. ✕ 0.065, Spec. No. 57–180–2–A.

Plate (dimensions as shown), Spec. No. 57–136–3.

Plate (dimensions as shown), U. S. Navy Spec. No. 47S14.

Welding rod, mild steel, U. S. Army Spec. No. 57–203–A, grade E.

Sizes: ¹/₁₆ inch for 0.028 thickness; ¹/₁₆ inch or ³/₃₂ inch for 0.065 thickness.

Material to be carefully cleaned for welding, as specified hereinbefore.

4. *Open butt tensile test (rotative and vertical position welding).*—This test requires the welding of six specimens similar to Figure D in each of the two grades of steel specified. For each grade of tubing, four of the six specimens shall be rotated during the welding

operations for the convenience of welder, the specimens being at all times horizontal with respect to the longitudinal axis, and shall be tested as hereinafter set forth. The welding shall be done in accordance with the specifications accompanying Figure D.

Two rotative and one vertically welded specimen (three in all for each grade of steel) shall be tested (in full-size section in a tensile-testing machine until rupture occurs) for strength at the yield point and at ultimate loads. The yield point shall be determined by the drop of beam. The speed of the movable head to be 0.43 inch per minute.

Two rotative and one vertically welded specimen (three in all for each grade of steel) shall be tested in full-size section in collapse as hereinafter set forth.

Required tensile strength.—The strength of the specimens shall be sufficient to either cause failure outside of the weld (for this purpose the width of the welds shall be taken as a section one-fourth of an inch
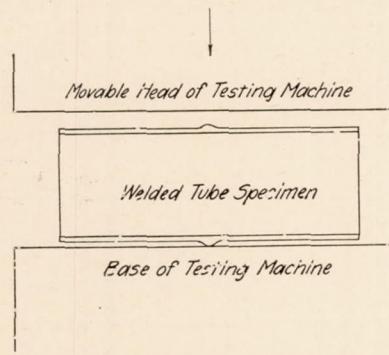
FIGURE E.—Collapsing or ductibility test

wide, centering with the center line of the joint) or shall in any event be not less than that given in the following table:

Material	Ultimate tensile strength, pounds per square inch
Spec. No. 57–180–1–A	50,000
Spec. No. 57–180–2–A	80,000

Collapsing or ductility test.—This test is to be used for welds that join tubes of the same diameter when all the branches are in the same plane. The welded test specimen should be placed on the tensile testing machine and crushed by pressure applied with the movable head, as shown in Figure E, so that the height of the specimen, when removed from the machine, has been reduced to one-half its original outside diameter. Any test weld in airplane tubing that is cracked by this treatment shall be considered unsatisfactory.

5. *Insert plate joint, fillet weld test (horizontal welding).*—This test requires the welding of one specimen similar to Figure F in each of the grades of steel specified herein. The specifications accompanying Figure F inform the welder of the welding requirements

governing this test specimen. Upon completion of welding, the specimens shall be cut in sections through (1)–(1) and (2)–(2), as shown in Figure G. The surfaces of these sections (one for each section exposed) should be prepared for macro-etching as recommended herein under "General specifications." The prepared surfaces in the zone of the welds shall be inspected for the following factors:

(*a*) Conformity of dimensions of welds to those given in the sketch, Figure F.
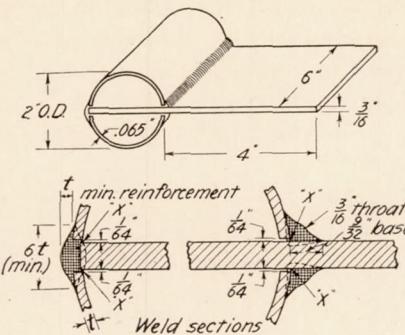
FIGURE F

(*b*) *Penetration of welds.*—Fillet welds shall have full penetration to the points marked "X." The tee butt weld shall have full penetration to the points marked "X."

(*c*) *Fusion.*—The several welds shall be uniformly and completely fused to the base metal at all points of contact.

(*d*) Sound weld metal, free from gas pockets or holes, fissures, plates of oxides, laps, or similar defects.
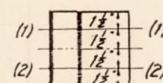
FIGURE G.—SPECIFICATIONS

Preparation of edges.—Cut square. Surfaces to be welded, including surfaces inside joints, to be thoroughly cleaned of oxides and any foreign matter as heretofore specified

Tacking.—Four tack welds, two each side, near end of plate at point of fillet welds and two tack welds near ends of plate at point of butt weld.

Method of welding.—Specimen to be placed in convenient position for each of the three welds. Welding is to be done forward or backward. Backward is recommended

Welding tip size.—See Section A. Material and Apparatus.

Oxygen pressures.—See Section A. Material and Apparatus.

Acetylene pressures.—See Section A. Material and Apparatus.

Reinforcement.—As shown for fillets. For the butt weld, wall thickness minimum, ⅛ inch maximum.

Penetration.—To points "X".

Width of finished welds.—As shown.

Contour of welds.—Tapered gradually to base metal either side of weld.

6. *Composite joint (general position welding).*—This test is specified for the purpose of observing the welder's ability to weld a typical 4-member reinforced joint for aircraft and in a position characteristic to that of production practices. The design and specifications are given in Figure H.[8]

The nature of the design and the position of the specimen for welding requires the welder to make welds

[8] The design of the specimen is similar to Fig. 7, Bureau of Standards drawings A–314, 315, 316, and 317, attached to their Report No. 1.

in several unhandy positions; also to superimpose welds upon previously made welds. His ability to produce a satisfactorily welded joint under these conditions shall be thus determined.

Upon completion of welding, sections through the specimens shall be exposed through the center of the welds (sections 3–3 and 4–4, fig. H) by sawing, and be prepared for macro-etching as recommended herein under General specifications. The prepared surfaces in the zone of the welds shall be inspected similarly as for final test (section 5, figs. F and G herein), especial attention being given to the locations where compound or rewelding has been done.

General Specifications

Heat treatment.—No heat treatment other than that which normally occurs immediately succeeding the welding operation shall be given any of the specimens
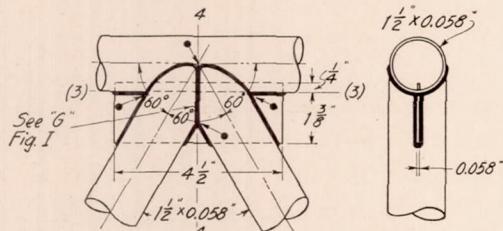

FIGURE H.—SPECIFICATIONS

Preparation of joints.—Intersections to be carefully matched. Surfaces to be welded including surfaces inside joints, to be thoroughly cleaned of oxides and any foreign matter as heretofore specified.

Tacking.—Tack welds $\frac{3}{16}$ inch to $\frac{1}{4}$ inch long where marked ●→.

Method of welding.—Specimen to be welded in fixed position, insert plate vertical with principal member uppermost. Welding to be done forward or backward. Backward is recommended.

Welding tip size.—See Section A. Material and Apparatus.

Oxygen pressure.—See Section A. Material and Apparatus.

Acetylene pressure.—See Section A. Material and Apparatus.

Penetration.—To the root of fillet.

Contour of weld.—Tapered gradually to base metal either side of weld.

welded for this investigation. Upon completion of welding, the specimens shall be cooled in air to room temperature.

Macro-etching

The specimens for macro-etching are prepared by grinding or filing until the surface is flat. Then the grinding or polishing should be continued on successively finer abrasive wheels or grades of emery paper. Each grinding should remove the scratches left by the previously used coarser wheels. The final polishing should be with No. 1 emery paper.

A saturated solution of ammonium persulphate should be used for the etching. It may be applied with a small cloth or wad of cotton. When the etching is finished, hold the specimen under running water and rub with a cloth or cotton, then wash with alcohol, and dry quickly.

The etched specimen may be inspected for the following: Thoroughness of penetration of the welding; contour of weld; fusion between weld metal and base metal; freedom from cold shuts, blowholes, and nonmetallic inclusions.
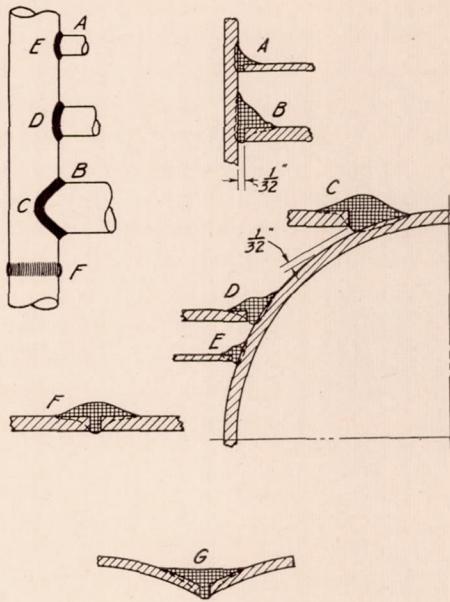

FIGURE I

Welding Specifications for Investigation Specimens

Material.—See section on Material, herein.

Preparation for welding.—The material shall be prepared for welding by machine tools or by grinding and the details shall be similar to those shown for
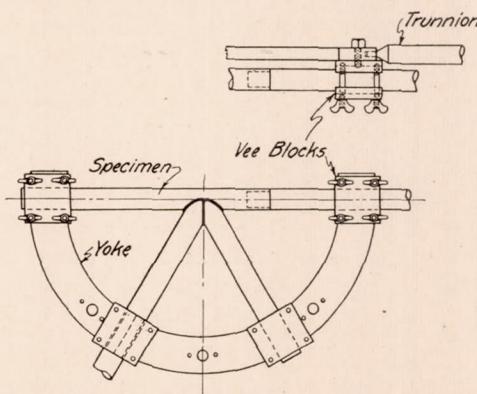
FIGURE J.—Universal specimen jig, permitting complete welding of specimen without removing specimen from jig

the several types of joints of Figure I herein. The faces of joints in tubes and plates for butt welding or butt fillet welding shall be machined square, that is, no beveling shall be done. For tubular intersection joints the edges of the tubes shall in general be either ground or filed to avoid thin sections which would readily melt away when applying the welding flame. (See fig. I herein.) Especial care should be given to obtain a neat fit at all points of intersection.

Before welding, the specimen shall be mounted accurately in a jig similar to that shown in Figure J herein, and tacked at a sufficient number of points to insure a constant joint spacing during the welding operation.

Position of specimens during welding.—All specimens shall be welded with the principal or longitudinal axis horizontal so that the majority of the welds can be made in a flat position. The jig shall not be moved, however, until the welding on one side of a horizontal plane is completed. The jig can then be turned over and the welds on the other side made as before. Variation to the above may be made under special provision by the Bureau of Standards.

minimum of $\frac{1}{16}$ inch and $\frac{1}{8}$ inch maximum, except as may be otherwise specified. Additional requirements for reinforcement are shown in Figure I herein.

Gaging welds.—For this class of construction, the gaging of welds is somewhat difficult except for the open-butt type due to unsimilarities. The committee submits for the bureau's consideration the type of gages which the American Bureau of Welding developed for gaging the welds involved in the program of its Structural Welding Committee.[9] The gages for the butt welds will apply with slight modifications, whereas the gages for the standard fillet welds and the various forms of fillet and butt welds
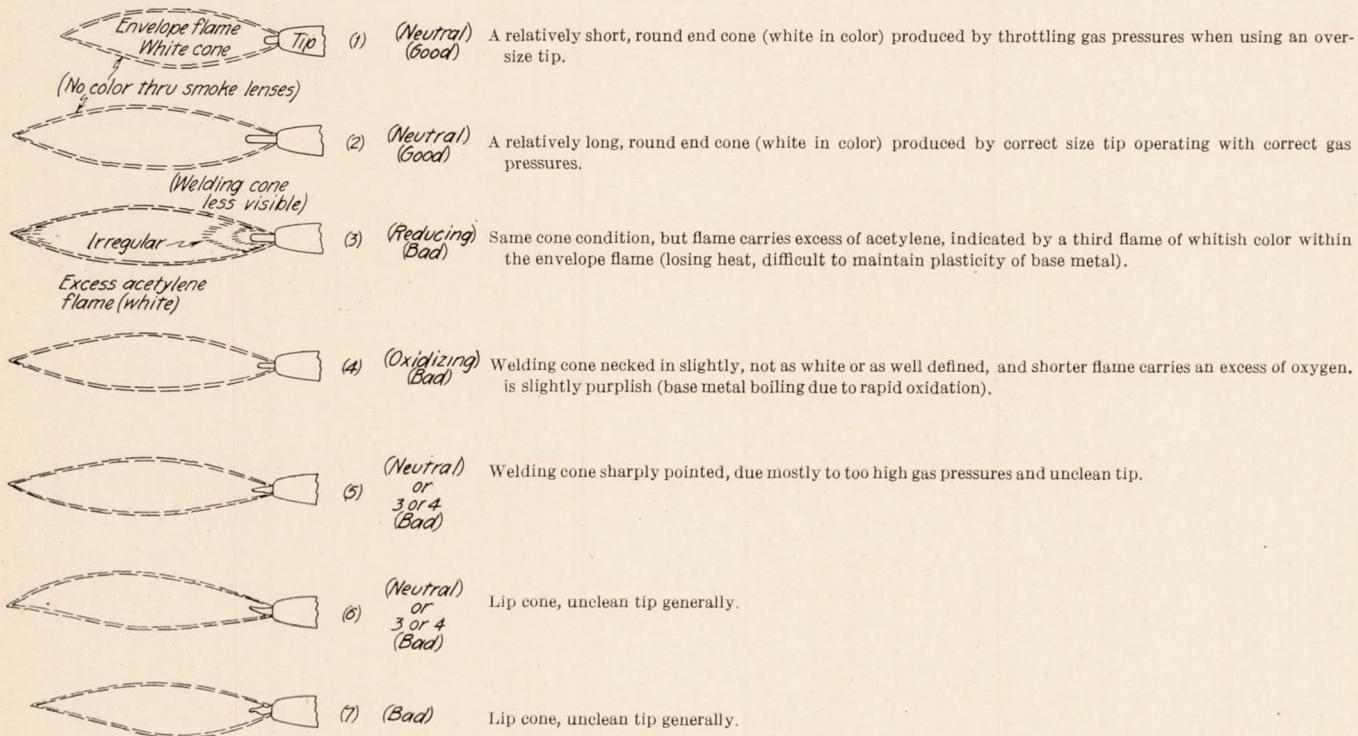

FIGURE K.—Flame characteristics

Welding gas flame.—The type of welding flames recommended are shown in Figure K herein, Welding flame characteristics (detail No. 1 or No. 2 being desirable).

Method of welding.—Either "forward" or "backward" welding method can be employed; however, the "backward" method is recommended wherever it is convenient to use. An explanation of this is illustrated in Figure L herein. Care should be exercised on the part of the welder to avoid undercutting of the base metal at the edges of the weld and to produce an even weld contour. In "closing out" a butt weld or when engaging a previously made weld of any type, the welder shall, in addition to affecting thorough fusion and penetration, reheat the weld zone at the closure for a reasonable distance beyond. Generally 1 inch is sufficient. Weld reinforcement should be not less than the wall thickness, or a

will require complete revision as to dimensions, due to limiting space allowed for gaging.

An experienced supervisor or inspector can determine to a fairly close degree the conformance of weld dimensions to the requirements of the design by careful visual inspection with the aid of a small steel rule.

Welding jigs and fixtures.—For assembling the specimens and for tacking and welding, the jig and fixtures shown in Figure J herein are submitted for consideration. Essentially, the design provides for assembling the several parts at various angles and for adjustment of the longitudinal plane of elevation of the principal member; also for access for welding on reverse side of specimen without taking it out of the jig. The fixtures provide for assembling the various types of gusset or insert plates to any size of tubing.

[9] See Figure M.

Recheck of welders.—It is recommended that the welders employed for welding the test specimens herein be rechecked or requalified in part at intervals of one week after the first welding has been started and at intervals of two weeks thereafter, until all of the specimens have been welded.

The "open butt tensile test," Figure D herein, is recommended for this purpose. However, the number of the specimens can be reduced to one-half. In the event the recheck discloses results below the requirements of the original qualification test, the welders shall be rechecked as set forth in the original qualification test.

Weld tightness.—Inasmuch as it is a desirable feature of welds in aircraft to be tight against leaks, it is recommended that the specimens be subjected to a pneumatic leak test. The pressure may be raised to three or more atmospheres, depending upon the service

The Air Reduction Sales Co. contributed the services of Mr. A. Rath, a member of its staff, as welding supervisor. He was present during all the welding. In his opinion, it complied with the procedure specifications.

In order to use representative apparatus, four of the principal manufacturers of welding equipment were invited to submit a complete set of their apparatus for use in welding the test specimens. Each set was used to weld specimens assigned to it when the program was prepared. The sets (see fig. 11) are designated by the letters A, B, C, and D.
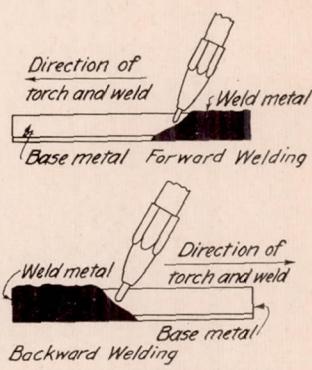

FIGURE L.—Methods of welding
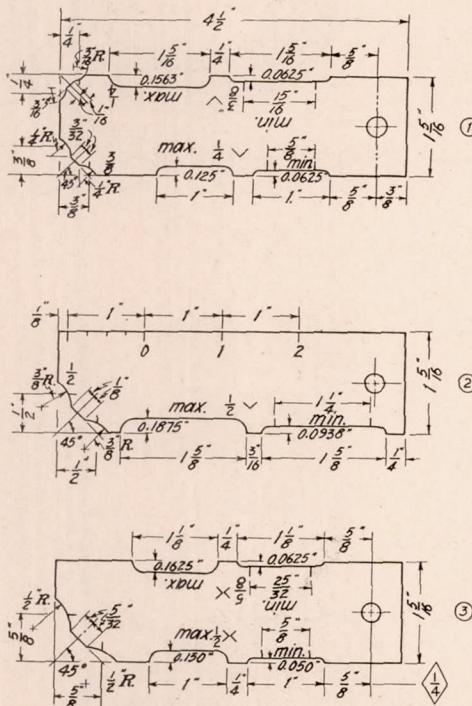
FIGURE M.—Gages for measuring butt and fillet welds and a sketch illustrating method of application of these gages

of the joint; and while the pressure is "on," inspection for tightness can be made by the aid of soapy water applied over the surfaces of the welds and adjacent metal. Any pinhole leaks can be corrected by rewelding. This procedure is recommended as a means of preventing interior corrosion of the tubes in service and to avoid the necessity for flushing the tubes with oil. Welding properly done and inspected as herein set forth may solve the problem of interior corrosion.

The Bureau of Standards employed Mr. M. I. Anderson, who welded all the joints. His experience had been obtained at the Keystone Aircraft Corporation and the Fokker Aircraft Corporation. He complied with the qualification tests of the procedure specifications.
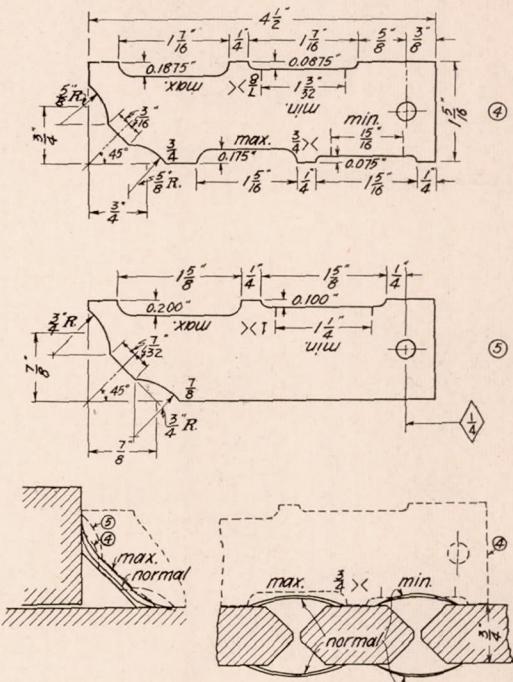
The oxygen and acetylene were purchased from the contractor given in the general schedule of supplies for the fiscal year 1929, prepared by the General Supply Committee of the Treasury Department.

Analysis of the oxygen showed a purity of 99.5 per cent. No analysis was made of the acetylene, but it complied with the specifications used by the United States navy yard, Washington, D. C., in purchasing this gas. These specifications are as follows:

The acetylene gas shall be dissolved in sufficient acetone to insure against explosion and shall be purified to the highest possible degree of purity, the hydrogen and sulphur being removed to such an extent that the gas will not color a piece of white blotting paper or similar material saturated in a 5 per cent solution of silver nitrate when held in the flow of the gas for 30 seconds.

The specimens were welded in a jig (see figs. 12 and 13) which was adjustable to fit all joints in the program. By mounting the jig in bearings so that it could be

bundle of welding wire used for each joint was weighed before and after welding, and the amount used was compared with the increase in weight. The weight of
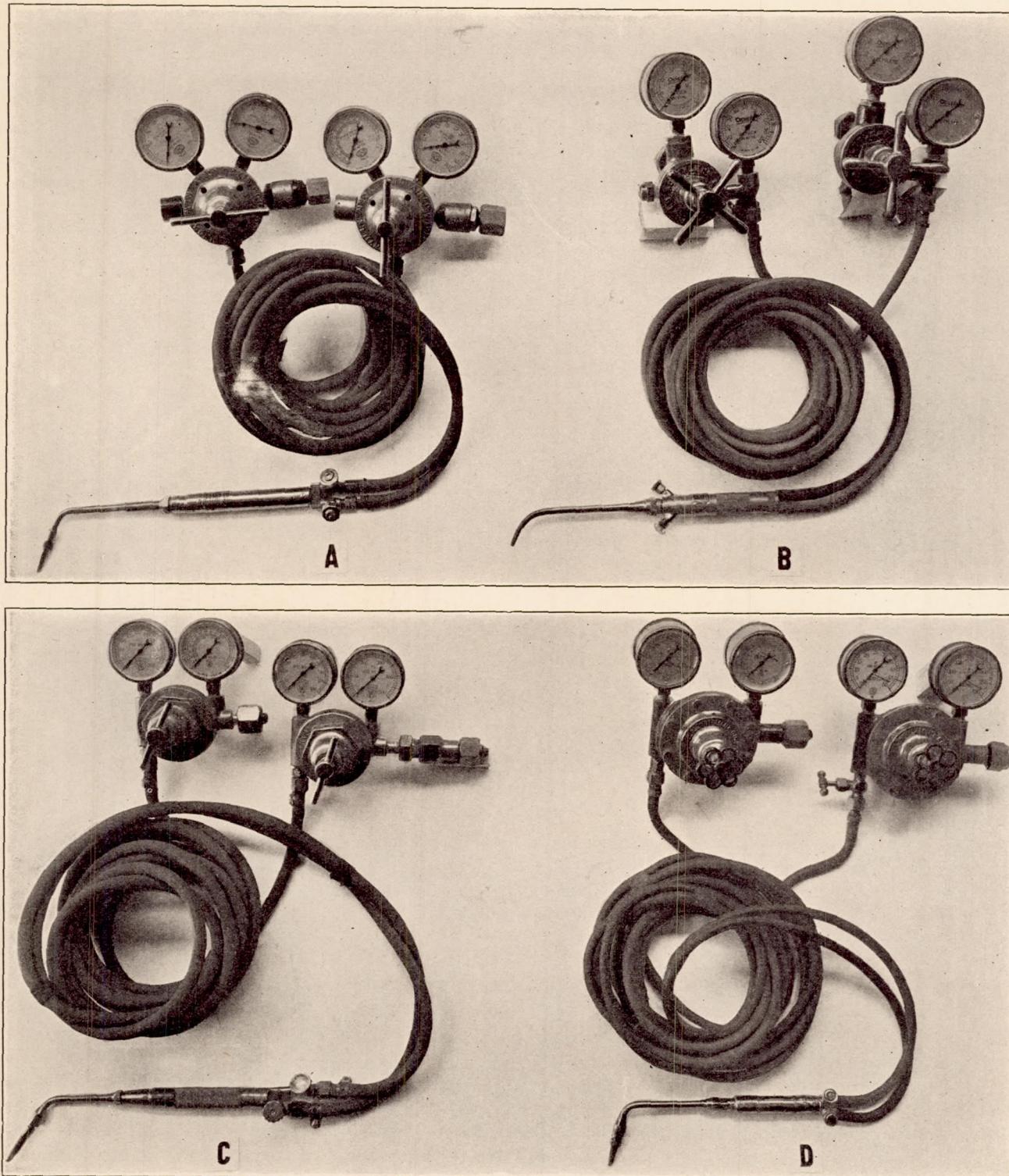
FIGURE 11.—The torches and equipment used to weld the specimens   Each torch was used to weld about an equal number of specimens

rotated, all parts of the joint were readily accessible to the welder.

The pieces of each joint were weighed before welding, and the joint was weighed after welding, the difference being the weight of the weld metal. As a check the

welding wire used was found to be about 10 per cent higher than the gain in weight of the pieces during welding.

In making the butt joints in tubes of 0.028 and 0.065 inch wall thickness, it was impossible to make beads of

the dimensions given in Figure A of the procedure speci-fications. The actual dimensions are given in Figure 14. For the thinnest base metal the bead is slightly wider but of less height than specified. For the thickest base metal both width and height are less. It is believed that an increase in bead size would not affect the test results as the majority of the specimens failed outside the weld.

By far the most serious difficulty encountered in the welding was the formation of cracks in the gusset plates. About one-fourth of all joints reinforced with plates had visible cracks. The numbers of such joints are 2251, 2252, 2253, 431, 441, 442, 452, 532, 751, 753, 7191, 7192, 851, 931, and 932. Photographs of the cracks in joints 753 and 851 are shown in Figure 15. Changing the order in which the welds

tension and compression based on the strength of the unwelded tube. There was apparently no relation between the efficiency and the size of the tube. Failure in all except one joint, No. 052, occurred in the tube about one-half inch from the weld. Tensile specimens failed by rupture at this point, and compressive specimens by formation of a circumferential fold.

To study the properties of the metal as affected by the heat of welding in the region in which failure occurred, hardness explorations and stress-strain measurements were made of the butt joints.

Hardness explorations were made of joints 011, 041, and 051, using a Vickers machine with a 30-kg. load applied for 10 seconds. The Vickers numbers are plotted against distance from the center of the weld in Figure 17. It is claimed by the makers of the Vickers
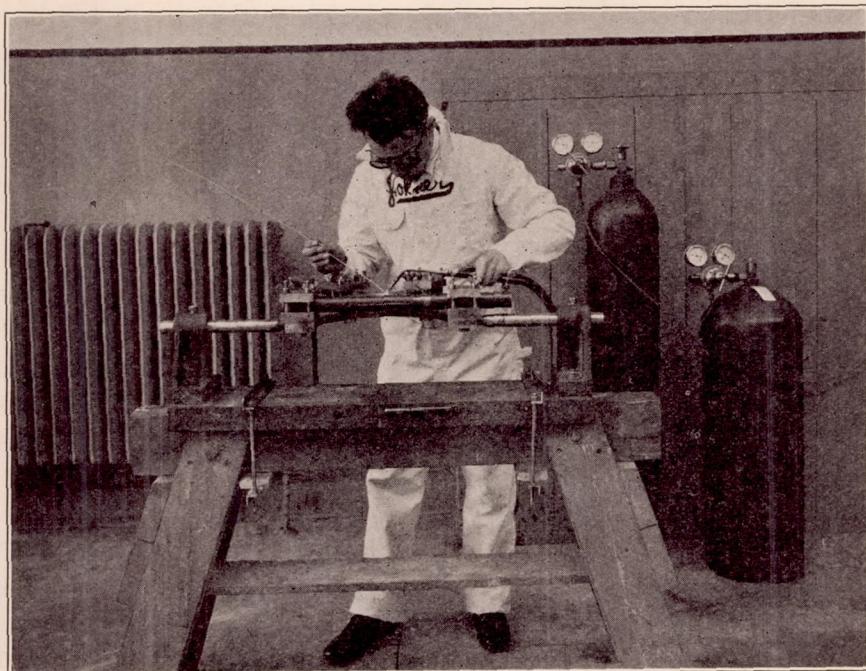

FIGURE 12.—A lattice joint being welded in the jig

were made or the direction of welding appeared to have no effect on the cracking.[10] Welding on one side only of plates not inserted in the tube was tried in joints Nos. 432, 433, and 453. No cracks were noted in these joints.

In testing specimens Nos. 2251, 2252, 2253, 431, and 532 the fracture started in a visible crack, probably resulting in a lower ultimate strength. It is believed that the strengths of the other specimens were not affected by cracks.

V TEST RESULTS

I. BUTT JOINTS

Tensile and compressive tests were made of butt joints in the five sizes of tubing. The efficiencies and maximum stresses are plotted in Figure 16. The efficiencies ranged between 78 and 93 per cent for both

machine that for material of the hardness of chromium-molybdenum tubing the Vickers numbers correspond closely to the Brinell numbers.

The tube has a much lower Vickers number at a distance of one-half inch from the weld center. At this point it has approximately the same hardness as the weld. For example, the tubing used to make specimen 041 had a hardness of about 225. This was reduced by the heat treatment accompanying the welding process to 160, one-half inch from the weld center and was increased to about 280 at the edge of the weld. The weld metal itself had an average hardness of 170.

The results of the hardness explorations are similar to those reported by Sisco and Boulton[11] and by J. B. Johnson,[12] who used Rockwell machines.

[10] Recent tests made by another laboratory seem to indicate that cracking in gusset plates can be reduced by welding from the apex of the angle formed by the intersection of the tubes outward.

[11] Welding Steel Tubing and Sheet with Chromium-Molybdenum Welding Wire Trans. A. S. S. T., vol. 8, No. 5, p. 589, November, 1925.

[12] Airplane Welding, p. 155, Goodheart Willcox Co. (Inc.), Chicago, Ill.

Two pairs of Huggenberger extensometers with 1-inch gage lengths were used to measure the elongation or compression of the specimens under load. (Fig. 18.) Pair A was placed on the tube where the material had not been affected by the welding heat. Pair B was placed immediately adjacent to the weld,

lbs./in.^{2} in tension and 22,000 lbs./in.^{2} and 34,000 lbs./in.^{2} in compression. This deviation was determined by the method used to find the proportional limit for the tubing specimens. (Figs. 1 and 2.) The proportional limit for curves A checked with the values given in Table III, varying between 45,000
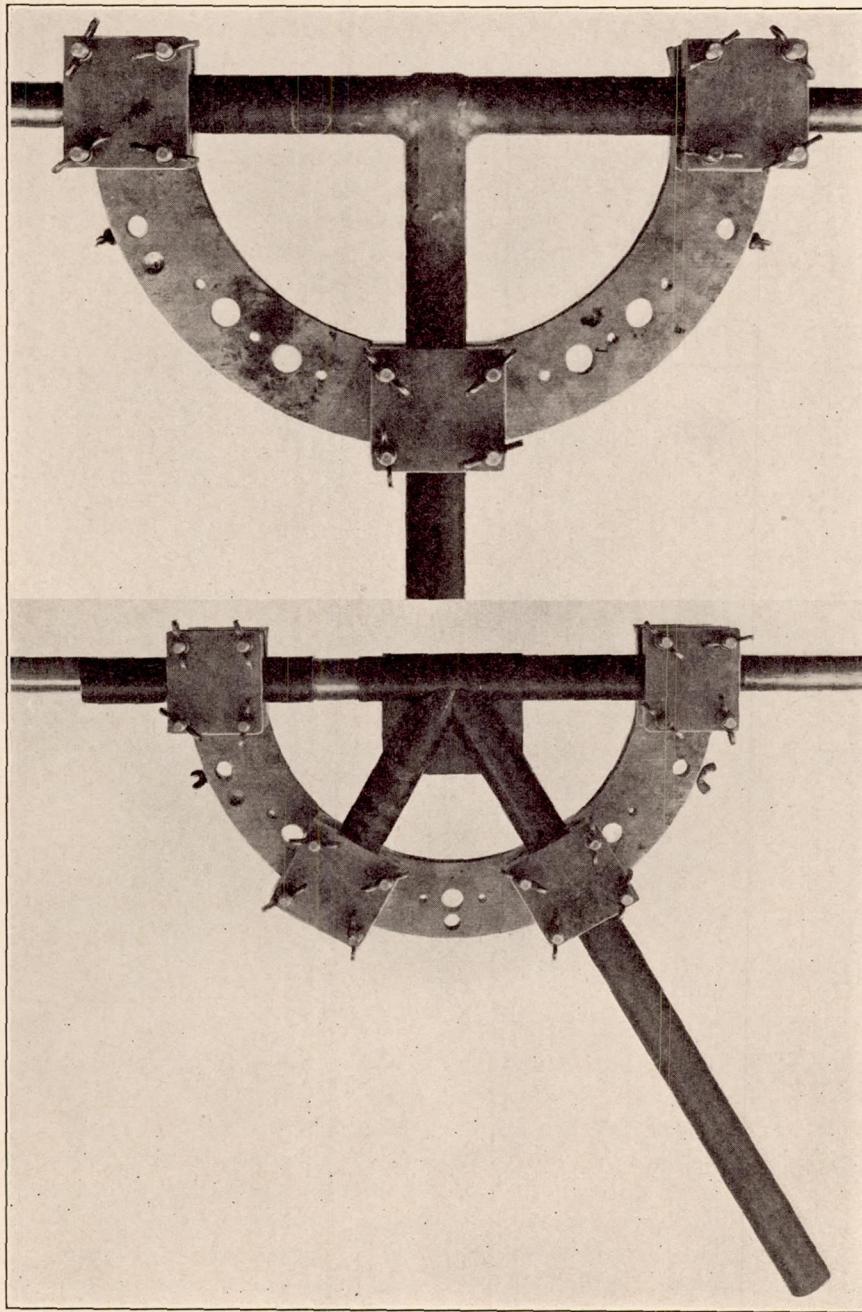
FIGURE 13.—A T joint (upper) and a lattice joint (lower) set up in the jig for welding. The tubes are clamped in V blocks bolted to the frame. Where tubes of different diameter were welded together, shims were placed under the blocks holding the small tubes. The jig may be turned over for welding on the bottom side

the gage length including the zone where failure usually occurred.

From the stress-strain diagrams, Figure 19, it may be seen that for the 1-inch gage length next to the weld the curves B deviate from a straight line at a low stress, varying between 22,000 lbs./in.^{2} and 27,000

lbs./in.^{2} and 60,000 lbs./in.^{2} in tension and above 60,000 lbs./in.^{2} in compression.

2. T JOINTS

The efficiencies of the T joints were computed by dividing the maximum load by the ultimate strength of tube B.

The maximum stresses and efficiences for the T joints are plotted in Figures 20, 21, and 22. Locations of the failure are indicated on the drawings. Thus, in loading I for joint 111, Figure 20, a stress of 25,000 lbs./in.² in tube B produced a crack in the lower side of tube A adjacent to the weld. The permanent deflection was 0.067 inch and the efficiency of this joint was 18 per cent. In loading II at a stress of 73,000 lbs./in.² in tube B tube A ruptured along the edge of the weld. The efficiency was 54 per cent.

Where it is believed that the strength in loading II was seriously lowered as a result of loading I, the value is plotted but not averaged with the others.

a. Loading I

Unreinforced T joints in which both tubes were the same diameter (120, 140, and 160) gave efficiencies ranging between 11 and 14 per cent in loading I. As would be expected, joints with the smaller tension member gave higher efficiencies.

Inserted plates (joints Nos. 230, 240, 250, 2230, 2240, and 2250) and straps (joints Nos. 3100, 3110, and 3120) produced very slight increases in efficiency.

Welding a triangular gusset plate in the angles formed by the intersection of the tubes increased the efficiency according to the size of the plate. Joint No. 430 had an efficiency of 12 per cent, practically no increase over the unreinforced joint which was 11 per cent. Joints Nos. 440 and 450, with larger gussets, had efficiencies of 14 and 24 per cent, respectively. Although the latter joint has a strength about twice that of the unreinforced joint, the time required to weld it is seven times as long (fig. 31), and the extra weight above the weight of the tubes is 0.56 pound compared with about 0.02 pound for the unreinforced joint.

The large gussets of joint No. 450 also produced a considerable deformation in tube A due to residual stresses when the joint cooled. These stresses were sufficient to cause a ¹⁄₁₆-inch deflection of the ends of tube A below the middle after cooling. Welding on one side only of the plate improved this condition.

Joints Nos. 530, 560, and 590 in which the load was applied through a rigid terminal all required a load of about 3,400 pounds to produce the permanent set.

b. Loading II

The efficiencies of the unreinforced T joints varied widely, ranging between 56 and 82 per cent. All except Nos. 121 and 153 failed by rupture of the A tube around the edge of the weld. Nos. 121 and 153 failed in tube B below the weld.

The joints reinforced by inserted gussets (Nos. 230, 240, and 250) had average efficiencies of 78, 69, and 74 per cent, respectively. The strength apparently did not depend on the depth of the gusset. All failed in tube A by rupture around the weld and by crushing around the plate at the top.

Joints having a wider gusset inserted in tube B only and welded to both tubes had about the same efficiency, 67 per cent for No. 2230 and 78 per cent for Nos. 2240 and 2250. It is apparently of no advantage to make the depth of the gusset greater than 1½ inches (No. 2240).

Of the joints reinforced by a strap, No. 3110 had the highest efficiency, 87 per cent. This was also the highest for all the T joints. No. 3100 was weakened by the ends of the strap being too near the joint. A strap extending 1 inch below the top of tube A is obviously long enough.

Joints reinforced by triangular gussets not inserted gave average efficiencies of 73 per cent for No. 430 having the small gusset to 84 per cent for No. 450 with the largest plates. The average efficiency of Nos. 432 and 433, which were welded on one side of the gusset plate only, was about the same as the efficiency of No. 431, which was welded on both sides. Joint
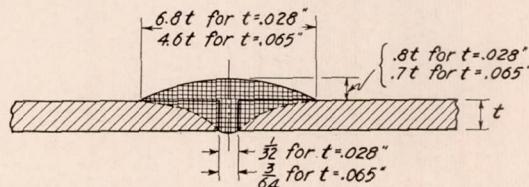

FIGURE 14.—Dimensions at sections of butt joints in tubing. A somewhat smaller bead was used than that prescribed in Figure A of the procedure specifications

No. 453 had an efficiency somewhat lower than the average and failed in tube A by tearing out of the gusset, starting on the unwelded side. The two that were welded on both sides of the gusset, Nos. 451 and 452, failed in tube B below the gusset.

Efficiencies of the lug joints were based on the strength of the tie-rods. Nos. 531 and 533 failed by the plate pulling out of tube A. The low efficiency of No. 532 apparently was caused by a crack in the plate. In No. 560 the pin sheared out of the plate. In No. 590 the tie-rod failed in tension.

3. LATTICE JOINTS

Two efficiencies were computed, E_t, the percentage of the strength of tube B in tension developed by the joint, and E_c, the percentage of the strength of the weakest of tubes A and C in compression.

E_c was always higher than E_t as the compressive strength of a tube was always lower than the tensile strength.

Most of the unreinforced joints (Nos. 610 to 680) failed by collapse of the tubes at the joint, the end of tube C being forced into the wall of tube A. Joints which failed in this manner are marked "X" on the drawings, Figures 26 and 27.

Maximum stresses and efficiencies are plotted in Figures 26 and 27. Looking at joint No. 611, for example (fig. 26), this joint failed when the stress in tube B reached 67,000 lbs./in.² by collapse of the tubes at the joint (X). The efficiency based on the tensile
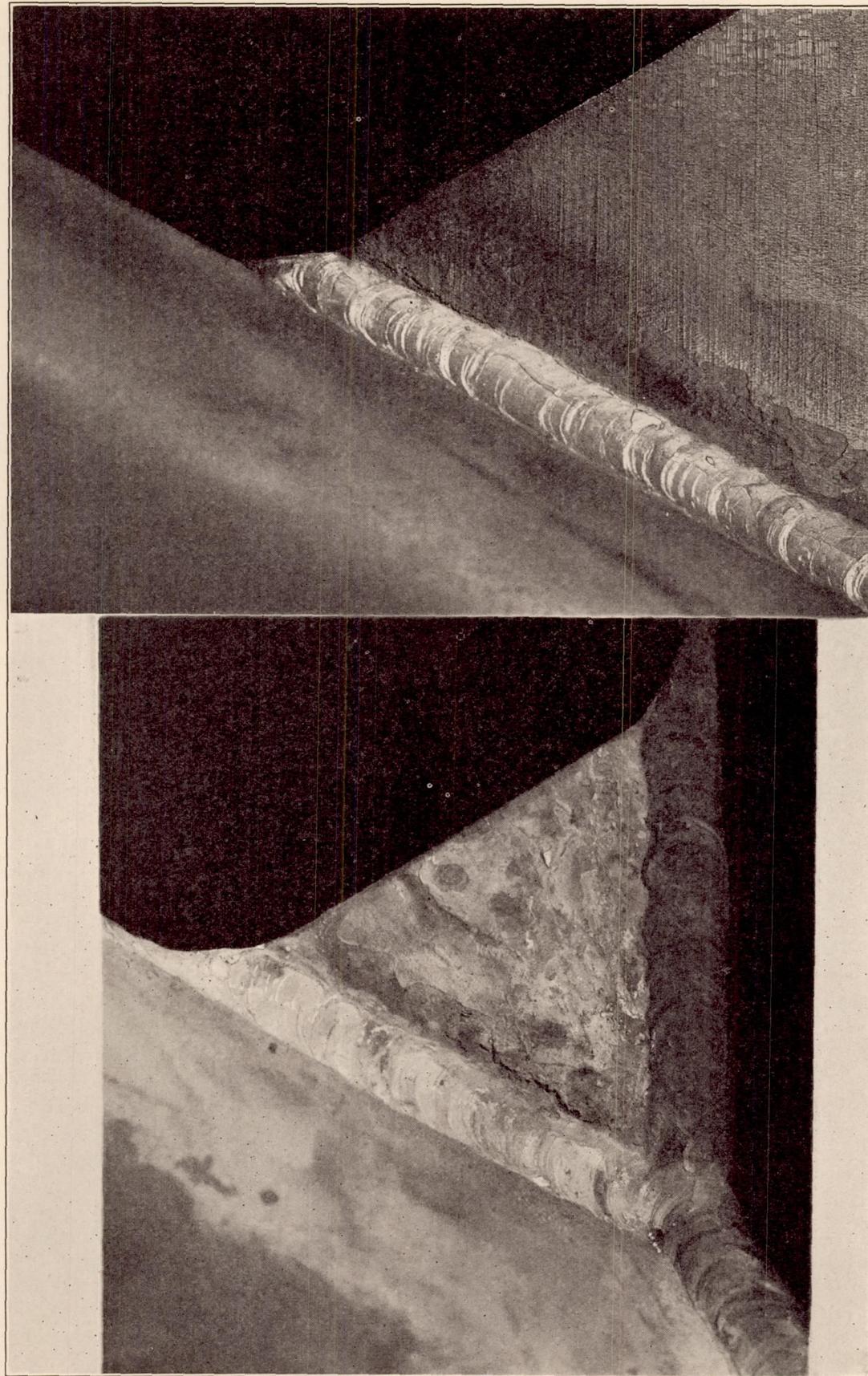
FIGURE 15.—Cracks produced by residual stresses in joints after cooling.   Upper, in specimen 753; lower, in specimen 851
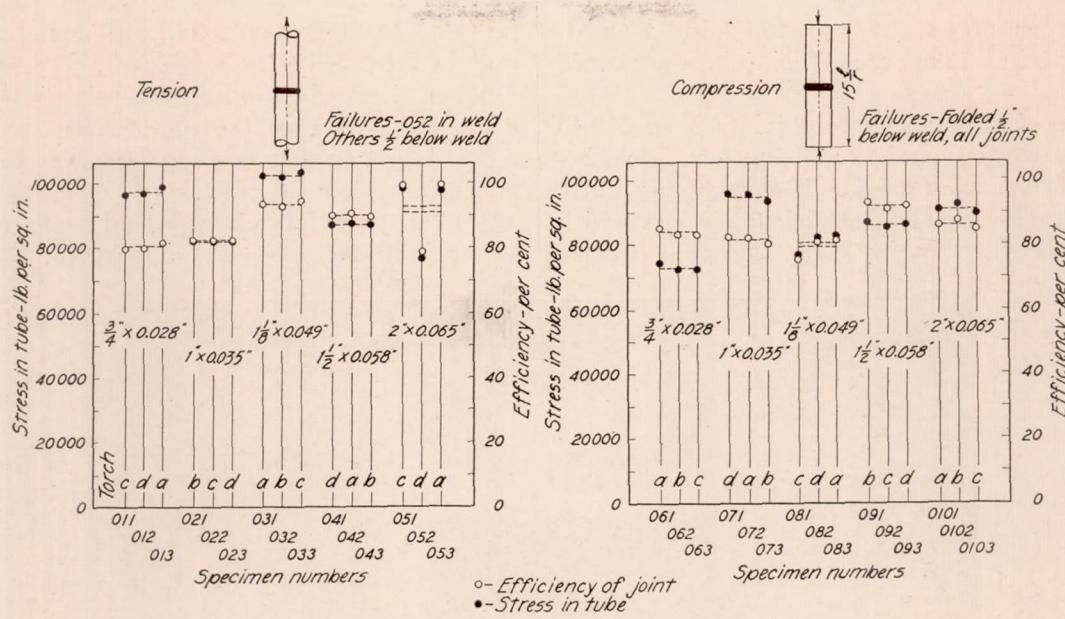
FIGURE 16.—Maximum stresses and efficiencies of butt joints
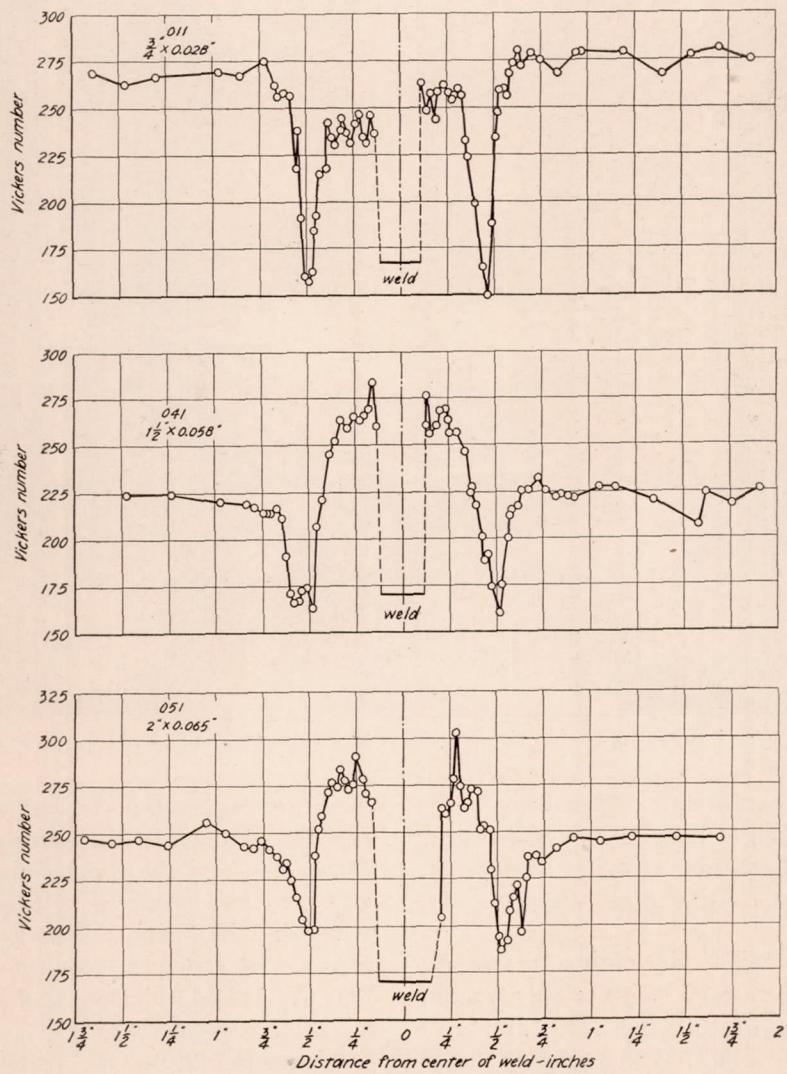
FIGURE 17.—Hardness explorations of butt joints

strength of tube B (E_t) is 68 per cent. Based on the lowest of the compressive strengths of tubes A and C the efficiency (E_c) is 72 per cent. This joint was welded with torch "a."

Efficiencies of the unreinforced joints Nos. 610 to 660 varied between 58 and 68 per cent for E_t and between 60 and 76 per cent for E_c. There was apparently no significant difference in the efficiency in joints with tubes B and C reduced in size (Ncs. 620, 640, and 660).

position of tubes B and C. A slight advantage in favor of No. 630 was noted, although the difference may be too small to be significant.

When the angle at which the tubes intersected was made 45° (No. 680) the compression components in tubes A and C were decreased so that tube B failed in tension below the weld.

Similar types of reinforcement were used in the lattice joints as in the T joints. No. 750, in which
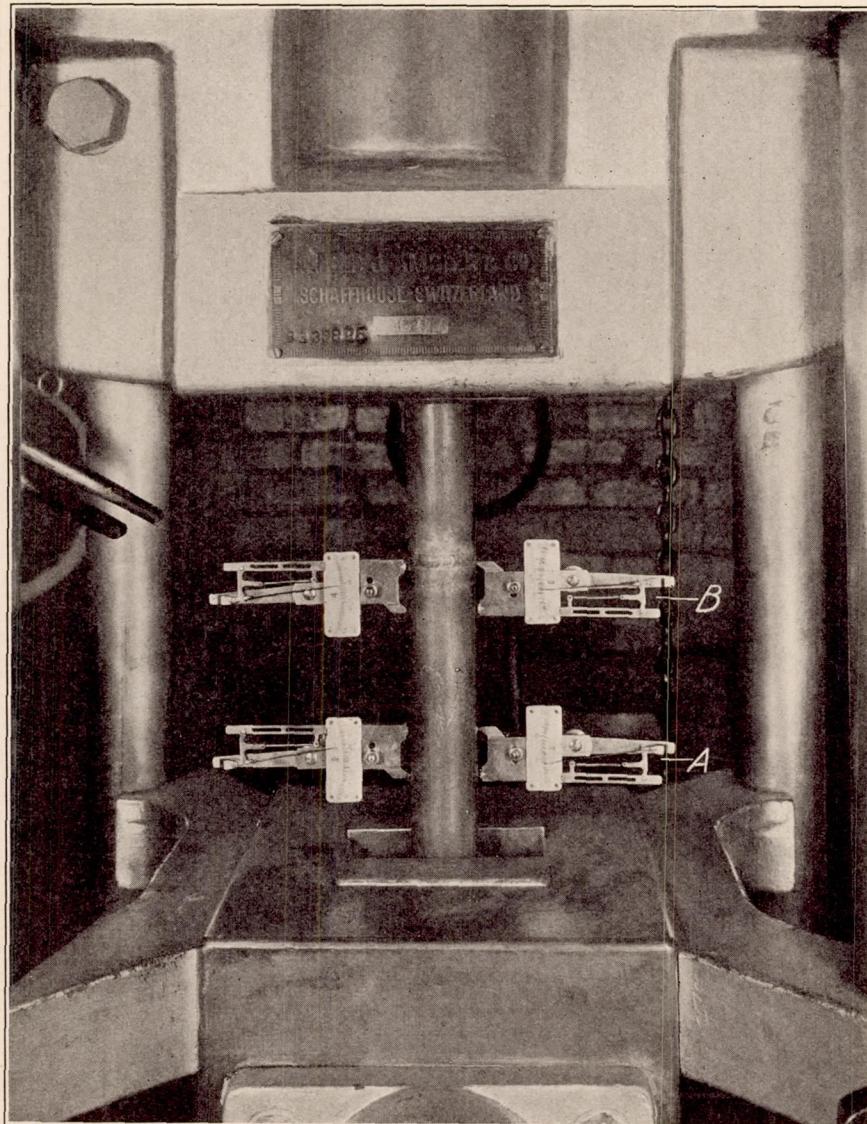
FIGURE 18.—Huggenberger extensometers on butt joint to measure the strain near the weld and at a distance from the weld

A 60° lattice joint could probably be made with the tension member B reduced at least 10 per cent in wall thickness with equal diameters and have the same strength as one in which all the tubes were the same size.

Joint No. 670 was tested to determine if any difference in strength would result if tube C were made the tension member instead of tube B. The difference in the shape of the tube ends resulting, for this condition, may be seen from Figure 10 by reversing the

an inserted gusset plate was used for reinforcement, was the strongest, the tensile efficiency, E_t, being 80 per cent and the compressive efficiency, E_c, 90 per cent. Failure occurred in tube A near the end supported by the fixture. This joint was approximately 20 per cent stronger than the unreinforced joint No. 630, which had efficiencies of 67 and 76 per cent for E_t and E_c, respectively.

Joint No. 7190 having a somewhat shallower gusset which was not cut through tube A gave slightly lower

efficiencies; 78 per cent for E_t and 82 per cent for E_c. Failure occurred by the crushing of tube A at the joint.

Joint No. 850 having large triangular gussets welded between the tubes but not inserted gave no higher efficiency than the unreinforced joint No. 630. The joint failed by the plates being forced into the wall of tube B.

The lug joints Nos. 930 and 9100 failed by the pin shearing out of the gusset.

Joint No. 1010, reinforced by a U strap, was practically as strong as the inserted-plate joint No. 750, the efficiencies being 79 and 91 per cent for E_t and

5. PNEUMATIC TEST

To investigate the possibilities of making welds tight against leaks as suggested in the procedure specifications, one specimen of each of the T and lattice joints was tested for the presence of small leaks by subjecting the tubes to an internal air pressure of 25 lbs./in.^{2} and applying soapy water to the joint, any leaks being indicated by bubbles.

Leaks were found in specimens Nos. 3101, 3102, and 3103 in tube B at the corner of the strap and in joints Nos. 451 and 453 in tube B below the lower corner of the gusset. None were visible to the naked eye.
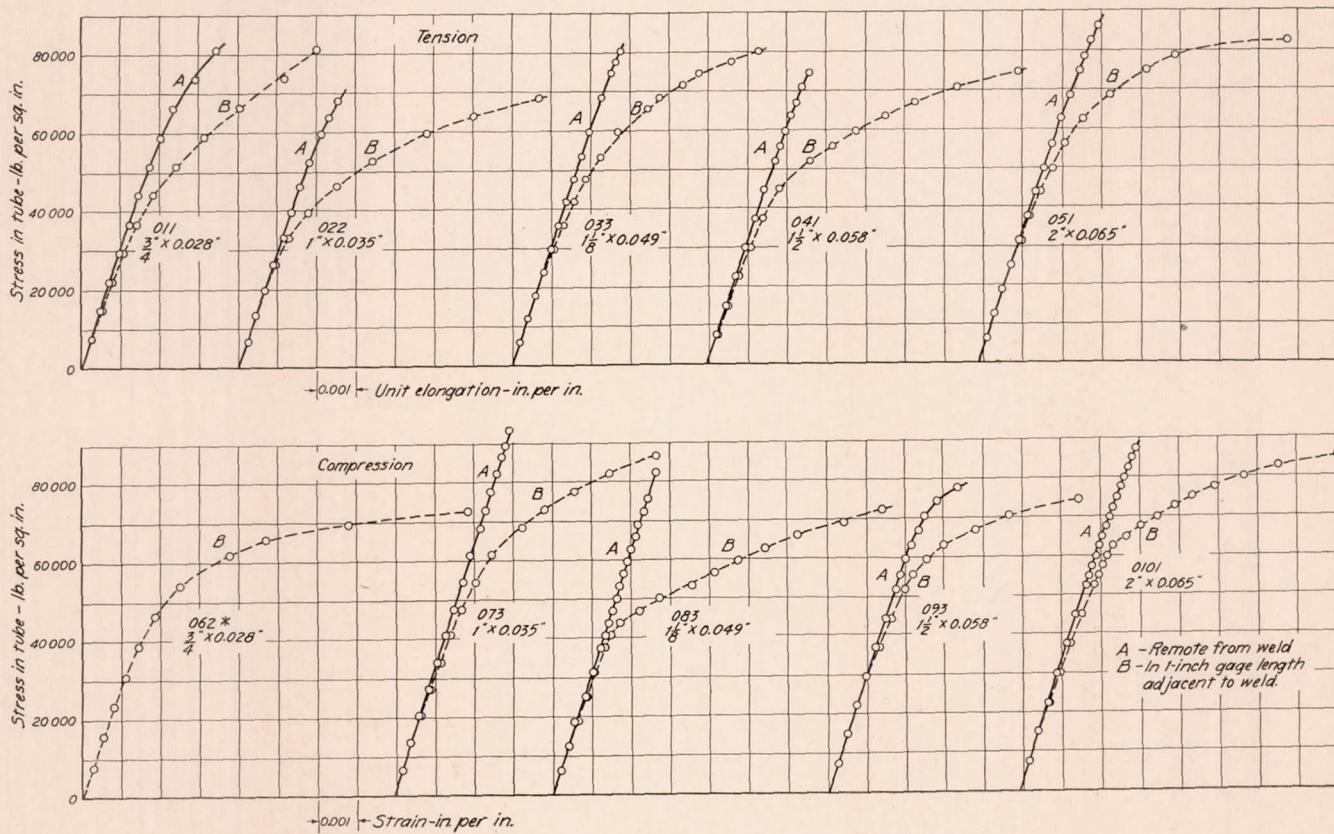

FIGURE 19.—Stress-strain diagrams for butt joints in tension and compression

E_c. Tube A failed in compression below the weld to the strap.

4. STRENGTH OF TUBE A IN TENSION

The effect of a welded joint in reducing the tensile strength of its members was determined for several joints. Nos. 170 and 180 represent the joining of two tubes B in an axis at right angles to a third Tube A. One set of three specimens was loaded along the axis of tube A and another set along the axis of tube B.

Joints Nos. 2T40, 5T30, 6T50, and 6T60 were made identical with Nos. 240, 530, etc., but were tested with tube A in tension, the other tubes remaining unloaded. The results are clearly indicated in the diagrams of Figure 29.

VI. CONCLUSIONS

For joints in chromium-molybdenum tubing ranging in size from ¾ in. O. D. × 0.028 in. wall thickness to 2 in. O. D. × 0.065 in. wall thickness, welded under procedure control by the oxyacetylene process, the following conclusions apply:

1. The point of minimum strength and hardness of the base metal is sharply defined and is located about one-half inch from the weld center. Here the material may have strength ranging between 80,000 to 100,000 lbs./in.^{2} in tension and 70,000 to 95,000 lbs./in.^{2} in compression and a Vickers number as low as 165.

2. For T joints loaded to high bending stresses near the joint it is probably more satisfactory to gain strength
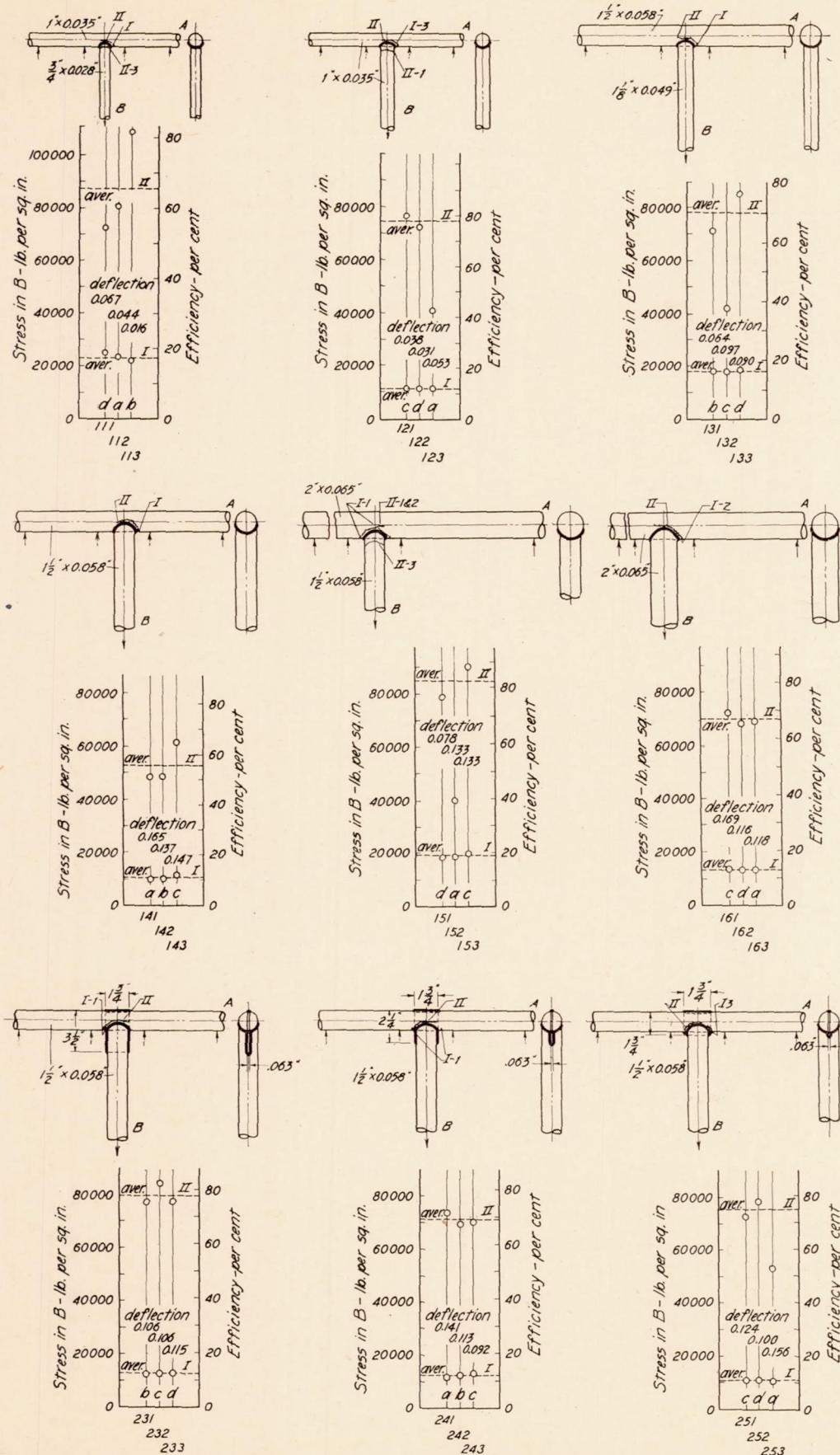
FIGURE 20.—Test results for T joints 110 to 250. Maximum stresses and efficiencies have been plotted on the same graph. For example, in joint 111, the maximum stress in loading I was 25,000 lb./in.² tension in tube B from the stress scale on the left side of the graph. The plotted points also indicate efficiency and on the right side, joint 111 is seen to have an efficiency of 18 per cent in loading I. The permanent deflection at midspan was 0.067 inch. In loading II the joint failed at a stress of 73,000 lb./in.² Its efficiency in loading II was 54 per cent
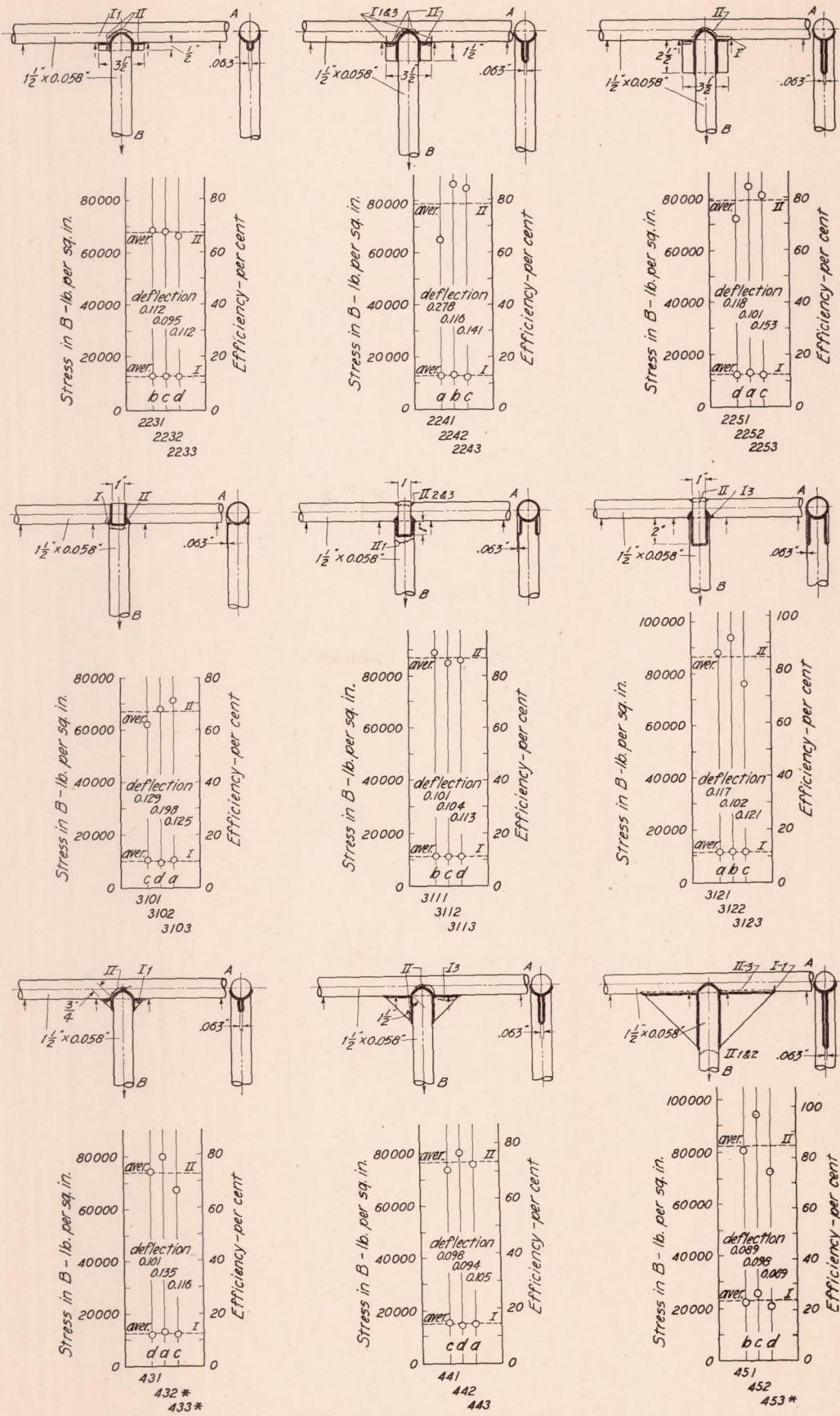
* Welded on one side of gusset plate only.

FIGURE 21.—Test results for T joints 2230 to 450
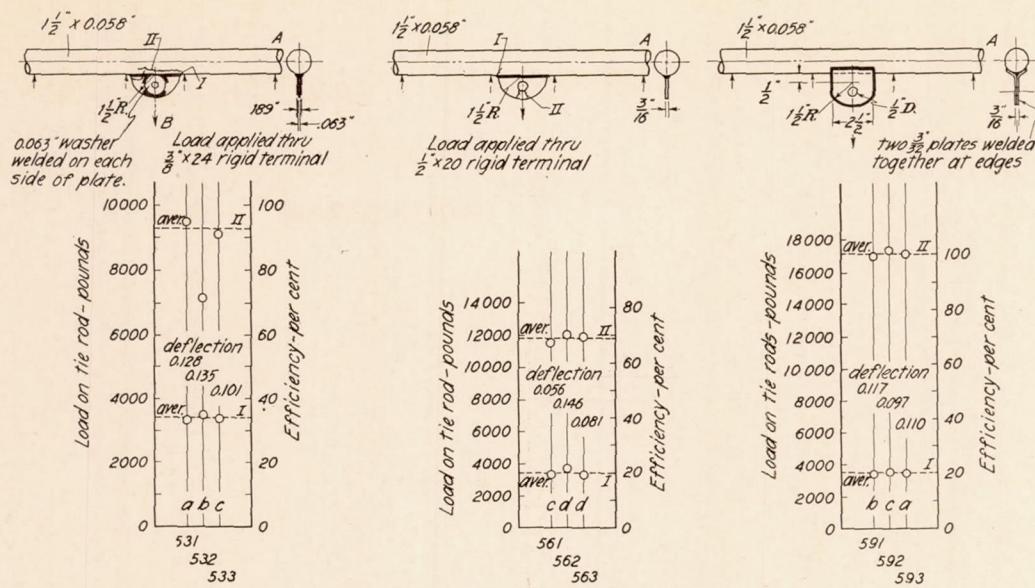
FIGURE 22.—Test results for lug T joints 530, 560, and 590
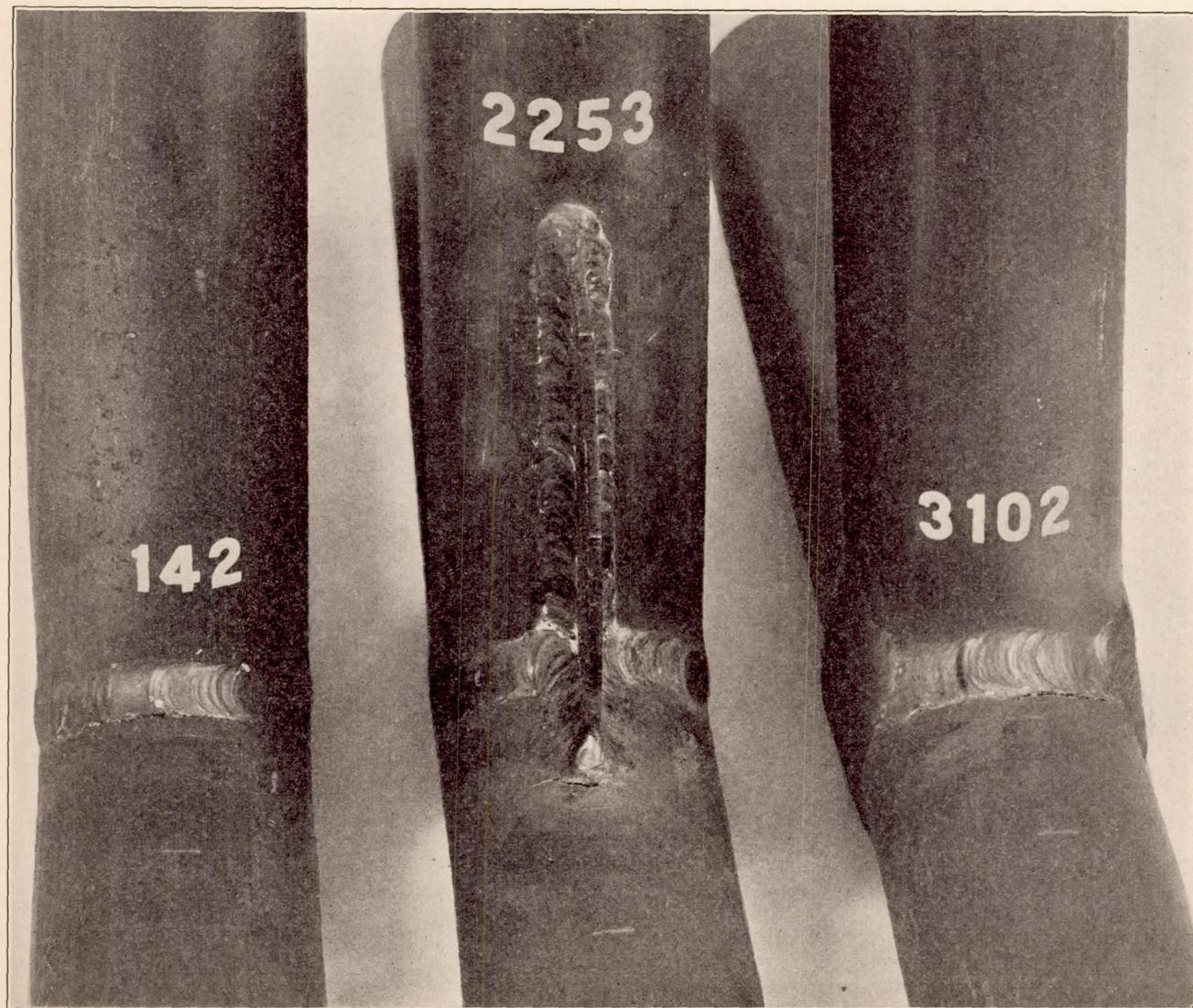
FIGURE 23.—Typical failures of T joints in loading I
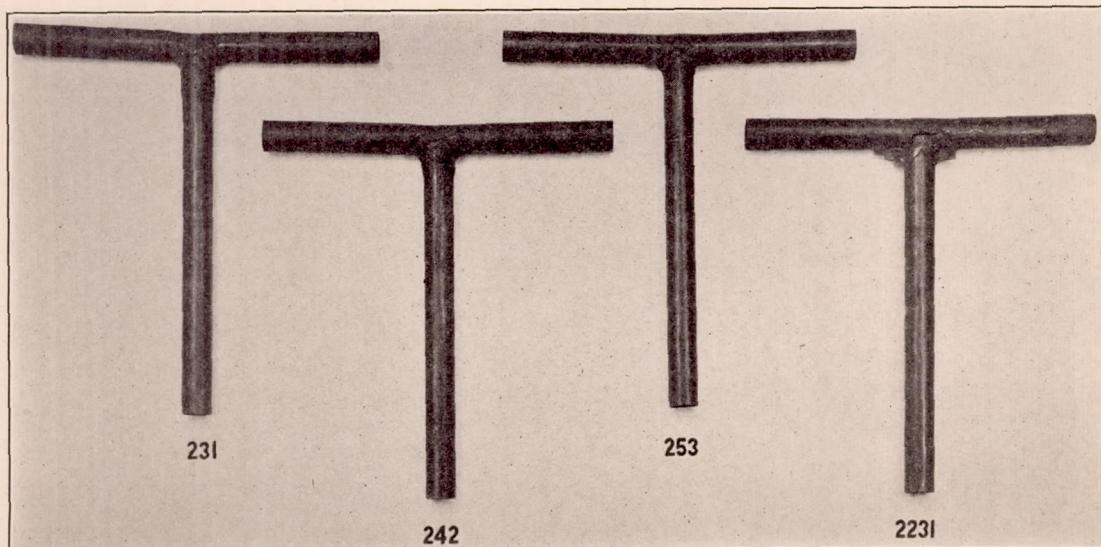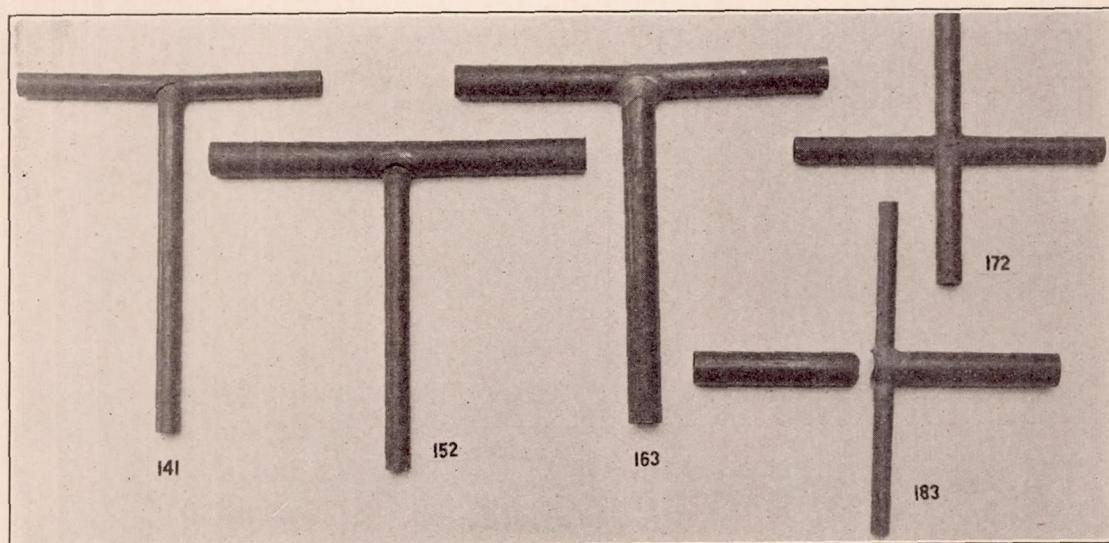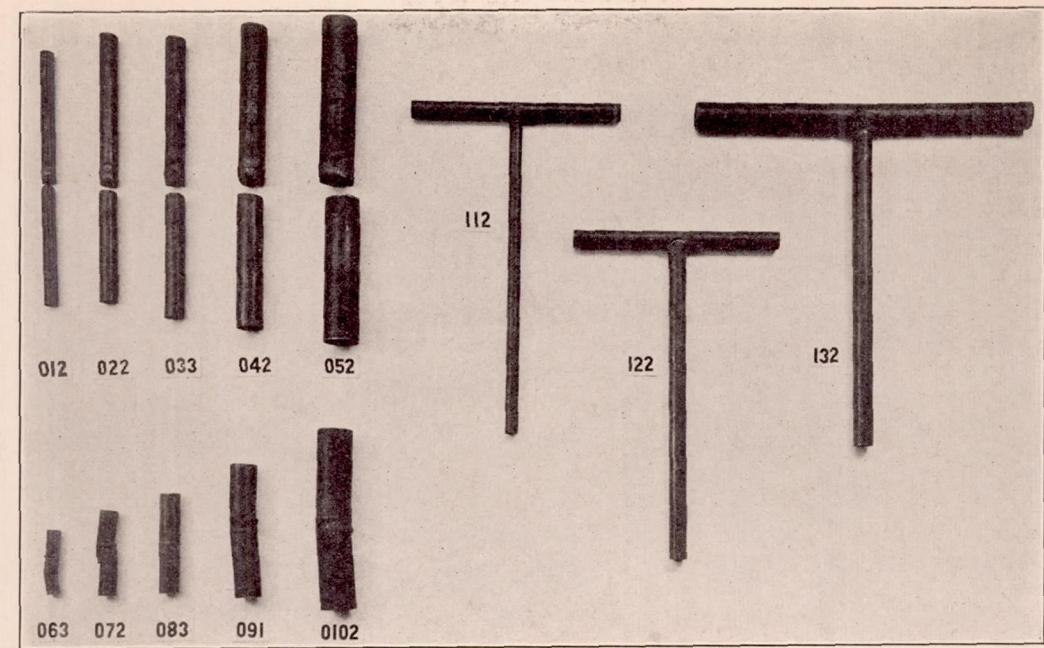
FIGURE 24.—Joints 012 to 2231 after test
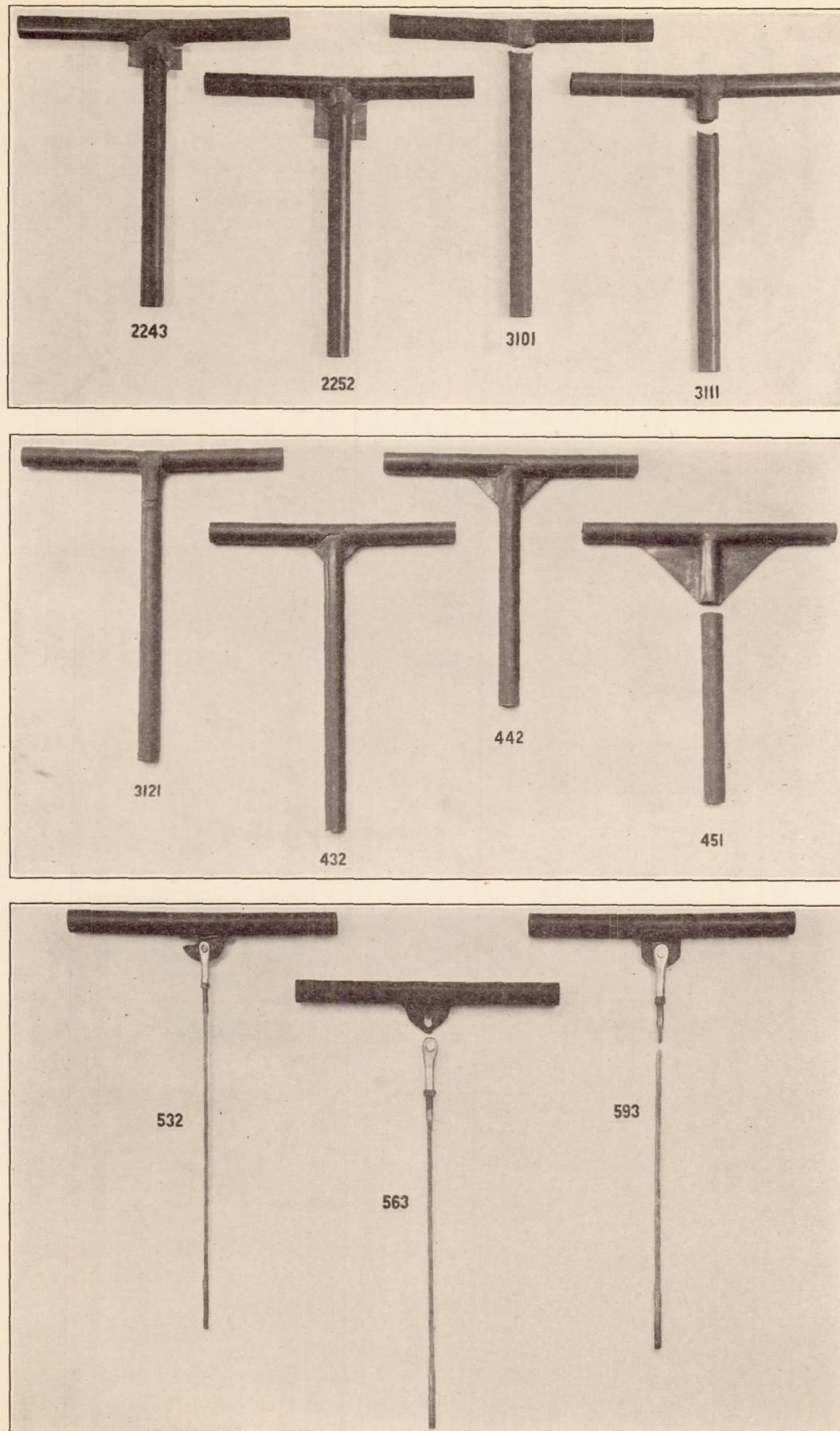
FIGURE 25.—Joints 2243 to 593 after test

by increasing the size of the tube rather than by adding plates, straps, etc. Where the joint is loaded in such a manner that bending stresses are kept to a low value, the efficiency may best be increased by welding a U strap around the joint, the ends extending at least 1 inch below the joint. The efficiency of an unreinforced joint was found to range from 55 to 77 per cent.

large triangular gussets between the intersecting tubes, but the weight and time required to fabricate are excessive. An unreinforced T joint in 1½ in. × 0.058 in. tubing requires about eight minutes to fabricate and the weld metal weighs about 0.02 pound. The strap joint requires 28 minutes to fabricate, and the weight of the weld metal and reinforcement is 0.16
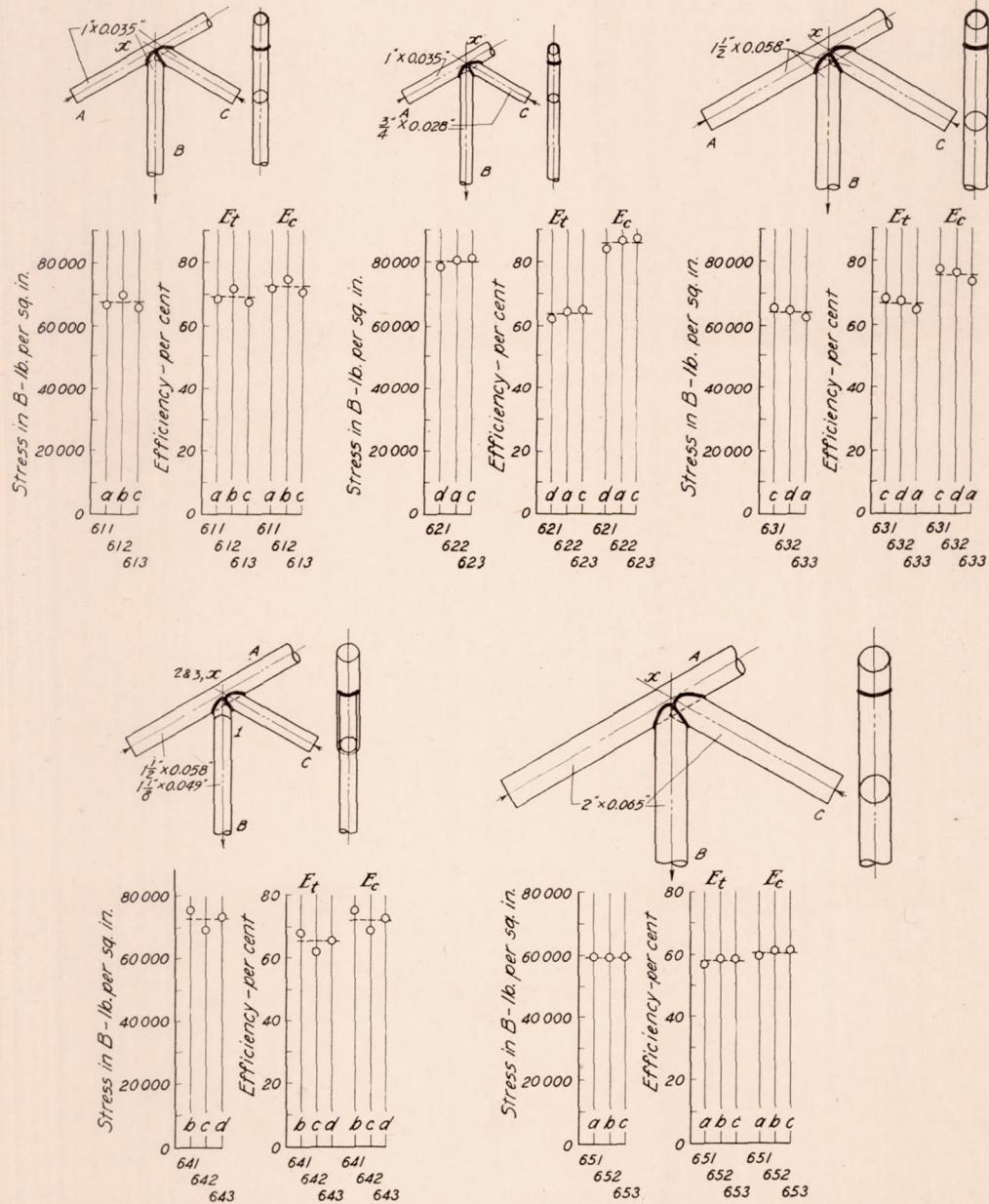
FIGURE 26.—Test results for lattice joints 610 to 650. The stress and efficiencies have been plotted separately for the lattice joints. For example, specimen 611 failed at a stress of 67,000 lbs./in.² in tube B. The tensile efficiency, E_t, was 68 per cent and the compressive efficiency, E_c, was 72 per cent

Reinforcement by means of U straps increased the efficiency to 87 per cent. Strap-reinforced joints in which a tube is encircled by a circumferential weld are, however, subject to a reduction in the tensile strength of this tube. This reduction in strength is probably greater than is produced by other types of reinforcement and should be taken into consideration. A joint can be made almost as efficient by welding

pound. These values are increased to 46 minutes and 0.56 pound for a joint having equal strength reinforced by corner gussets.

3. The best reinforcement for the lattice joint is one which reinforces it against collapse of the tubes. This reinforcement may be either an inserted plate or a strap welded around the joint. Both methods increase the strength of the unreinforced joint about

2"×0.065" x · A · 1½"×0.058" · C · B

1½"×0.058" x · Special shape of tube ends · A · B · C

1½"×0.058" · A · B · C

E_t E_c

Stress in B-lb. per sq. in. — Efficiency-per cent

80000 · 60000 · 40000 · 20000 · 0

c d a — c d a — c d a
661 — 662 — 663

b c d — b c d — b c d
671 — 672 — 673

100000 · 80000 · 60000 · 40000 · 20000 · 0 — 100 · 80 · 60 · 40 · 20

a b c — a b c — a b c
681 — 682 — 683

1½"×0.058" · 3¾" · 4½" · A · B · C · .063

1½"×0.058" · x · 1¾" · 4⅝" · A · C · B · .063

1½"×0.058" · A · C · B · 3" · .063"

E_t E_c

100000 · 80000 · 60000 · 40000 · 20000 · 0 — 100 · 80 · 60 · 40 · 20

Stress in B-lb. per sq. in. — Efficiency-per cent

a b c — a b c — a b c
751 — 752 — 753

d a c — d a c — d a c
7191 — 7192 — 7193

c d a — c d a — c d a
851 — 852 — 853

1½"×0.058" · 1½" · 2¾" · A · B · C · 0.063"

1½"×0.058" · Hole for attaching standard ½"×20 rigid tie-rod terminal · 1" Dia. · Reinforcing washer welded on each side of plate · A · B · C · .063" · .189"

1½"×0.058" · Hole for attaching standard ⅜"×24 rigid tie-rod terminal · 3/8"D. · ¾" · 11/32" · A · B · C · .250"

E_t E_c

100000 · 80000 · 60000 · 40000 · 20000 · 0 — 100 · 80 · 60 · 40 · 20

Stress in B-lb. per sq. in. — Efficiency-per cent

b c d — b c d — b c d
1011 — 1012 — 1013

20000 · 16000 · 12000 · 8000 · 4000 · 0 — Load in tie-rod-pounds — Efficiency-per cent

a b c — a b c — a b c
931 — 932 — 933

20000 · 16000 · 12000 · 8000 · 4000 · 0 — Load in tie-rod-pounds — Efficiency-per cent

d a b — d a b — d a b
9101 — 9102 — 9103

36

FIGURE 28.—Lattice joints after test

20 per cent. The inserted-plate joint takes longer to fabricate and weighs somewhat more than the strap-reinforced joint. In the latter joint the tensile strength of the tube encircled by the strap is undoubtedly reduced. When gusset plates are used for reinforcement a decided gain in strength is obtained by inserting

welding each type of joint should be worked out experimentally, and designs which can not be welded consistently without cracking should be discarded.

5. In using four representative oxyacetylene torches there was no indication that differences in the joint strength could be attributed to the torch.
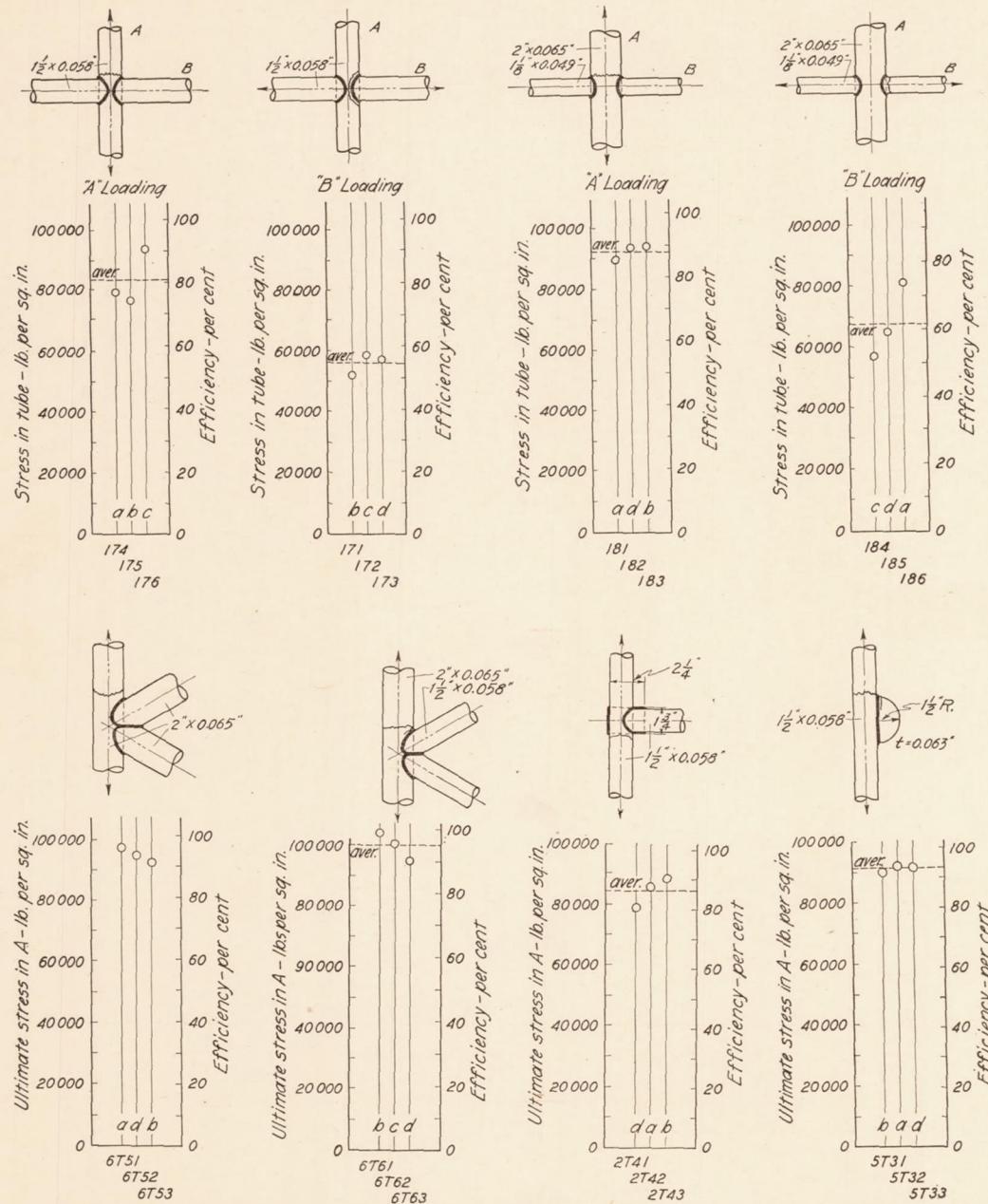

FIGURE 29.—Test results showing reduction in tensile strength for various joints. Maximum stresses and efficiencies are plotted. For example, in specimen 174 tube A when loaded in tension failed at a stress of 80,000/lbs./in.², which was 77 per cent of its tensile strength

one plate in all tubes rather than welding several plates in the angles between the tubes. No reinforcement is necessary when the tubes meet at angles of 45°.

4. Cracking is an important problem when gusset plates are used for reinforcement. A procedure for

6. Low-carbon rod apparently gives enough strength in the weld to cause the specimen to fail in the base metal for the majority of joints.

Bureau of Standards,
February 6, 1930.

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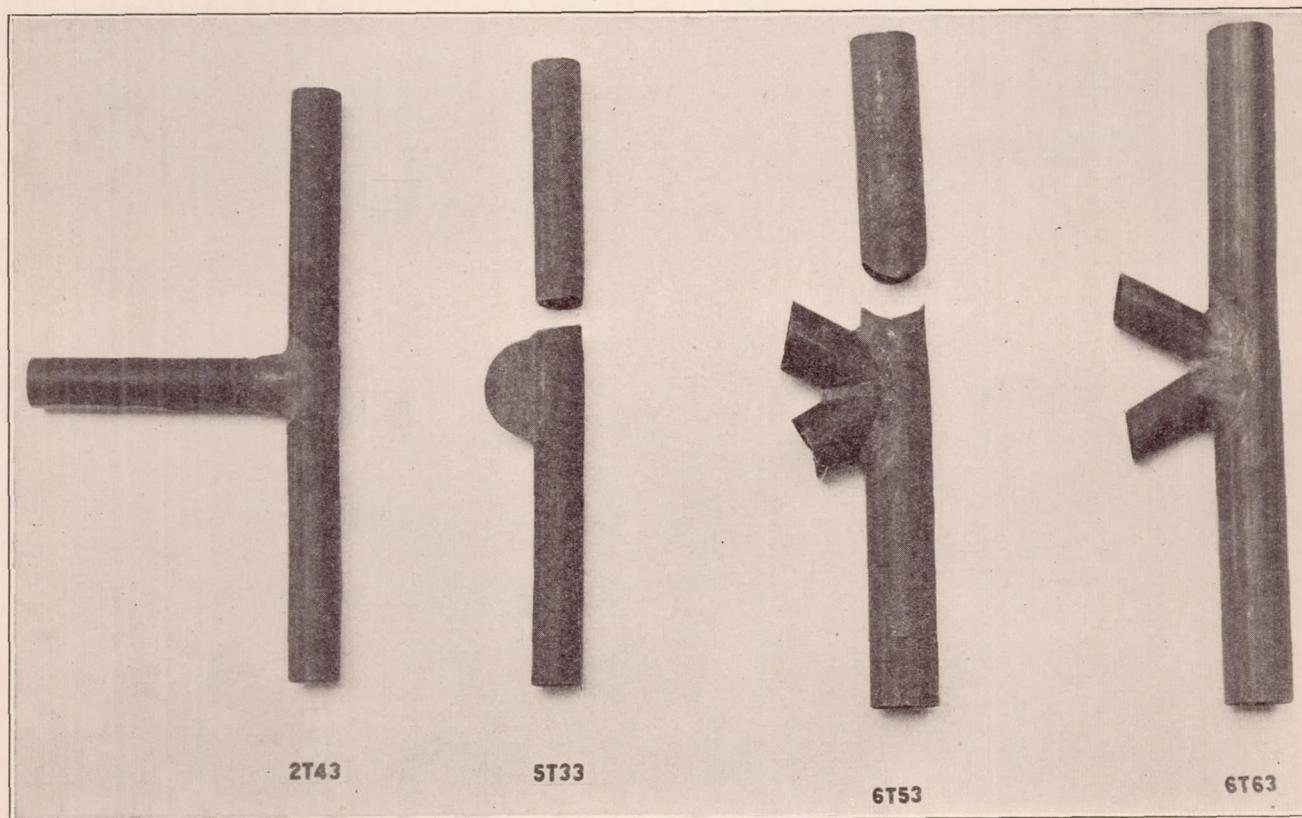
FIGURE 30.—Some of the joints of Figure 29 after test

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(a) Time required to machine and weld T-joints.
(b) Weights of weld metal and reinforcent in T-joints (average of three specimens)

* Gusset plate welded on one side only. Weights of
  specimens welded on both sides are plotted.
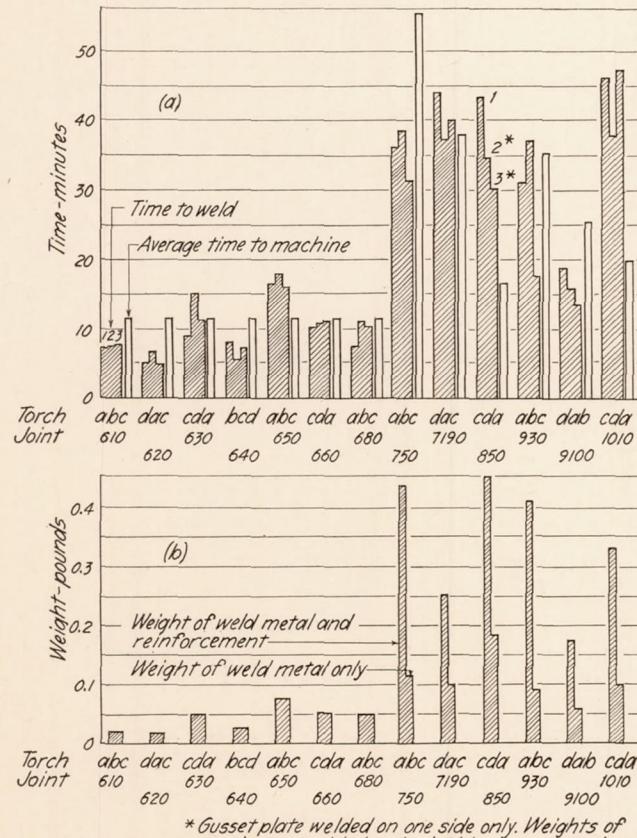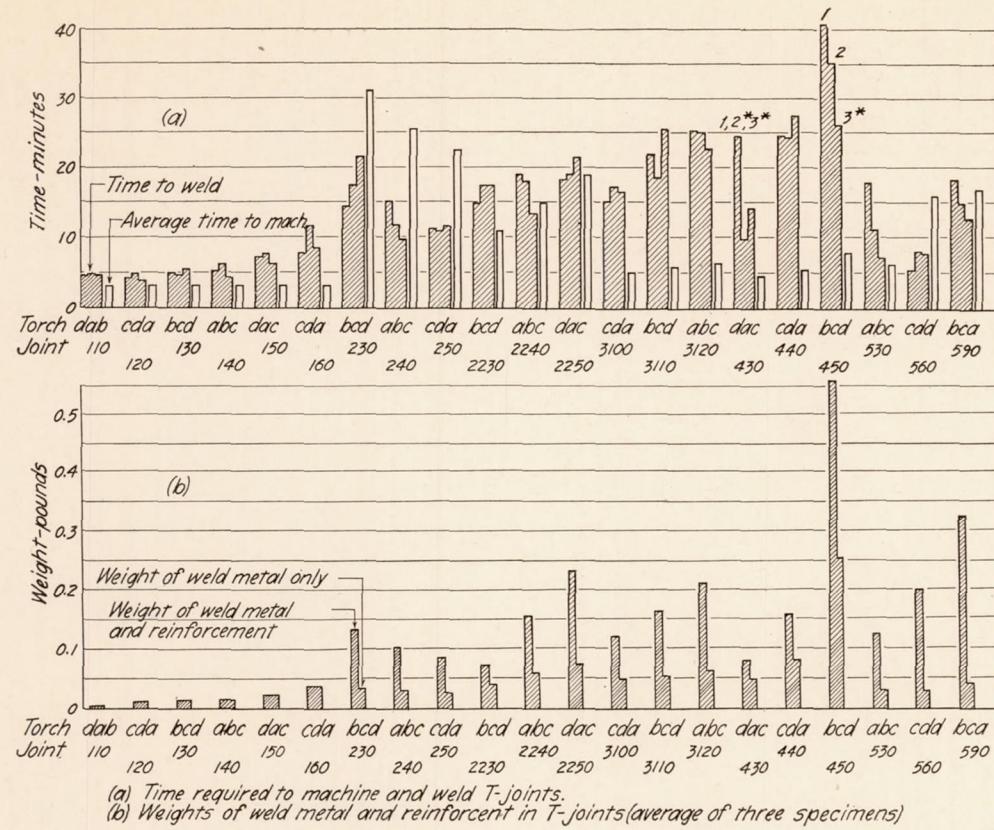
(a) Time required to machine and weld lattice joints.
(b) Weights of weld metal and reinforcement in lattice joints.
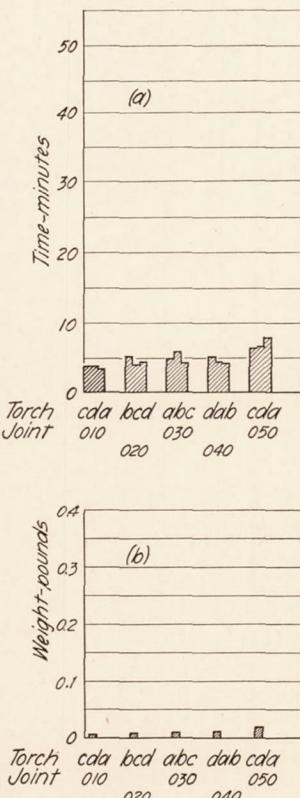
(a) Time required to weld butt joints.
(b) Weights of weld metal in butt joints.

FIGURE 31.—Time required to machine and weld joints; weights of weld metal and reinforcement

17. Oxy-Acetylene Welding in the Aircraft Industry, J. B. Johnson, Airway Age (30 Church Street, New York, N. Y.), vol. 9, No. 12, p. 65, December, 1928, and vol. 10, No. 1, p. 49, January, 1929.

18. Welding in Aircraft Construction, R. M. Mock, Journal of the American Welding Society (33 West Thirty-ninth Street, New York, N. Y.), vol. 8, No. 4, p. 32, April, 1929.

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20. Development of Welded Aircraft Construction, S. C. Clark and W. I. Gaston, Aeronautical Engineering (American Society of Mechanical Engineers, 29 West Thirty-ninth Street, New York, N. Y.), vol. 1, No. 2, p. 49, April–June, 1929.

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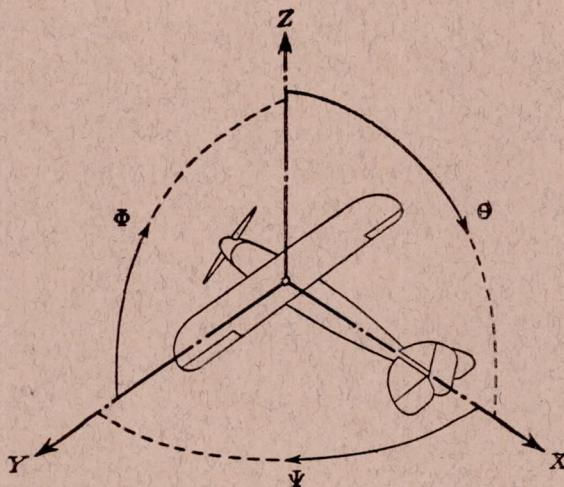
Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Sym-bol		Designa-tion	Sym-bol	Positive direction	Designa-tion	Sym-bol	Linear (compo-nent along axis)	Angular
Longitudinal___	X	X	rolling_____	L	$Y \longrightarrow Z$	roll_____	Φ	u	p
Lateral_____	Y	Y	pitching____	M	$Z \longrightarrow X$	pitch_____	Θ	v	q
Normal_____	Z	Z	yawing_____	N	$X \longrightarrow Y$	yaw_____	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \qquad C_M = \frac{M}{qcS} \qquad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

$D,$ Diameter.
$p_e,$ Effective pitch.
$p_g,$ Mean geometric pitch.
$p_s,$ Standard pitch.
$p_v,$ Zero thrust.
$p_a,$ Zero torque.
$p/D,$ Pitch ratio.
$V',$ Inflow velocity.
$V_s,$ Slip stream velocity.

$T,$ Thrust.
$Q,$ Torque.
$P,$ Power.
    (If "coefficients" are introduced all units used must be consistent.)
$\eta,$ Efficiency $= T\,V/P$.
$n,$ Revolutions per sec., r. p. s.
$N,$ Revolutions per minute, r. p. m.
$\Phi,$ Effective helix angle $= \tan^{-1}\left(\dfrac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp $= 76.04$ kg/m/s $= 550$ lb./ft./sec.
1 kg/m/s $= 0.01315$ hp
1 mi./hr. $= 0.44704$ m/s
1 m/s $= 2.23693$ mi./hr.

1 lb. $= 0.4535924277$ kg
1 kg $= 2.2046224$ lb.
1 mi. $= 1609.35$ m $= 5280$ ft.
1 m $= 3.2808333$ ft.