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SHEAR STRENGTH OF FILLET WELDS IN ALUMINUM ALLOY 2219

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16. ABSTRACT

Fillet welds in aluminum alloy 2219 (2319 filler) are used in the fabrication and assembly of components for the Solid Rocket Booster (SRB) forward and aft skirts, External Tank (ET), and other support equipment. The fillet weld size is normally specified on the engineering drawing and is a theoretical dimension. In this report fillet size is discussed in terms of theoretical or design dimensions versus as-welded dimensions, drawing attention to the inherent conservatism in the design load sustaining capabilities of fillet welds.

Problems associated with inspection of fillet welds are addressed and a comparison is drawn between defect counts obtained by radiographic inspection and by visual examination of the fracture plane.

Fillet weld quality is related lineally to ultimate shear strength. Correlation coefficients are obtained by simple straight line regression analysis between the variables of ultimate shear strength and accumulative discontinuity summation. Shear strength allowables were found to be equivalent to 57 percent of butt weld "A" allowables (F_{tu}).

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SHEAR STRENGTH OF FILLET WELDS IN ALUMINUM ALLOY 2219

SUMMARY

Fillet welding is used extensively in the fabrication of 2219 aluminum alloy components for the Solid Rocket Booster (SRB) forward and aft skirts. Fillet welds are also used in assembly of components for the External Tank (ET) and many other aerospace applications. Some of these welds will be required to sustain a service load which is equivalent to the design load. An important part of the complete design is in specifying sizes and lengths of fillet welds necessary to sustain the expected loads on such joints.

In this study, radiographic inspection of fillet welds in experimental "tee" panels revealed a smaller quantity/area of defects than that detected by fracture plane inspection. The disparity between the two methods of defect summations can be explained on the basis of preferred defect growth during welding and the resultant X-ray angle as related to the shear plane angle.

The shear ultimate strength (SUS) was found to be lineally related to the quantity of fillet weld internal defects. Simple straight line regression analysis resulted in correlation coefficients of -0.95 and -0.98, respectively, for as-welded fillet welds and aged fillet welds. SUS allowables were found to be 20 ksi (137.9 MN/m^2) for as-welded fillet welds and 22 ksi (151.7 MN/m^2) for aged fillet welds. The 22 ksi (151.7 MN/m^2) value was derived by a statistical method which is known as ratio analysis. A value of 22 ksi (151.7 MN/m^2) can also be achieved with aged fillet welds by taking 57 percent of the aged butt weld "A" allowable (F_{tu} = 38.5 ksi = 265.5 MN/m^2), 0.57×38.5 (265.5) = 22 ksi (151.7 MN/m^2). An appropriate statistical approach was used to obtain the 22 ksi (151.7 MN/m^2) value which assures its conformance with the 99 percent probability and 95 percent confidence factors required for an "A" design allowable. The 20 ksi (137.9 MN/m^2) value for as-welded fillets was obtained by using 57 percent of the as-welded butt weld "A" allowable (F_{tu} = 35 ksi = 241.3 MN/m^2). This value is believed to have the same probability/confidence as the 22 ksi (151.7 MN/m^2) value, but statistically can not be characterized as such. However, the 20 ksi (137.9 MN/m^2) value for as-welded fillets will continue to be

used by MSFC for design purposes because (1) the value has historically been used for design purposes on hardware in the past with no failures, (2) aged fillet welds showed identical values with the 57 percent method and the statistical ratio analysis method, (3) the actual shear plane area of fillet welds on the hardware is always larger than the theoretical shear plane area as specified by the fillet size on the engineering drawing, and (4) 20 ksi (137.9 MN/m^2) is conservative with regard to shear strength degradation as a result of the maximum internal discontinuities permitted per welding specification MSFC-SPEC-504A.

I. INTRODUCTION

Aluminum alloy 2219 is amenable to fillet welding and most commonly results in a joint where the heat affected zone of the base material is not as seriously degraded as with butt welding. Fillet welds are used extensively in the fabrication of components for the SRB forward and aft skirts. Fillet welds are also used in assembly of components for the ET and many other aerospace applications. Some of these welds will be required to sustain service loads which are equivalent to the design loads. An important part of the complete design is in specifying sizes and lengths of fillet welds necessary to sustain the expected loads on such joints.

When specifying the size of a fillet weld to be loaded in shear, the designer must be sure that the shear strength is equal to or greater than the shear stress that is applied to the fillet weld by the service load. The common practice is to conduct prototype tests. The resultant shear strength is reduced by a "safety factor," and the reduced value is an allowable shear stress for design purposes [1]. There is no statistical probability/confidence associated with the direct reduction of shear strength as a safety factor. In aerospace endeavors the welds are designed to the most stringent aerodynamic conditions. Thus, a weld failure could result in catastrophic failure and, consequently, loss of mission and/or life. Weight saving is a highly desirable objective because a reduction in hardware weight results in a higher payload weight. To accomplish a weight saving with fillet welds, a design allowable (F_{su}) must be used which will assure a 99 percent probability of meeting the F_{su} value with 95 percent confidence, as practiced with butt welds.

SUS is correlated with fillet weld quality in this evaluation. Also, weld quality is addressed with regard to the problems associated with radiographic inspection. Discussions include fillet weld "built-in" safety factors as related to the theoretical throat dimension and root penetration versus the actual throat dimension and root penetration. Rationale are presented for the specified design allowables as well as fillet weld radiographic requirements.

II. SPECIMEN PREPARATION AND TESTING

The base materials (2219-T37 and 2219-T87), fillet wire (2319), and shielding gas were all procured to appropriate aerospace specifications. The chemical composition limits of each material are given in Table 1 [2].

TABLE 1. CHEMICAL COMPOSITION LIMITS OF BASE MATERIAL AND FILLER METAL [2]

Element	2219 Specification (%)	2319 Specification (%)
Si	0.20	0.20
Fe	0.30	0.30
Cu	5.8-6.8	5.8-6.8
Mn	0.20-0.40	0.20-0.40
Mg	0.02	0.02
Zn	0.10	0.10
Ti	0.02-0.10	0.10-0.20
V	0.05-0.15	0.05-0.15
Zr	0.10-0.25	0.10-0.25
Be	—	0.0008
Others, Each	0.05	0.05
Others, Total	0.15	0.15
Al	Remainder	Remainder
(Maximum unless shown as a range)		

Preweld sections (6 in./15.24 cm by 24 in./60.96 cm) used in this evaluation were fabricated from two base material thicknesses of plate, 0.50 in. (1.27 cm) thick for the web member and 0.80 in. (2.032 cm) thick for the plate member. The automatic Tungsten Inert Gas (TIG) weld process was used to join the two thicknesses to form a tee panel with a fillet weld on each side of the web member. Defects were introduced by faulty weld procedures, s:.h as contaminating the fusion faces of the base materials, contaminating the deposited fillet material after the first pass (more than one pass was required to complete the weld), or a combination of both. The discontinuity concentrations in this effort actually exceed those limitations imposed by any (government or contractor) aerospace specification.

The first group of tee panels were welded with the torch inclined at a 45 deg angle, the plate member in a vertical position, and the web member in a horizontal position (Fig. 1a). The second group of panels was completed by positioning the torch horizontally, whereas the plate and web members were inclined at an angle of 45 deg to the torch. The web of the second group was positioned totally below the torch (Fig. 1b). The third group of panels was welded into tee joints by aligning the web and plate members into a trough configuration with the torch in a downhand position (Fig. 1c). The first two groups of experimental tee panels were applicable to as-welded fillet welds in aluminum alloy 2219-T87. The third group of panels consisted of fillet welds in aluminum alloy 2219-T37 with a post-weld aging cycle of 350°F (177°C) for 18 hr.

Shear specimen configuration consisted of simple strips with parallel sides which were removed from each experimental tee panel (Fig. 2). To eliminate surface contour variables and leg size differences, each fillet was machined at a 45 deg angle to web and plate members. The target fillet size was 0.5 in., but after the machining operation the resultant fillet size was approximately 0.4 in. (1.016 cm). Radiographic inspection followed normal procedures. Fillet weld shear tests were conducted at ambient temperature with the test setup shown in Figure 3.

Standard lap joint specimens [3] were used to determine SUS. These values were eventually used to determine the allowable (F_{su}) of aged welds. Basically, aluminum alloy 2219-T37 was fillet welded and post-weld aged at 350°F (177°C) for 18 hr. The fillet weld surfaces of these specimens were also machined at a 45 deg angle to the base material surfaces. The resultant shear strength values were processed in a statistical manner to yield a shear allowable with 99 percent probability and 95 percent confidence. The determination of a shear allowable was possible because of the existence of a sufficient data base from a previous evaluation.

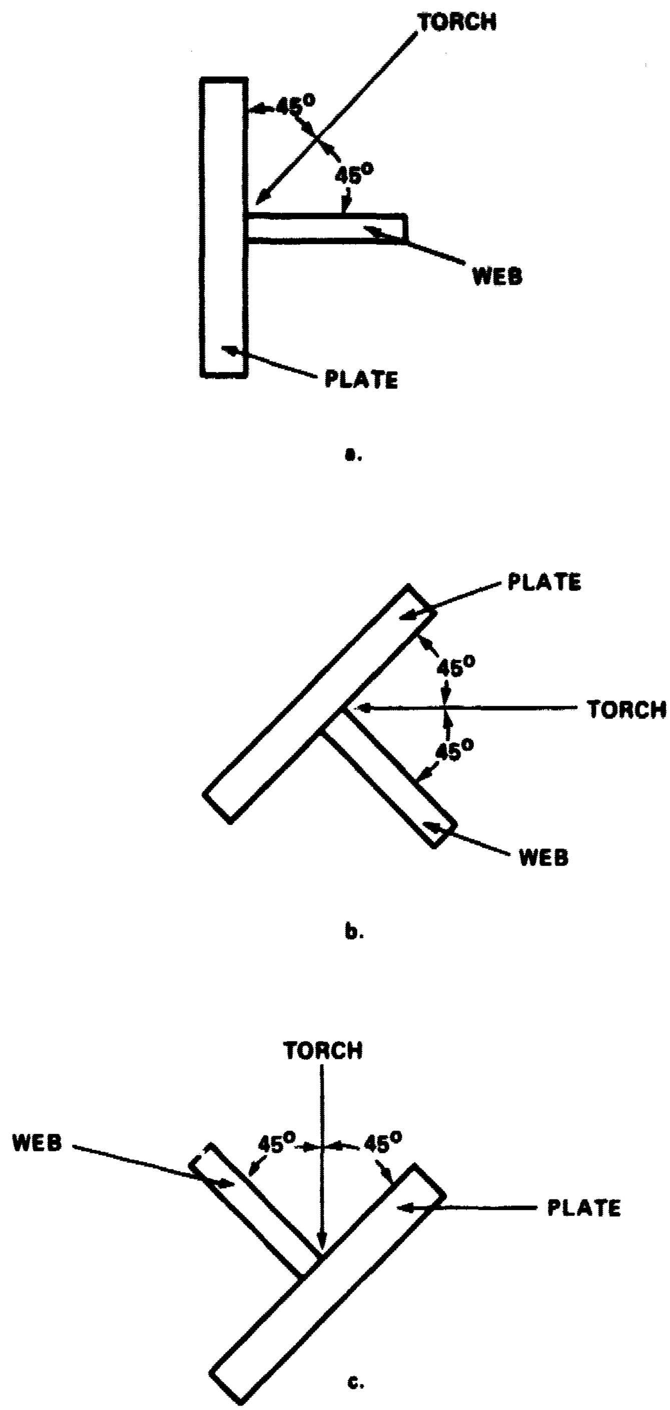

Figure 1. Tee panel joining procedure.

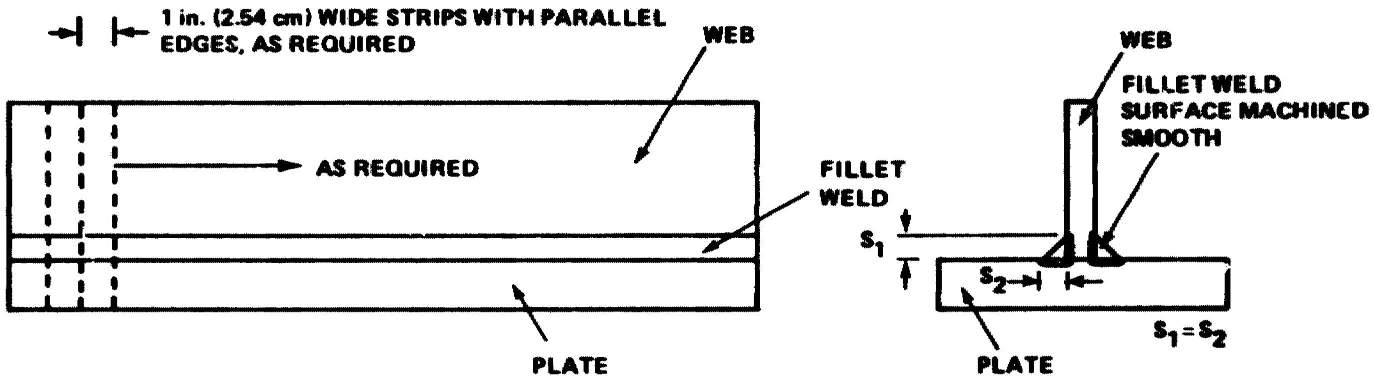

Figure 2. Shear specimen configuration.

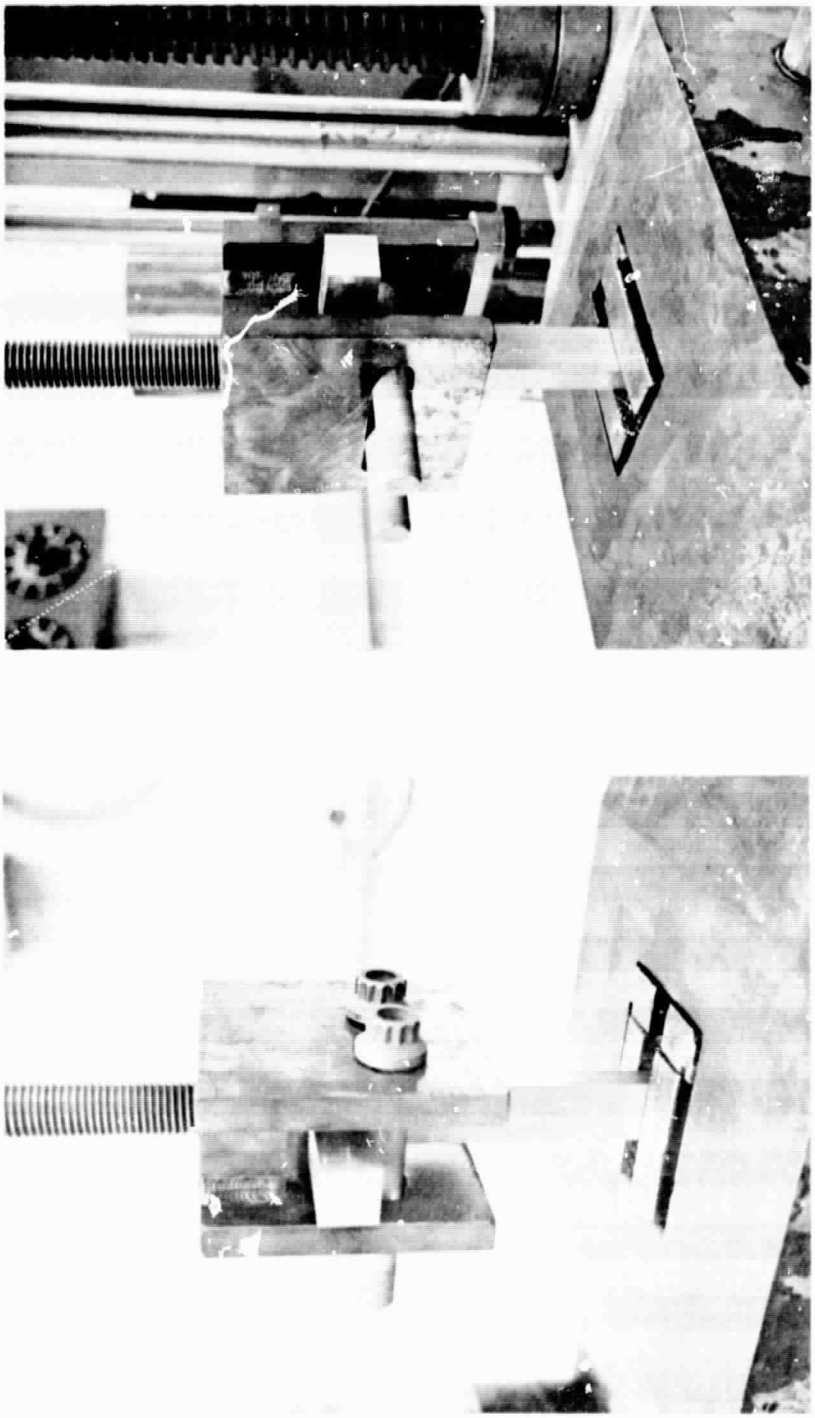

Figure 3. Shear test setup.

III. DISCUSSION AND RESULTS

A. Fillet Weld Size and Geometry

The size of a fillet weld is specified as leg length(s) in inches [4]. In most cases, fillet welds in aerospace hardware are designed with equal leg lengths. Fillet welds are considered to be triangular in cross section, the triangle being the largest right triangle (isosceles for aerospace applications) which can be inscribed within the weld cross section. In actual fabrication practices, the triangle which can be inscribed within the deposited fillet weld is invariably larger than the triangle which can be inscribed by using the fillet size as specified on the engineering drawing. In addition, the specified fillet size and resultant cross section triangle do not account for penetration beyond the theoretical root of the joint. Root penetration beyond the theoretical root of the joint is a variable which is dependent upon weld parameters. The depth of penetration into the root of the joint does have an effect on the shear strength of the joint. Root penetration beyond the theoretical line inherently increases the net shear plane area, and, consequently, the joint is able to sustain a greater load than specified by design. This advantage is negated if the theoretical throat dimension is used when calculating the SUS allowable from a series of individual tests. When using the theoretical throat dimension for the purpose of calculating SUS, the theoretical shear plane area is somewhat smaller than the actual shear plane area and a higher SUS value results. In addition, variables in fillet weld surface contour (e.g., convexity or concavity) tend to cause considerable scatter in a group of SUS values. In summation, both root penetration and surface contour characteristics are additives to the net shear plane area but are rarely, if ever, considered by the test engineer in calculating SUS. These variables are addressed in this evaluation.

B. Fillet Weld Quality

Radiographic inspection of the fillet welds always revealed a smaller quantity/area of defects than that detected by optical comparator inspection of the shear fracture plane. The wide disparity between the two methods of defect summations can be explained on the basis of preferred defect growth and X-ray angle. The disparity is not totally related to radiographic interpretation. Fillet welds in tee joints are normally X-rayed at an angle inclined approximately 20 deg to the web member. Discontinuities in the fillet weld tend to protrude and/or elongate in a direction which is in proximity to the same 20 deg angle of X-raying. This preferred defect growth tendency exists for discontinuities which originate at either the root (penetration line) of the weld or within the fillet weld. Pores tend to be oval, whereas other discontinuities are platy with the flat dimension orientated at approximately a 20 deg angle to the web member. Thus, radiographic inspection of fillet welds reveals only the short diameter of a pore and only the length and width of other discontinuities. The long diameter of pores and the depth of platy discontinuities are obscured by their growth orientation with respect to the X-ray angle. In each case, these are the dimensions most desired to exactly delineate fillet weld quality and/or to assess shear load capabilities. Transverse SUS failure occurs along a plane which is in proximity to the preferred defect growth orientation. Thus, most of the defects (including defect desired dimensions) contained within a fillet weld are easily tabulated from the fracture surface with an optical comparator. A comparison of the defect summation between radiographic inspection and fracture plane inspection is given in Tables 2 and 3.

C. Transverse SUS as a Function of Fillet Weld Quality

The SUS values obtained in this evaluation were from specimens where the surface contour was machined smooth at an angle of 45 deg to the plate and web members of tee joints. This practice eliminated surface contour variables. In addition, SUS calculations were based on the net shear plane area after shear failure rather than the theoretical shear area and/or inscribed triangle concept. This was done to consider root penetration in the net shear plane area. The SUS values are given in Tables 3 and 4. The SUS values were shown to be lineally related to the internal discontinuity area summations (Figs. 4 and 5). Correlation coefficients were obtained by simple straight line regression analysis between the variables of SUS and area percent of internal discontinuities within the shear plane area [5]. The correlation coefficients were found to be -0.95 for as-welded fillet welds and -0.98 for aged fillet welds. Such strong linear relationships indicate that (1) the technique which was used to measure defects within each shear plane area was consistent from specimen-to-specimen and (2) the actual shear plane was inclined at the theoretical angle of 22.5 deg for the most part and did encompass most of the defects within the fillet weld. As previously noted, the defect summation by radiographic inspection failed to yield results comparable to fracture plane inspection. Such a disparity precluded a plot of radiographic inspection results versus SUS.

D. Fillet Weld SUS Allowables

In a previous research effort, the "A" design allowable (F_{tu}) of aged butt welds in 0.5 in. (1.27 cm) thick plate of aluminum alloy 2219 was found to be 38.5 ksi (265.5 MN/m^2) [6]. Using this data base and a sufficient number of

TABLE 2. DEFECT SUMMATION OF AS-WELDED FILLET WELDS BY RADIOGRAPHIC INSPECTION AND THE CORRESPONDING FRACTURE PLANE INSPECTION

Specimen Number	Percentage of Area Defective (Area of Accumulative Defects/Shear Plane Area × 100)			
	Radiographic Inspection		Fracture Plane Inspection	
	Group 1	Group 2	Group 1	Group 2
1-1	0	0	0	0
1-2	0	0	0	0
1-3	0	0	0	0
1-4	0	0	0	0
1-5	0	0	0	0
1-6	0	0	0	0
2-1	0.4	0.6	15.1	4.6
2-2	1.2	0.2	19.9	2.7
2-3	1.3	1.5	9.2	12.7
2-4	2.6	1.2	14.5	19.6
2-5	2.2	2.1	12.8	16.5
2-6	1.5	1.4	12.5	20.2
3-1	2.7	2.7	16.9	15.2
3-2	2.3	3.9	15.5	17.0
3-3	3.0	3.6	17.7	5.6
3-4	2.2	2.5	20.3	18.9
3-5	2.3	2.1	21.1	15.8
3-6	3.6	4.7	22.7	8.5
4-1	10.0	6.6	11.7	15.3
4-2	10.0	1.0	13.0	1.4
4-3	1.7	1.8	14.7	3.6
4-4	7.5	0.9	18.4	8.6
4-5	5.1	1.4	10.2	3.9
4-6	6.4	1.8	15.5	5.5
5-1	3.0	5.6	12.5	20.2
5-2	7.9	5.4	13.5	18.6
5-3	6.4	5.6	8.3	14.6
5-4	6.6	9.1	10.3	12.4
5-5	7.4	5.7	11.1	16.8
5-6	4.9	6.5	9.0	18.9
6-1	7.9	9.0	12.5	20.7
6-2	7.8	10.3	12.6	17.6
6-3	5.4	11.1	12.0	17.0
6-4	8.0	6.8	14.3	11.7
6-5	9.5	8.4	13.4	17.9
6-6	6.7	8.1	14.1	18.0

Notes:
1. Base material is 2219-T87 with 2319 fillet weld alloy.
2. In Group 1 the plate member was in a vertical position, web member was in a horizontal position, and the torch was inclined at a 45 deg angle in the upper portion of the tee joint during welding.
3. In Group 2 the torch was positioned horizontally, whereas the plate and web members were inclined at an angle of 45 deg to the torch during welding. In this setup, the web member was positioned totally below the torch.

TABLE 3. TRANSVERSE SUS OF AGED FILLET WELDS AND THE CORRESPONDING DEFECT SUMMATION

Specimen Number	SUS		Percentage of Area Defective[a]	
	ksi	(MN/m^2)	Radiographic Inspection	Fracture Plane Inspection
1-1	29.0	199.9	0	0
1-2	31.3	216.5	0	0
1-6	31.0	213.7	0	0.2
1-7	25.8	177.9	0	0
1-8	25.1	173.1	0	0.9
1-9	25.9	178.6	0	1.1
2-1	26.3	181.3	0.1	0.2
2-2	27.5	189.6	0.3	1.9
2-3	21.2	146.2	0.2	11.3
3-2	26.9	185.5	1.2	7.0
3-5	26.5	182.7	3.3	5.7
3-6	24.6	169.6	3.9	11.8
3A-3	22.9	157.9	3.7	12.9
3A-4	23.7	163.4	3.7	6.5
3A-5	24.8	171.0	2.5	10.3
3A-7	20.6	142.0	12.1	24.0
3A-9	25.6	176.5	3.9	7.9
4-5	22.6	155.8	7.7	21.0
4-8	22.2	153.1	5.6	21.9
4-10	23.3	160.6	3.0	5.6
5-1	23.0	158.3	6.1	21.5
5-2	21.7	149.6	6.8	15.3
5-3	20.7	142.6	8.0	17.9
5-7	26.4	182.0	2.8	6.6
6-1	15.8	108.9	10.8	27.1
6-2	18.8	129.6	9.2	22.3
6-3	22.2	153.1	8.8	17.0
6-6	19.2	132.4	6.2	21.0

a. Area of accumulative defects/shear plane area × 100.

TABLE 4. TRANSVERSE SUS OF AS-WELDED FILLET WELDS

Specimen Number	SUS ksi (MN/m^2) Group 1		Group 2	
1-1	24.2	(166.9)	24.7	(170.3)
1-2	23.7	(163.4)	24.3	(167.5)
1-3	24.4	(168.2)	24.4	(168.2)
1-4	24.1	(166.2)	24.0	(165.5)
1-5	23.6	(162.7)	23.4	(161.3)
1-6	23.1	(159.2)	22.5	(155.1)
2-1	20.1	(138.6)	20.8	(143.3)
2-2	18.4	(126.9)	19.8	(136.5)
2-3	20.0	(137.9)	16.4	(113.4)
2-4	21.1	(145.5)	14.5	(100.0)
2-5	21.0	(144.8)	15.3	(105.5)
2-6	19.9	(137.2)	15.9	(109.6)
3-1	18.2	(125.5)	16.1	(111.0)
3-2	17.8	(122.7)	16.9	(116.5)
3-3	16.2	(111.7)	20.3	(140.0)
3-4	16.7	(115.2)	16.7	(115.2)
3-5	15.9	(109.6)	16.1	(111.0)
3-6	15.4	(106.2)	16.8	(115.9)
4-1	21.8	(150.3)	17.2	(118.6)
4-2	18.9	(130.3)	22.0	(151.7)
4-3	19.0	(131.0)	22.4	(154.5)
4-4	18.1	(124.8)	22.7	(156.5)
4-5	21.8	(150.3)	22.6	(155.8)
4-6	20.2	(139.3)	23.0	(158.6)
5-1	19.7	(135.8)	17.4	(120.0)
5-2	17.2	(118.6)	18.3	(126.2)
5-3	19.7	(135.8)	17.7	(122.0)
5-4	21.4	(147.6)	18.0	(124.1)
5-5	21.0	(144.8)	17.7	(122.0)
5-6	22.9	(157.9)	16.8	(115.9)
6-1	20.1	(138.6)	16.4	(113.4)
6-2	19.1	(131.7)	16.0	(110.3)
6-3	19.7	(135.8)	17.7	(122.0)
6-4	18.2	(125.5)	17.5	(120.6)
6-5	20.9	(144.1)	17.9	(123.4)
6-6	19.9	(137.2)	18.1	(124.8)

Notes:
1. Base material is 2219-T87 with 2319 fillet weld alloy.
2. In Group 1 the plate member was in a vertical position, web member was in a horizontal position, and the torch was inclined at a 45 deg angle in the upper portion of the tee joint during welding.
3. In Group 2 the torch was positioned horizontally, whereas the plate and web members were inclined at an angle of 45 deg to the torch during welding. In this setup, the web member was positioned totally below the torch.

aged fillet weld SUS results, the shear stress allowable (F_{su}) was determined by the statistical ratio analysis method. The resultant F_{su} was 22 ksi (151.7 MN/m^2). A shear strength allowable of 22 ksi (151.7 MN/m^2) corresponds exactly to taking 57 percent[1] of F_{tu} (38.5 ksi or 265.5 MN/m^2) which was the procedure employed by the designer to determine a shear allowable prior to the actual determination by the specified statistical method. The F_{tu} of as-welded butt welds in aluminum alloy 2219-T87 is 35 ksi (241.3 MN/m^2) [7]. Using the same mathematical procedure, 57 percent of 35 ksi (241.3 MN/m^2) is 20 ksi (137.9 MN/m^2), the current shear allowable for as-welded fillet welds. The data base is not sufficient to determine a shear allowable for as-welded fillets by statistical methods in this evaluation. Because aged fillet welds displayed the same F_{su} by either the 57 percent × F_{tu} or statistical method (99 percent probability and 95 confidence) of ratio analysis, MSFC will accept and continue to use 20 ksi (137.9 MN/m^2) (0.57 × 35 ksi or 241.3 MN/m^2) as a shear allowable for as-welded fillets. In addition, the 20 ksi (137.9 MN/m^2) represents a conservative value with regard to actual shear plane area versus theoretical shear plane area as specified by the fillet size on an engineering drawing. Figures 4 and 5 show the maximum internal discontinuities permitted in fillet welds per MSFC-SPEC-504A [9]. As can be noted, each F_{su} value (Class I or Class II) is conservative with regard to shear strength degradation as a result of the maximum internal discontinuities permitted. This discontinuity latitude is required because of the problems associated with radiographic inspection. Figures 6 and 7 show the allowable shear strength of fillet welds plotted as a function of fillet size.

---

1. Using the distortion-energy theory for the case of pure shear

$$\tau_o = \frac{\sigma_o}{\sqrt{3}} = 0.5773\,\sigma_o \quad .$$

Using the octahedral shear theory of aluminum (fcc) for the case of pure shear,

$$\tau_o = \frac{1.293}{2.238}\,\sigma_o = 0.5777\,\sigma_o$$

where τ_o is the yield strength in shear and σ_o is the shear yield strength [8].

Assuming an equal amount of work hardening in pure tension and pure shear, since deformation occurs as shear on the maximum shear plane in both cases,

$$F_{su} \approx 0.57\,F_{tu} \quad .$$

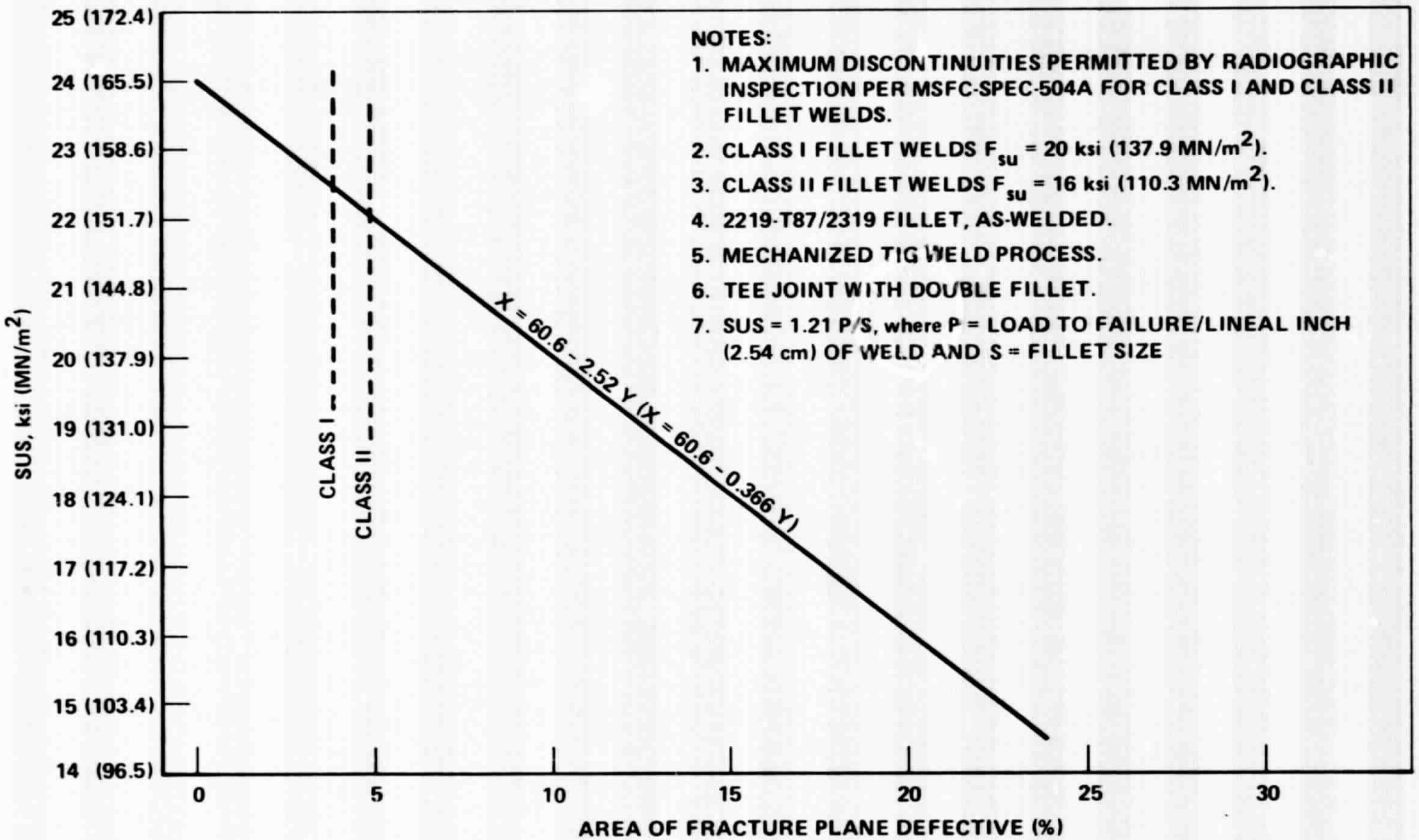

Figure 4. Transverse SUS of as-welded fillet welds shown as a function of defect concentration.

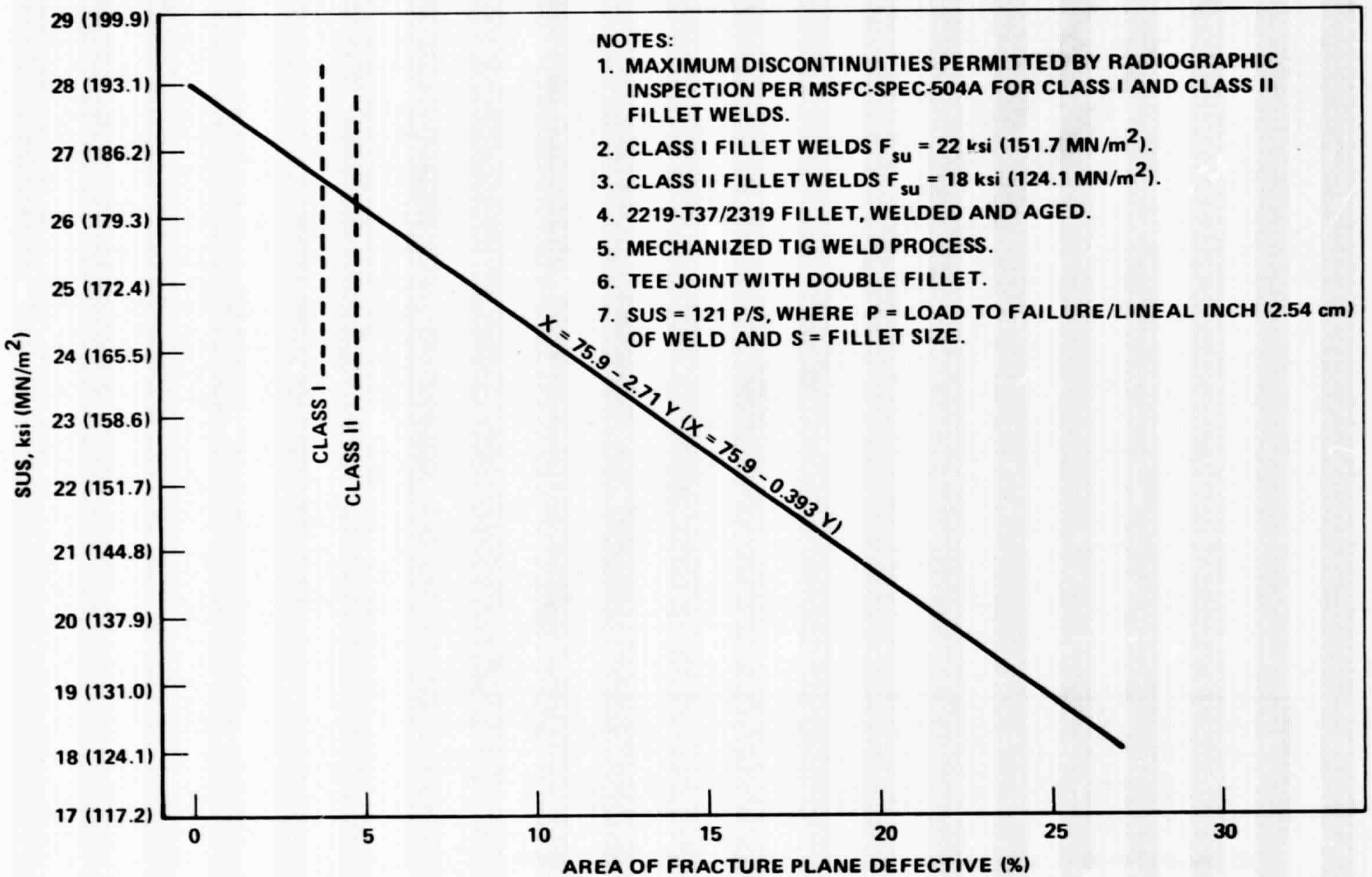

Figure 5. Transverse SUS of aged fillet welds shown as a function of defect concentration.

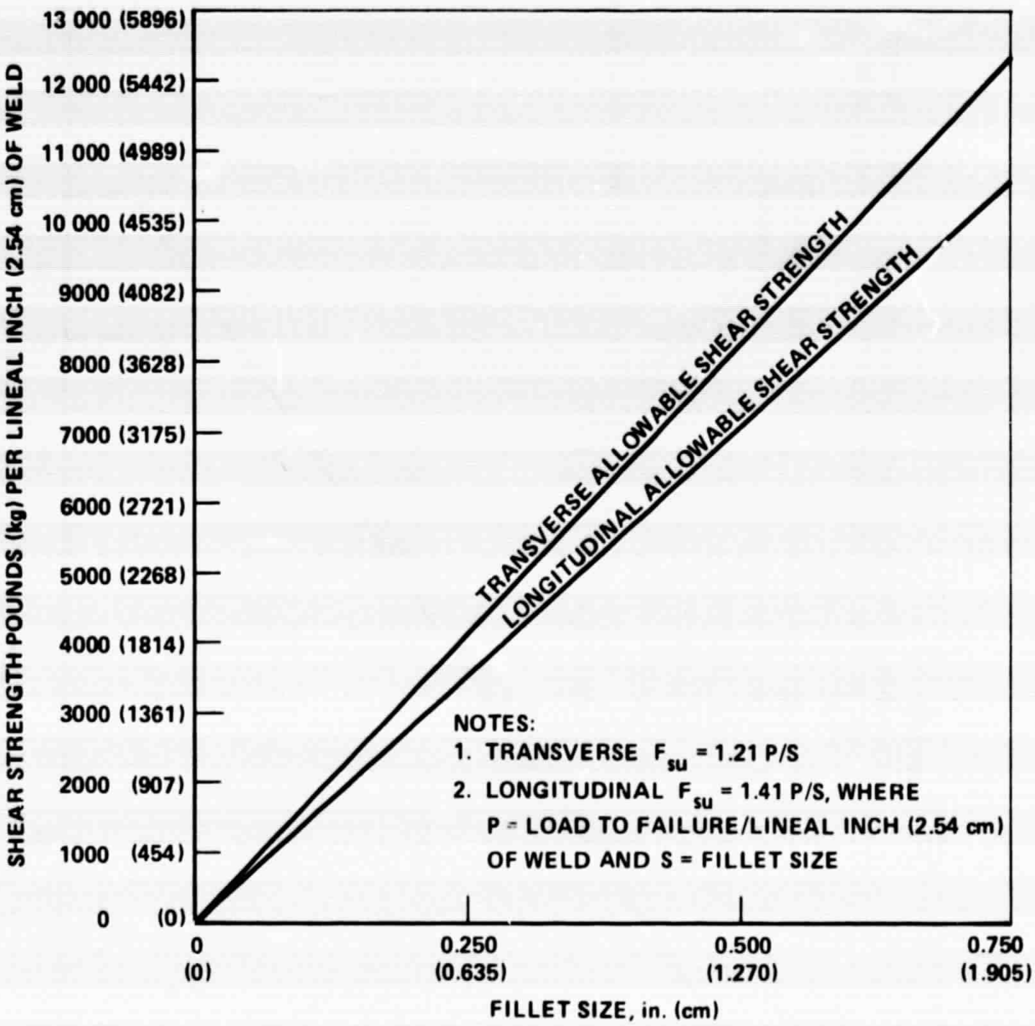

Figure 6. Allowable SUS of as-welded fillet welds in aluminum alloy 2219 with 2319 filler metal.

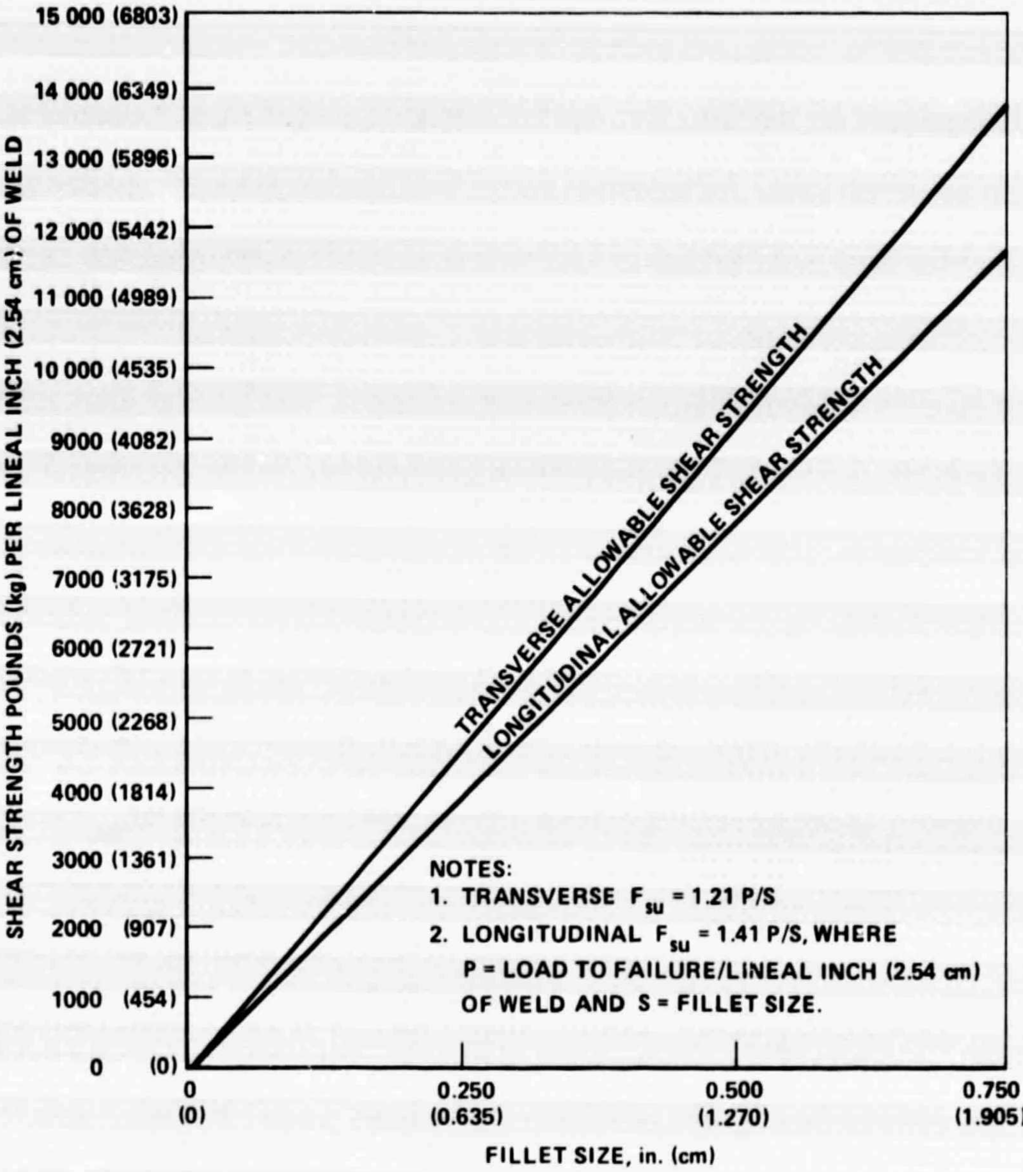

Figure 7. Allowable SUS of aged fillet welds in aluminum alloy 2219 with 2319 filler metal.

IV. CONCLUSIONS

Fillet welds are used extensively in the assembly of 2219 aluminum alloy components for the SRB, ET, and for aerospace ground support equipment. Some of these welds will be required to sustain a service load which is equivalent to the design load. An important part of the complete design is specifying sizes and lengths of fillet welds necessary to sustain the expected loads on such joints. For the most part, aerospace hardware is normally constructed with welds which meet statistical factors of 99 percent probability and 95 percent confidence.

Radiographic inspection of fillet welds in experimental tee panels revealed a smaller quantity/area of defects than that detected by fracture plane inspection. The disparity between the two methods of defect summations can be explained on the basis of preferred defect growth during welding, and the resultant X-ray angle as related to the shear plane angle.

The SUS was found to be lineally related to the quantity of fillet weld internal defects. Simple straight line regression analysis resulted in correlation coefficients of -0.95 and -0.98, respectively, for as-welded fillet welds and aged fillet welds. SUS allowables were found to be 20 ksi (137.9 MN/m^2) for as-welded fillets and 22 ksi (151.7 MN/m^2) for aged fillets. The 22 ksi (151.7 MN/m^2) value was derived by a statistical method which is known as ratio analysis. A value of 22 ksi (151.7 MN/m^2) can also be achieved with aged fillets by taking 57 percent of the aged butt weld "A" allowable (F_{tu} = 38.5 ksi or 265.5 MN/m^2).

An appropriate statistical approach was used to obtain the 22 ksi value which assumes its conformance with the 99 percent probability and 95 percent confidence factors required for an "A" design allowable. The 20 ksi value for as-welded fillets was obtained by using 57 percent of the as-welded butt weld "A" allowable (F_{tu} = 35 ksi or 241.3 MN/m^2). The value is believed to have the same probability and confidence as the 22 ksi (151.7 MN/m^2) value, but statistically can not be characterized as such. However, the 20 ksi (137.9 MN/m^2) value for as-welded fillets will continue to be used by MSFC for design purposes because (a) the value has historically been used for design purposes on hardware with no failures, (b) aged fillet welds showed identical values with the 57 percent method and the statistical ratio analysis method, (c) the actual shear plane area of fillet welds on the hardware is always larger than the theoretical shear plane area as specified by the fillet size on the engineering drawing, and (d) 20 ksi is conservative with regard to shear strength degradation as a result of the maximum internal discontinuities permitted per welding specification MSFC-SPEC-504A.

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APPROVAL

SHEAR STRENGTH OF FILLET WELDS IN ALUMINUM ALLOY 2219

By Charles V. Lovoy

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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