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GENERAL DYNAMICS
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COMPILATION OF

MATERIALS RESEARCH DATA

A. F. Hooper

Fourth Quarterly Progress Report - Phase I
1 March 1963 to 27 May 1963

Contract AF33(616)-7984
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27 May 1963

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AR-592-1-374

11 December 1962

SUBJECT: Metallographic Examination of Radiographically Detected Defects in Resistance Spot Welds in 0.010" thick 301 Stainless Steel Centaur Intermediate Bulkheads.

ABSTRACT: A number of resistance spot welds, which were removed from the longitudinal weld joints of both the structural and spring ring bulkheads from the first Centaur C-2, (EID No. 55-0501-2, originally assigned to F-2) were chosen for microscopic examination on the basis of radiographically detected defects on the periphery or within the spot welds. The main objective of this study is the correlation of the defect detected radiographically with the type of defect actually found to be present by microscopic examination of a cross-section of the spot weld.

It was found that the location of the defect indication relative to both the light halo image which encompasses the resistance spot weld and the weld nugget image may serve as an aid in the radiographic interpretation of the type of defect present. Any thinning or yielding of the sheet metal near the weld nugget appeared on the X-ray film as dark crescent-shaped images on the inner circumferential edge of the light halo image. Corrosion pits near the weld nugget were detected on the X-ray film as dark crescent-shaped images on the outer circumferential edge of the halo image. Scattered weld porosity was detected radiographically as dark irregular shaped images within the weld nugget which appeared visually to consist of branch cracking.

Prepared by: Charles J. Kropp

APPROVED BY: A. Hurlich
Chief of Materials Research

AH:CJK:vmb

11 December 1962

TO: Distribution

FROM: MATERIALS RESEARCH GROUP, 592-1

SUBJECT: Metallographic Examination of Radiographically Detected Defects in Resistance Spot Welds in 0.010" thick 301 Stainless Steel Centaur Intermediate Bulkheads.

REFERENCES

(A) GD/Astronautics Report No. AA-61-0106

(B) "Leak Checking of C-2 Centaur Bulkhead", Report No. A1-9

(C) "Centaur C-2 Intermediate Bulkhead Evaluation", Report No. 55B 1471-1

(D) "Detection of Cracks Adjacent to Spotwelds by Radiography in Thin Stainless Steel Sheet", Report No. MRG-289

BACKGROUND

Tests Conducted on the First Centaur at AMR. After the first Centaur C-2* and the Atlas 104-D were mated at the Atlantic Missile Range, several attempts were made to tank the Centaur with propellants. These attempts were started on 19 June 1961 and continued until 10 August 1961. During this period, several tanking tests were cancelled because of malfunctions in the propellant storage tanks, propellant transfer system and in the Centaur.

Either liquid nitrogen or liquid oxygen was used to fill the aft tank on six occasions; however, liquid hydrogen was used to partially fill the forward tank on only four of these tanking tests. The aft tank was filled with liquid nitrogen on two dates (19 June and 13 July 1961). Tanking tests on 6 July, 12 July, 27 July and 10 August 1961 involved the filling of the aft tank with liquid oxygen. On 10 August 1961, the forward tank was filled approximately 93% with liquid hydrogen, but the test was stopped because a pressure of 6.8 psig was recorded in the forward tank. The normal pressure in this tank is 4.5 psig. During this test the pressure in the aft tank decreased to 14.0 psig. The minimum pressure allowed in this tank is 13.8 psig. The above data was obtained from Report No. AA-61-0106.

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*This Centaur was identified as EID No. 55-0501-1 and was originally assigned to F-2 ("Centaur Committee Report on Materials and Fabrication", Lewis Research Center Report No. E-1976, 6 November 1962)

Based on the tests conducted at AMR, it was concluded that leaks in eith the structural or the spring ring bulkheads were causing at least a portion of the difficulties encountered. In an attempt to pinpoint the exa location of the leaks, two individuals from the Aerophysics Group at GD/ were sent to AMR to assist in this phase of testing.

During the leak checking investigation, the aft tank was purged with argon gas and the forward tank was purged with helium gas. The purging was repeated several times, but the pressures were not documented. The bulkhead cavity was evacuated to an average pressure of 2 mm Hg after both tanks were filled (Report No. Al-9). The results of the leak checking investigation were not conclusive because it was found at a later date that one of the instruments used (an Alphatron vacuum gage) was not purged.

Leak Checking Tests Conducted At GD/Astronautics. After the forwa tank was cut and removed at approximately Station 360, the remaining por tion of the aft section was then delivered to GD/A for a more complete investigation of the location of leaks in the bulkheads. A detailed doc mentation of the procedure involved in this investigation is given in Report No. 55B 1471-1. A summary of the higher pressures used is given below:

> The aft tank was filled four times to an appreciable pressure: twice at 5 psig ± 1 psig and twice at 8 psig ± 1 psig. The bulkhead cavity was also pressurized one time to 6 psig ± 0.5 psig. Only helium gas was used during these tests.

From this investigation, nine leaks were found in the structural bulkhe but no leaks were detected in the spring ring bulkhead.

After the completion of the radiographic inspection of both the structu and spring ring bulkheads from the first Centaur C-2, the bulkheads and the radiographic films were obtained by the Materials Research Group so to determine the actual internal conditions of some resistance spot wel which, by the interpretation of the radiographs, contained defects. Th internal conditions would be observed by microscopic examination of the cross-sectioned spot welds. The microscopic observation would then be correlated with the images of the defects recorded on the radiographic films. The radiographic films were exposed with a beryllium window tub

A similar investigation was described in a previous report (MRG-289) wh contained photomicrographs of cracks which developed adjacent to resist spot welds as a result of fatigue testing at -423° F. These fatigue cracks were recorded on the radiographic films as dense crescent-shaped images on the inner circumferential edge of the light halo of the spot weld.

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Radiographic inspection of the two Centaur bulkheads detected defects on the periphery and within the resistance spot welds which were not completely similar in geometry and image density as those reported in MRG-289.

The purpose of the present report is to document the types of spot weld defects which occurred in the first Centaur C-2 bulkheads by the comparison of radiographic images with the internal conditions of the cross-sectioned spot welds. The documentation of the results of this investigation should be of some assistance in the interpretation of defects found in the radiographs of resistance spot welds.

PROCEDURE

Radiographs of both the structural and spring ring bulkheads from the first Centaur C-2 were examined with particular attention given to the various types of defects present in the resistance spot welds. These defects appeared as dark crescent-shaped or irregular shaped images (like branch cracking), respectively, on the periphery or in the center of the weld nugget.

At least one of each type of spot weld defect was chosen for microscopic examination and the radiograph of the spot welds chosen was photographed at a magnification of 5X.

The spot welds which represented the dark crescent-shaped defect were prepared for microscopic examination by cross-sectioning through the area containing the crescent. The samples were then ground and polished to the center of the crescent indication and examined microscopically. To accomplish this task, the spot weld samples were carefully oriented with the respective radiographs.

The spot welds which contained the branch cracking type of defect were prepared for microscopic examination by performing the grinding and polishing on the doubler sheet so that a plan view of the weld nugget was obtained. This method of sample preparation results in permitting observation of the spot weld in a plane similar in manner to the image of the weld as recorded on the radiographic film. Grinding and polishing of the samples was performed in steps so that approximately 0.003" was removed. This stepwise procedure was continued until the defect was observed with a magnifying lens.

RESULTS

Spot Welds from the Structural Bulkhead. A sketch of the structural bulkhead is included to show the location of two spot welds which were removed from the bulkhead for microscopic examination of the defects, as recorded radiographically (see Fig. 1).

A reproduction of the radiograph, which shows the two spot welds that were cross-sectioned, is shown in Figure 2. The defects, which are seen as crescent-shaped images on the periphery of the weld nuggets, were interpretated as crack indications. These two defect images are of approximately equal density and seem to obscure a sector of the light halo image.

Photomicrographs of the cross-sections obtained from the above two weld nuggets are shown in Figures 3 through 6. It can be seen that a crack does exist in one spot weld in the area which contained the crescent image on the radiographic film (see Fig. 4). The photomicrograph of the cross-section through the second spot weld at the crescent area is shown in Figure 6, but this spot weld does not contain a crack. The chief similarity between these two spot welds is the almost equal amount of thinning (yielding) of the gore skin. Thinning of the sheet would result in a dark image (crescent) being recorded on the radiographic film. It is believed that, since the two crescent images are of equal density, the small crack (11% through the loaded sheet), as seen in Figure 4, contributed little, if any, density to the crescent, and was not actually detected on the X-ray film. This belief is also based on the conclusions of the previous investigation (MRG-289), which stated that a crack must have a length greater than 15% through the loaded sheet if it is to be detected by radiographic inspection with a beryllium window tube.

The photomicrographs at 100X, shown in Figures 3 and 5, are cross-sections of the same two spotwelds, showing the other ends of the nuggets diametrically opposite the side containing the crescent areas. It can be seen that these areas do not contain cracks and that no thinning of the sheets exists.

<u>Spot Welds from the Spring Ring Bulkhead</u>. A sketch of the spring ring bulkhead is also included to show the location of the five spot welds which were also removed from the bulkhead for microscopic examination of the defects as recorded radiographically (see Fig. 7).

The two spot welds shown in the radiograph in Figure 8 contain dark crescents on the periphery of the weld nugget; however, it can be seen that these crescents are finer in appearance than those shown in Figure 2. The radiographic inspection report concluded that these crescent images were indicative of cracks at the nugget. Based on the finest of the crescent images, it is believed that this conclusion is reasonable; however, the photomicrographs showing the cross-sections at these areas proves that something other than cracks in the stainless steel sheets were recorded on the radiographs.

Photomicrographs of cross-sections of the two spot welds shown in Figure 8 can be seen in Figures 9 through 12. The areas of these spot welds, which contained the crescents, actually show various degrees of thinning or yielding at the faying surface of the gore skin within the heat-affected zone (approximately midway between the weld nugget and the carbide precipitation zone, (see Figs. 10 and 12).

The remaining photomicrographs of the two spot welds are included to show the condition of the weld nugget areas which are diametrically opposite the crescent (see Figs. 9 and 11).

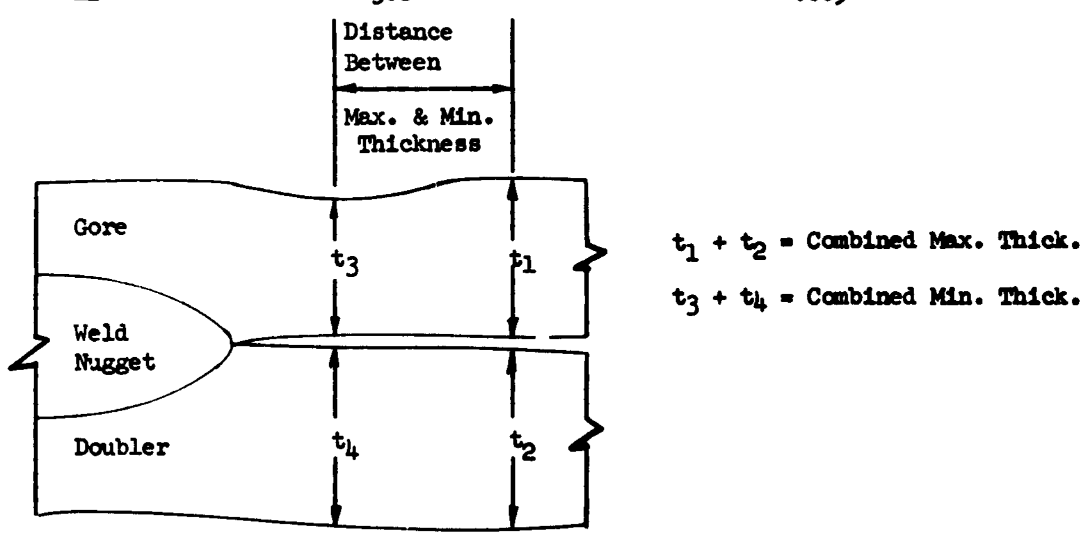
Even though the crescents seen in the radiographs of the above two spot welds are similar in appearance, the photomicrographs show the various degrees of severe and localized sheet thinning which apparently can be detected radiographically.

Measurements were made to obtain the percent reduction in thickness (thinning) of the two stainless steel sheets near the spot welds shown in Figures 4, 6, 10 and 12. The percent reduction of thickness was based on the difference between the maximum and minimum values of the combined thickness of both the gore skin and the doubler sheet within the heat-affected zone. The distance between the combined maximum and minimum thickness values was also measured.

The table below contains the measurements obtained and also illustrates, on the basis of the radiographs included in this report, the range of abrupt sheet thinning which can be detected radiographically.

TABLE

Figure No.	Percent Reduction in the Combined Sheet Thickness	Distance Between the Maximum and Minimum Combined Sheet Thickness, in.
4	6.5	0.013
6	6.0	.013
10	9.9	.012
12	3.6	.009



The radiograph reproductions shown in Figures 13 and 16 also contain defects on the periphery of the spot welds, however, it can be seen that the dark defect images are located on the outside circumferential edge of the light halo. The previous spot weld defects were either located within the light halo area and obliterated a sector of the halo (see Fig. 2) or located on the inside circumferential edge of the light halo (see Fig.8).

The photomicrographs of the two spot welds shown in Figures 15 and 17 illustrate that the radiographically detected defects are corrosion pits at the faying surface of the two sheets in the carbide precipitation zone. The resistance to corrosion attack is lowered in the carbide precipitation zone of a 301 stainless steel weld because the chromium content in these areas is depleted during the heat cycle of welding. A corrosive fluid may have become entrapped at the faying surface and the subsequent pits were formed.

The last reproduction of a radiograph shows a spot weld with what appears to be internal weld cracking along with weld metal expulsion or spitting (see Fig. 18). The photomicrograph of a plan view of this spot weld (Fig. 19) indicates that the dark images within the weld nugget are actually scattered weld porosity. This photomicrograph also shows that the weld metal expulsion has resulted in enlarging a portion of the heat-affected zone. Note also that the two small dark images located on the inner circumferential edge of the light halo correlate with the two small weld pores on the inner edge of the heat-affected zone.

CONCLUSIONS

Based on the observations made in this study, it is believed that the shape and density of the image of a defect, as recorded on X-ray film, along with the location of the defect image in relation to both the light halo and weld nugget images, may aid in the future radiographic interpretations of alleged defects in resistance spot welds. The locations of the defect images may be divided into three categories along with the type of defect which may be present as follows:

1) Crescent-shaped dark images at the inner circumferential edge of the light halo may indicate a crack or severe and localized thinning or yielding in the load sheet (gore skin). It is believed at the present time that the thinning or yielding shown in this report was caused by localized overloading of certain spotwelds due to discontinuity effects within the pressurized bulkhead and was not produced at the time of welding. However, if excessive electrode pressure caused indentation of the welded sheets, visual observation of the surface of the weld could be used to determine if a dark crescent X-ray image is due to electrode indentation. Based on evidence presented in this report, the defect would be located midway between the weld nugget and the carbide precipitation zone.

2) Irregular shaped dark images at the outer circumferential edge of the light halo indicates the possible presence of a corrosion pit in the carbide precipitation zone. Corrosion pits in a 301 stainless steel weld are caused by a relatively long exposure time to a corrosive liquid. If corrosion attack is not observed on the surface of the weld, the corrosive liquid became entrapped at the faying surface and pitted the sheets in the carbide precipitation zone.

3) Irregularly shaped dark images within the weld nugget may indicate the presence of internal weld porosity. These images may appear to be discontinuous which is the result of the formation of weld porosity under electrode pressure.

It is believed that this investigation, along with the one previously referenced, should be beneficial in the radiographic inspection of resistance spot welds. It is recommended that further investigations of this type be continued to obtain more case histories of defects in spot welds and to attempt to determine the effects of the types of defects on the mechanical properties of welded joints.

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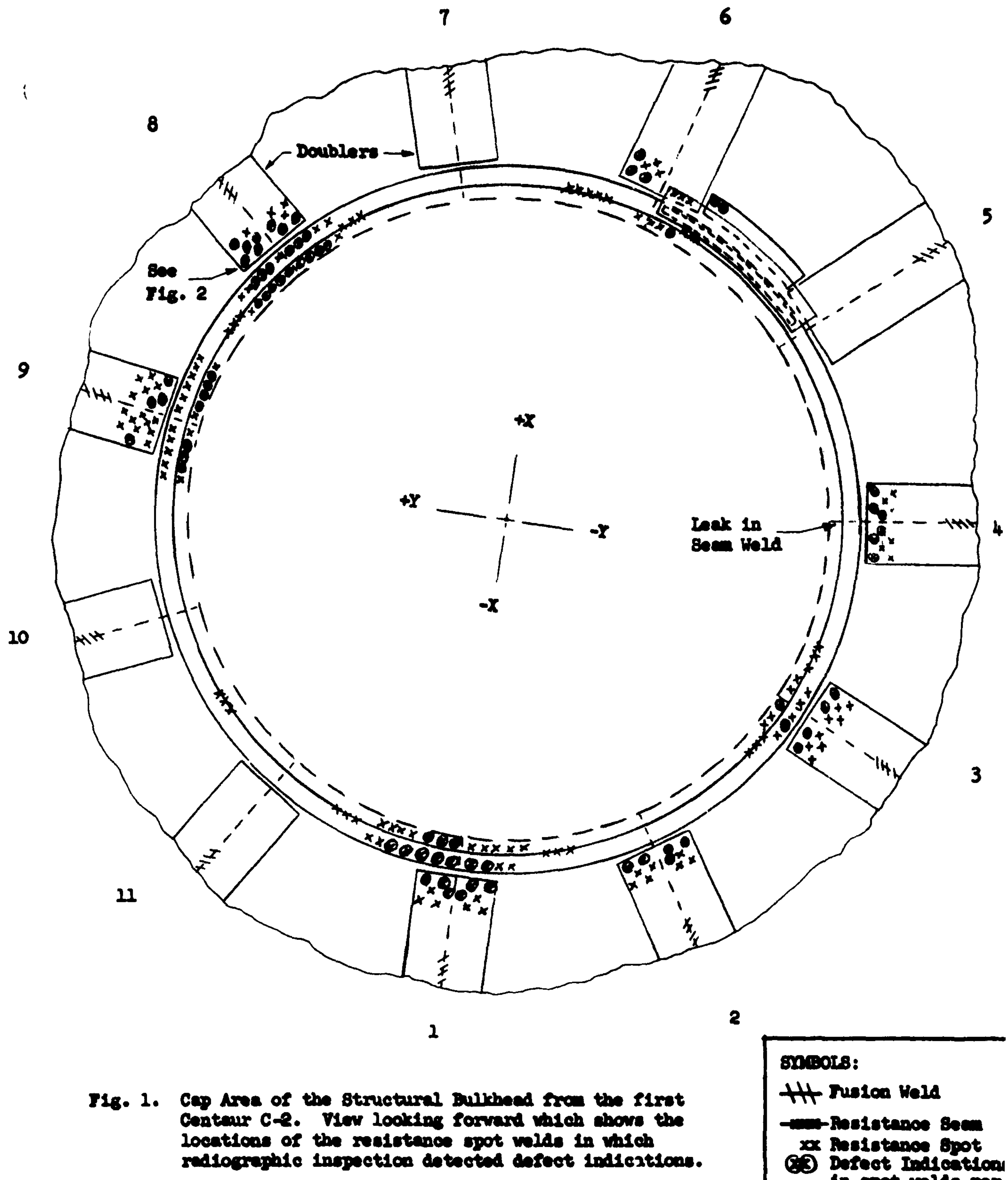


Fig. 1. Cap Area of the Structural Bulkhead from the first Centaur C-2. View looking forward which shows the locations of the resistance spot welds in which radiographic inspection detected defect indications.

Cap Location

Magnification: 5X

Figure 2. Reproduction of a radiograph of two spot welds which were interpreted by radiographic inspection as crack indications. The two spot welds shown above were located in the longitudinal weld joint near the cap. A portion of the cap can be seen at the top of this photograph. The spot weld on the right was in the first row of spot welds, while the spot weld on the left was in the third row of spot welds. Refer to Figure 1 for the location of these two spot welds in relation to the cap. The white circular images were found to be caused by small disks entrapped between the gore skin and the doubler and cap. The disks were identified by spectrographic analysis as being composed of a low melting temperature alloy, similar to Cerro Bend. This sample was obtained from the first Centaur C-2 Structural Bulkhead.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

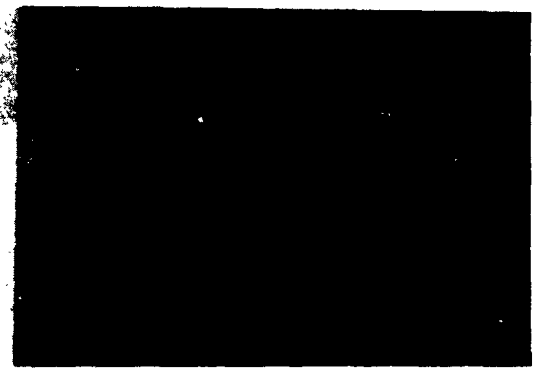
Figure 3. Photomicrograph of the cross sectional view of the spot weld shown on the left side of the radiograph in Fig. 2. The area shown is diametrically opposite the dark crescent.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 4. Photomicrograph of the cross-sectional view of the same spot weld shown at left, but at the opposite end of the nugget and therefore indicates the condition of the nugget at the crescent. The crack shown is approximately 11% through the gore skin. Note the thinning in the gore skin.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 5. Photomicrograph of the cross-sectional view of the spot weld shown on the right side of the radiograph in Fig. 2. The area shown is diametrically opposite the dark crescent.



Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 6. Photomicrograph of the cross-sectional view of the same spot weld shown at left, but at the opposite end of the nugget and therefore indicates the condition of the nugget at the crescent. Note the nearly equal amount of gore skin thinning, as seen here and Fig. 4.

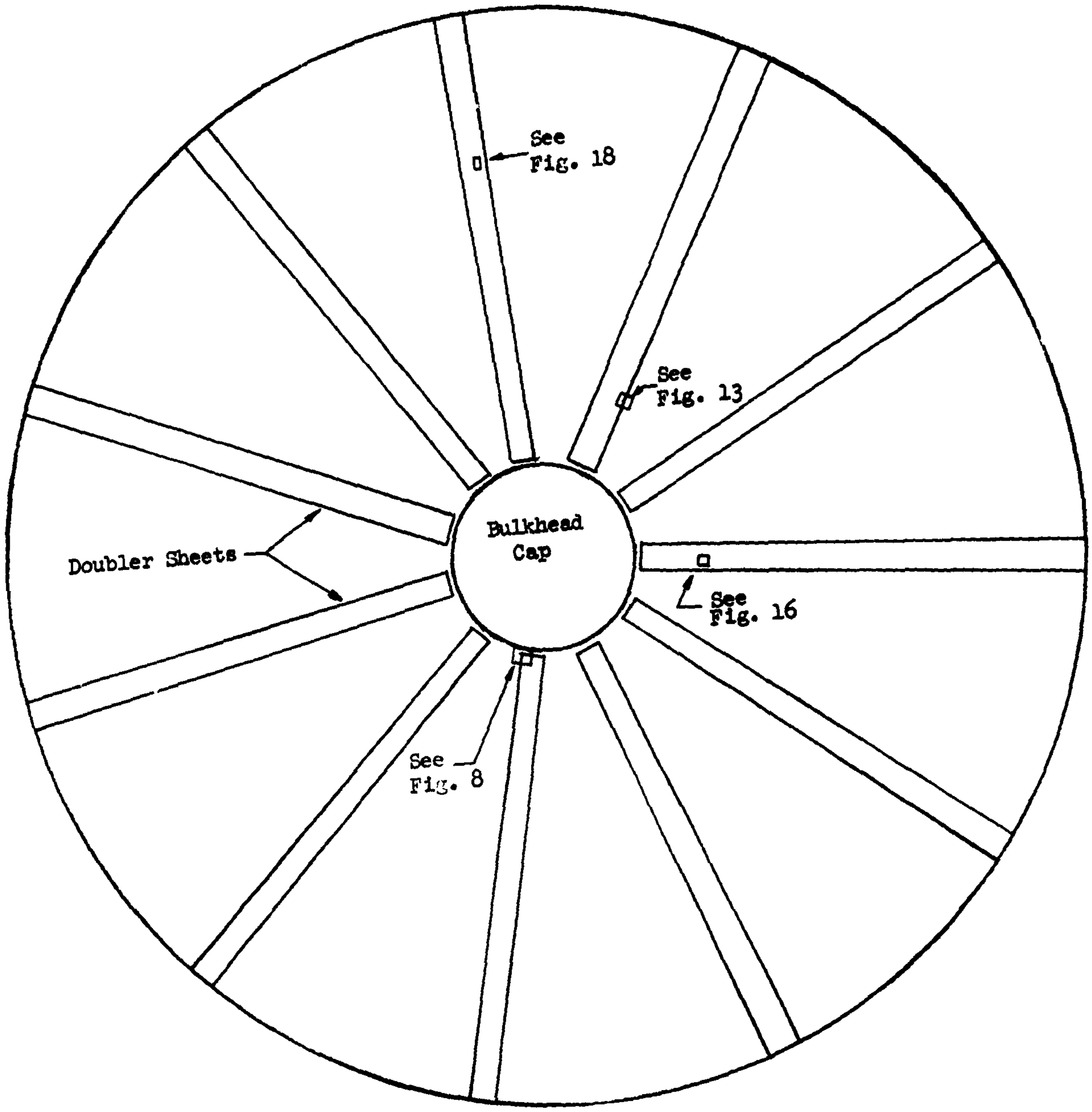


Figure 7. The above sketch shows the location of the two spot welds shown in Figures 8, 13, 16 and 18. The sketch represents the Spring Ring Bulkhead of the first Centaur C-2.

Magnification: 5X

Figure 8. Reproduction of a radiograph of two spot welds which were interpreted by radiographic inspection as cracks. The two spot welds shown above were located in the longitudinal weld joint near the cap. The nugget on the left was located in the first row of spot welds, while the nugget on the right was located in the third row of spotwelds. The top edge of the four-inch wide doubler sheet can be seen at the top of this radiograph. The section lines indicate the planes of cross-sectioning for the metallographic specimen. This sample was obtained from the first Centaur C-2 Spring Ring Bulkhead.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 9. Photomicrograph of the cross-section through the nugget shown on the left side of Fig. 8. The area shown is diametrically opposite the crescent.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

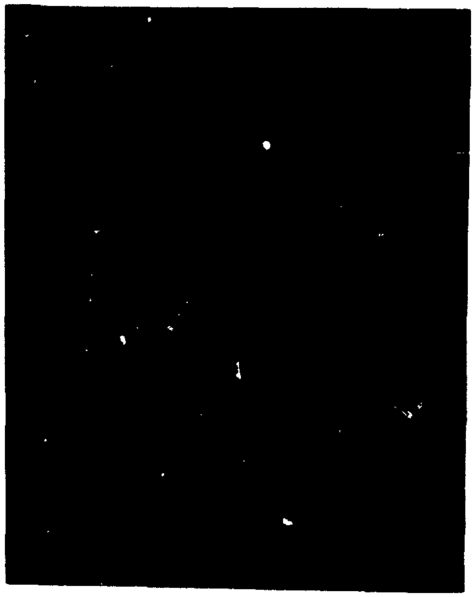
Figure 10. Photomicrograph of the cross-section of the same spot weld shown at left but at the opposite end of the nugget. This area represents the condition of the nugget at the crescent. Note the thinning of the gore skin in the heat-affected zone at the faying surface.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 11. Photomicrograph of the cross-section through the nugget shown on the right side of Fig. 8. The area shown is diametrically opposite the crescent.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 12. Photomicrograph of the cross-sectional view of the same spot weld shown at the left, but at the opposite end of the nugget. This area represents the condition of the nugget at the crescent. Note the thinning of the gore skin in the heat-affected zone at the faying surface.



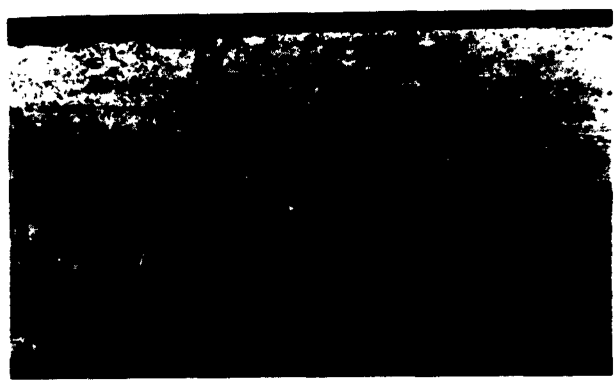
Cap
Location

Magnification: 5X

Figure 13. Reproduction of a radiograph of a spot weld in the first row of spot welds in the longitudinal weld joint near the cap. The lengthwise edge of the doubler sheet is seen on the left side of the above photograph. The radiographic laboratory interpreted the dark area on the periphery of the spotweld as a crack indication. Note that this dark area is on the outside circumferential edge of the light halo. The section lines of the metallographic cross-sections are shown. This sample was obtained from the first Centaur C-2 Spring Ring Bulkhead.

Magnification: 100X
Etchant: Electrolytic Oxalic Acid

Figure 14. Photomicrograph of the cross sectioned spot weld shown in Fig. 13. The area shown is diametrically opposite the dark area on the periphery of the light halo.



Magnification: 100X
Etchant: Electrolytic Oxalic Acid

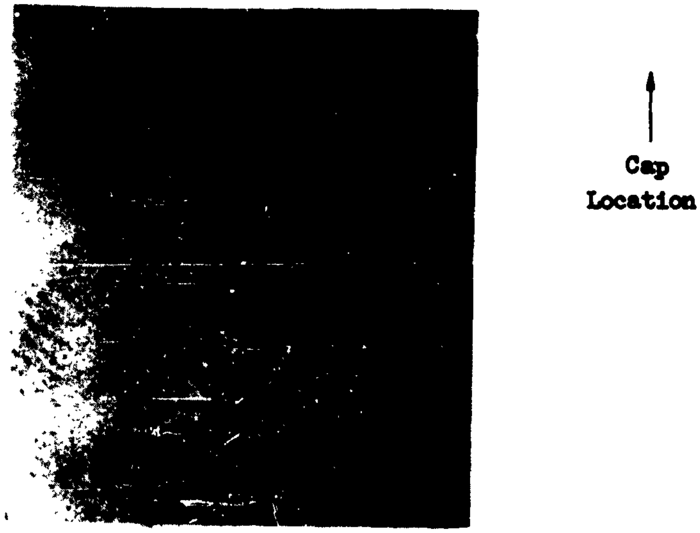
Figure 15. Cross sectional view of the same weld nugget shown at left, but the section represents the condition through the dark area. This defect appears to be a corrosion pit at the faying surface at the carbide precipitation zone.

Magnification: 5X

Figure 16. Reproduction of a radiograph of a spot weld in the second row of spot welds in the longitudinal weld joint near the cap. The dark area at the top of the nugget was interpreted by the radiographic laboratory as a crack. Note that this dark indication is also located on the outside circumferential edge of the light halo (compare with Fig. 13). This sample was obtained from the first Centaur C-2 Spring Ring Bulkhead.

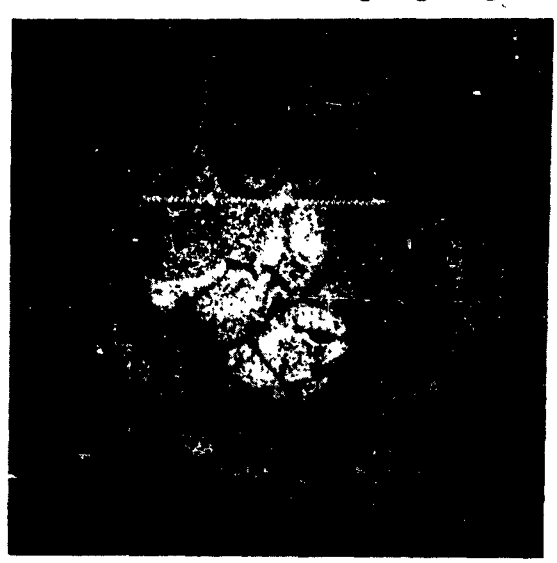
Magnification: 30X Etchant: Electrolytic Oxalic Acid

Figure 17. Photomicrograph of a plan view of the spot weld shown above. The grinding and polishing of this nugget was performed on the doubler sheet. This defect was located in the gore skin since 0.011" was removed by grinding and polishing. When compared to the radiograph, it is seen that this photomicrograph shows the nugget in a view which is turned slightly counterclockwise. This defect, like the one in Fig. 15, also appears to be a corrosion pit at the carbide precipitation zone.



Magnification: 5X

Figure 18. Reproduction of a radiograph of a spot weld in the second row of spot welds in the longitudinal weld joint near the spring ring. The internal dark images were interpreted by the radiographic laboratory as internal weld cracking. Weld metal expulsion or spitting can also be seen at the top left side of the nugget. This sample was obtained from the first Centaur C-2 Spring Ring Bulkhead.



Magnification: 30X   Etchant: Electrolytic Oxalic Acid

Figure 19. Photomicrograph of a plan view of the spotweld shown above. The grinding and polishing of this nugget was performed on the doubler sheet. The appearance of scattered weld porosity was located in the gore skin since 0.0105" was removed by grinding and polishing. It will be noted that the weld metal expulsion has caused a slight increase in the width of the heat affected zone.

11 December 1962

PHOTOGRAPHIC IDENTIFICATION INDEX

Figure Number	NRG Negative Number
2	M-4857
3	M-5825
4	M-4829
5	M-5826
6	M-4851
8	M-5492
9	M-5827
10	M-5466
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