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THICK SECTION ALUMINUM WELDMENTS FOR SRB STRUCTURES

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16. ABSTRACT

The Space Shuttle Solid Rocket Booster (SRB) forward and aft skirts were designed with fracture control considerations used in the design data. Fracture control is based on reliance upon nondestructive evaluation (NDE) techniques to detect potentially critical flaws.

In the aerospace industry, welds on aluminum in the thicknesses (0.500 to 1.375 in.) such as those encountered on the SRB skirts are normally welded from both sides to minimize distortion. This presents a problem with the potential presence of undefined areas of incomplete fusion and the inability to detect these potential flaws by NDE techniques. To eliminate the possibility of an undetectable defect, weld joint design was revised to eliminate blind root penetrations. Weld parameters and mechanical property data were developed to verify the adequacy of the new joint design.

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INTRODUCTION

Weld joints thicker than 0.500 in. are normally welded from both sides to minimize distortion and expensive joint preparation. On previous space flight vehicles, square butt joints as thick as 1.000 in. were welded using the double sided welding technique. When double sided welding is used, lack of nugget tie-in (Fig. 1) can result in a very tight lack-of-penetration type defect. Earlier work at MSFC showed that such defects are not reliably detected by ultrasonics or radiographic nondestructive evaluation (NDE) techniques. When the double-sided technique was used, weld parameters were established on destructively tested samples representative of the joint thickness, alloy, and heat sink to assure that the weld nuggets overlapped a minimum of 0.125 in.

Because of the varying heat sinks encountered on some of the SRB skirt weld joints, the possibility of having an unfused weld joint increased. Previous vehicles were proof tested before use to assure that undetected defects did not cause structural problems in flight. However, because of the expense involved, the skirts are not being proof tested. The possibility of a flaw not being detected necessitated the development of a welding process that is completely inspectable.

Five weld joints on the SRB skirts, ranging in thickness from 0.5 to 1.375 in., had been originally designed for double sided welding of the type used on previous programs. However, the identification of these joints as fracture critical precluded this approach. The fracture critical designation required that the joint design be modified to provide reliable inspection and structural tolerances demanded that the process be optimized to minimize distortion. A summary of these five joints is given in Table 1. Figures 2 and 3 show the location of the welds on the forward and aft skirts.

APPROACH

Previous experience with welding 2219 aluminum at MSFC dictated many of the decisions concerning preweld cleaning, the welding process, shielding gases, welding position, etc. The direct-current, straight polarity, Gas Tungsten Arc Process was chosen because of its penetration capabilities.

TABLE 1. SUMMARY OF FIVE JOINTS

Weld No.	Joint Thickness (in.)	Parts To Be Joined
1	1.250	Forward skirt skin to thrust post
2	0.500 in.	Forward skirt skin to skin
3	0.500 to 1.250	Forward skirt to attach ring
4	1.375 in.	Aft skirt conical skins to hold down posts
5	1.375	Aft skirt to forward ring on 18 deg angle

Vertical up was chosen as the welding position to minimize internal defects and to better control the molten puddle on a through penetration type weld. Preweld cleaning included removal of all oil, dirts, and foreign matter with chemicals, then just prior to welding, filing or scraping the abutting edges of the joint. Helium was selected over argon as the shielding gas because of its deeper penetrating characteristics.

Two approaches to weld joint design were taken to improve inspectability. The first approach involved using a "witness" type groove machined into the weld joint which would appear as a void during radiographic inspection if the weld joint was not completely fused. The second approach involved design of a weld joint that could meet the following criteria: (1) visual inspection to assure complete penetration of the joint, (2) balance of shrinkage forces to minimize distortion, (3) ease of welding, and (4) machining of the joint to be as simple as possible (i.e., no step type joints if possible).

DISCUSSION

Several joint configurations containing "witness grooves" were designed (Fig. 4). The incorporation of this groove required an extra machining operation, thus increasing joint preparation costs. In addition, the configurations containing witness grooves proved significantly harder to clean prior to welding. When joints containing witness grooves were welded, a significant increase in porosity was noted over that normally encountered without a groove. This increase in porosity was attributed to contamination which could not be easily removed from the groove.

When intentional lack-of-penetration was induced in welds with witness grooves, detection of this condition by radiographic inspection was inconsistent. Investigation revealed that the following two factors contributed to inconsistent detection: (1) filling of the witness groove with metal and (2) coining of the groove surfaces by weld shrinkage forces.

In the first instance, weld metal would flow into the witness groove with insufficient heat to fuse to the groove walls. In the second instance, the elevated temperature due to welding and the shrinkage forces in the weld caused the side wall of the groove to be forced together with sufficient force to coin the surfaces. This defect is too tight to be detected; therefore, work on witness grooves was abandoned in favor of a simpler solution.

The second approach investigated involved redesigning the joint configuration to eliminate the possibility of hidden lack-of-penetration defects during welding. In determining joint configurations, four objectives were to be met:

1. Visual verification of root penetration
2. Minimum number of fill pass
3. Easy-to-machine configuration
4. Adequate accessibility for the welding torch.

Five joint designs were evolved which met these requirements.

Land thicknesses were determined by finding the maximum thickness that could be easily penetrated and controlled. This land thickness is dependent upon factors such as heat sink and weld position. Land thickness varied from 0.250 in. thickness for the 0.500 in. thick joint to 0.375 in. thickness on the 1.250 in. thick material. Joint details are shown in Figure 5. Filler wire is not added on the penetration pass; this allows better control of the penetration bead due to a smaller volume of molten metal. During the penetration pass, the underbead can be visually observed. Adjustments in machine settings can be made when necessary to correct for varying heat sink conditions. The resultant penetration bead is smooth enough for the filler passes to be made directly on it without any mechanical preparation. After the root pass is made, visual inspection is adequate to assure that no lack of penetration occurred.

Except for weld No. 3, all of the joints have straight sidewalls. This straight sidewall design decreases the number of fill passes required. Weld No. 3 was designed with a 2.5 deg side angle because of the depth of the groove. Due to the depth of the groove, operator visibility was limited with straight sidewalls.

Figures 6 and 7 are micrographs of the 1.250 and 1.375 in. weld cross section. The narrow "U" type groove allows the filler passes to tie-in to the preceding weld pass and both sidewalls without transverse movement of the weld torch. This results in a narrow weld nugget as compared to a "V" type joint preparation.

Table 2 gives a summary of the average mechanical strength properties obtained from the five weld joints. The 2219 aluminum for the skirts is welded in the T37 heat treat condition, then artificially aged to the T87 condition. Artificial aging after welding increases the ultimate strength by 10 to 25 percent and the yield strength by 23 to 45 percent as compared to the as-welded T87.

TABLE 2. MECHANICAL PROPERTIES

Weld No.	Joint Thickness (in.)	TUS (ksi)	TYS (ksi)	Elongation (% in 2 in. gage)
1	1.250 plate to forging	46.2	36.6	2.7
2	0.500 plate to plate	48.9	33.7	5.4
3	1.250 forging to forging	46.1	32.8	3.9
	1.250 plate to forging	46.2	36.6	2.7
4	1.375 plate to forging	48.6	35.8	4.0
5	1.375 plate to forging	48.6	35.8	4.0
	1.375 forging to forging	46.6	35.9	3.1

Note:

1. All welds were subjected to a post weld aging cycle of 350°F for 18 h.
2. TUS/TYS/El are average values from 15 to 24 tensile observations.

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CONCLUSIONS

The use of witness grooves in thick aluminum welds does not improve the detectability of lack of nugget tie-in in double-sided welds. The incorporation of these grooves increases joint preparation cost and increases the probability of getting porosity due to the difficulty involved in cleaning the grooved area. For this reason, this approach cannot be recommended.

The use of a joint configuration where root penetration is accomplished in a single pass provides adequate assurance, by visual inspection, that lack of penetration did not occur. This approach, combined with double-sided welding, provides for pass sequencing to balance shrinkage forces and eliminates distortion. The same benefits cannot be gained by welding from one side.

The implementation of the revised weld joint designs and well pass sequencing developed during this study on the SRB satisfied the inspectability requirements for fracture control. The reduced distortion possible with this improved process easily satisfies design requirements.

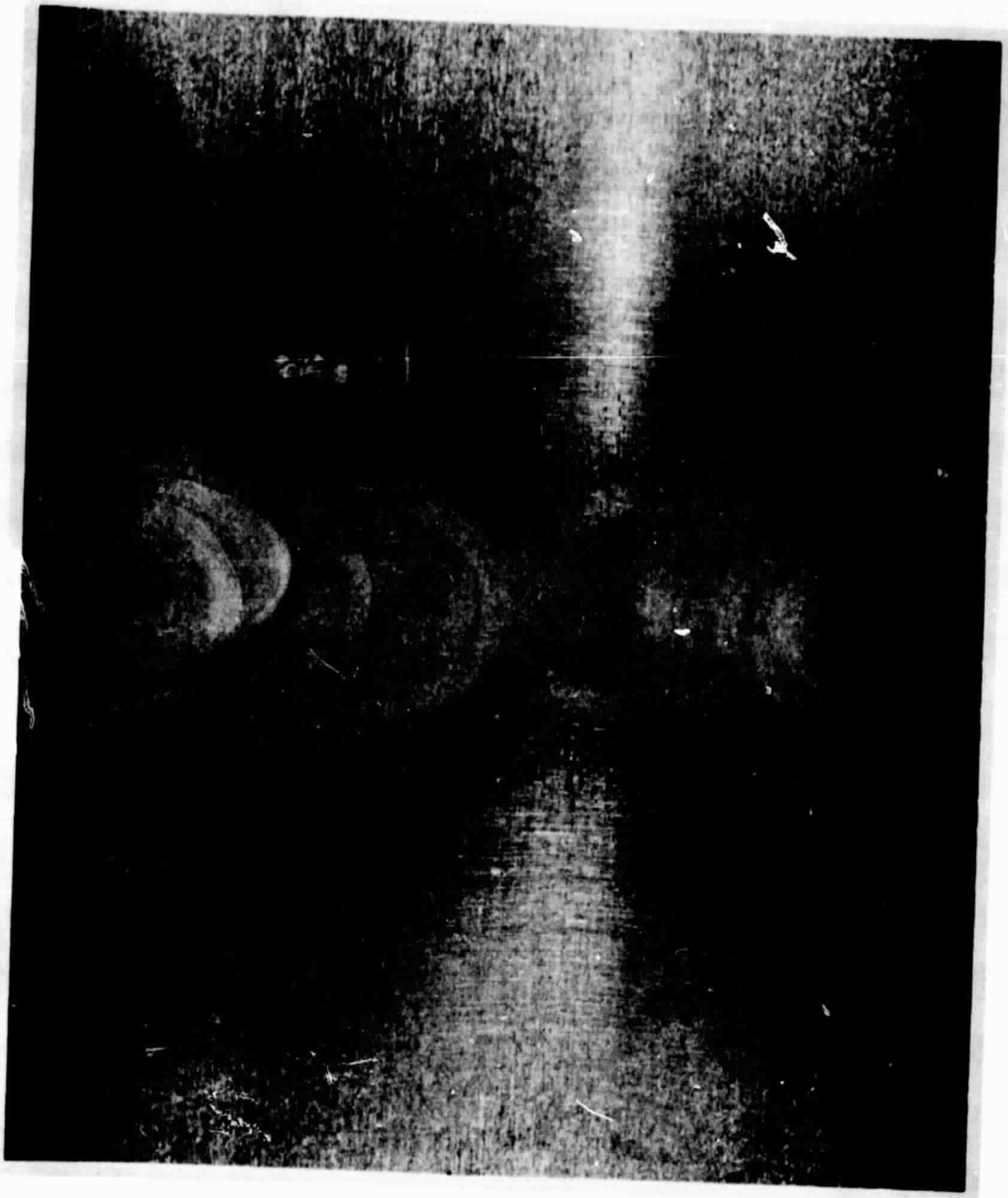

Figure 1. Lack of nugget tie-in.

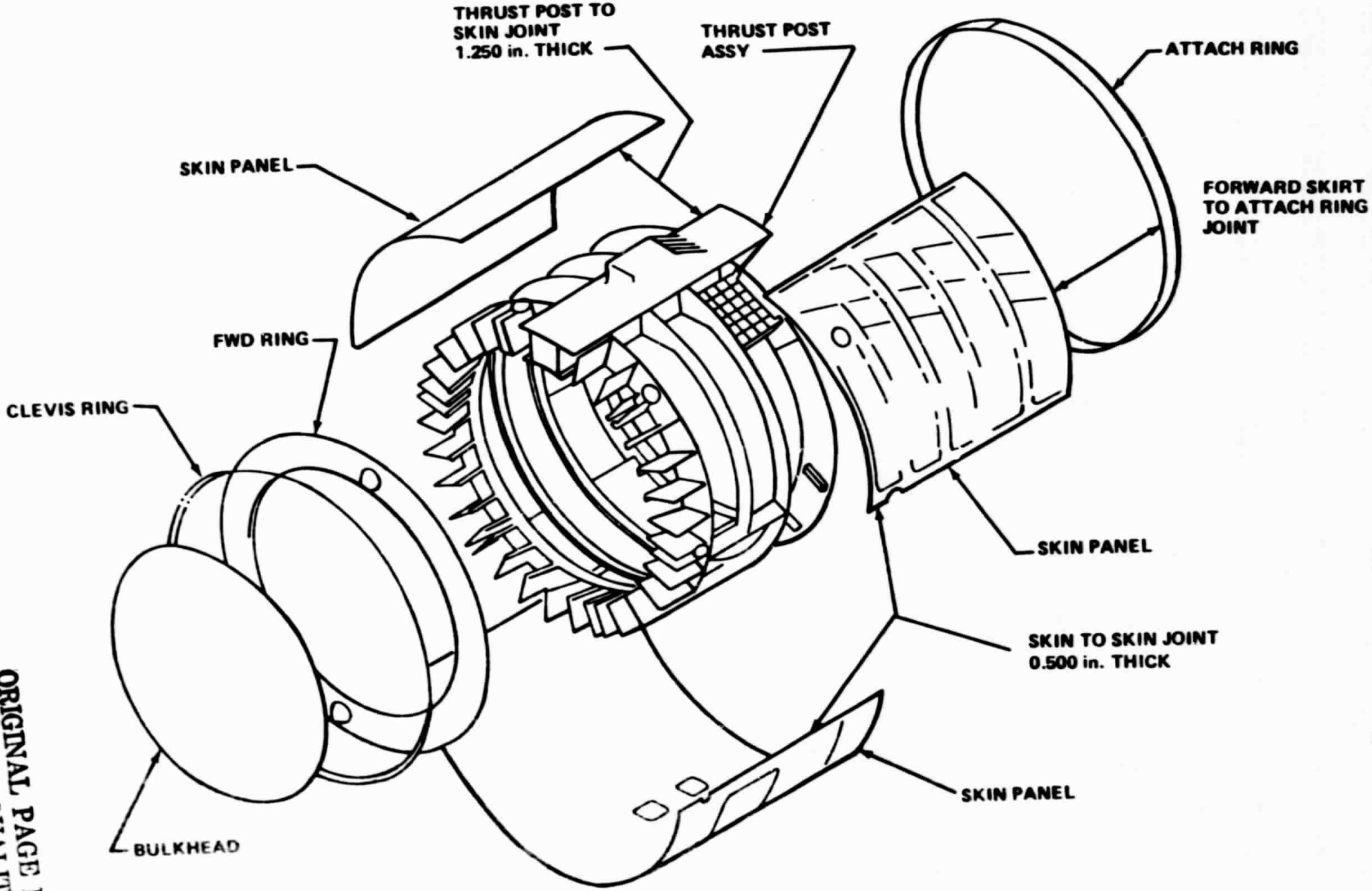

Figure 2. Forward skirt.

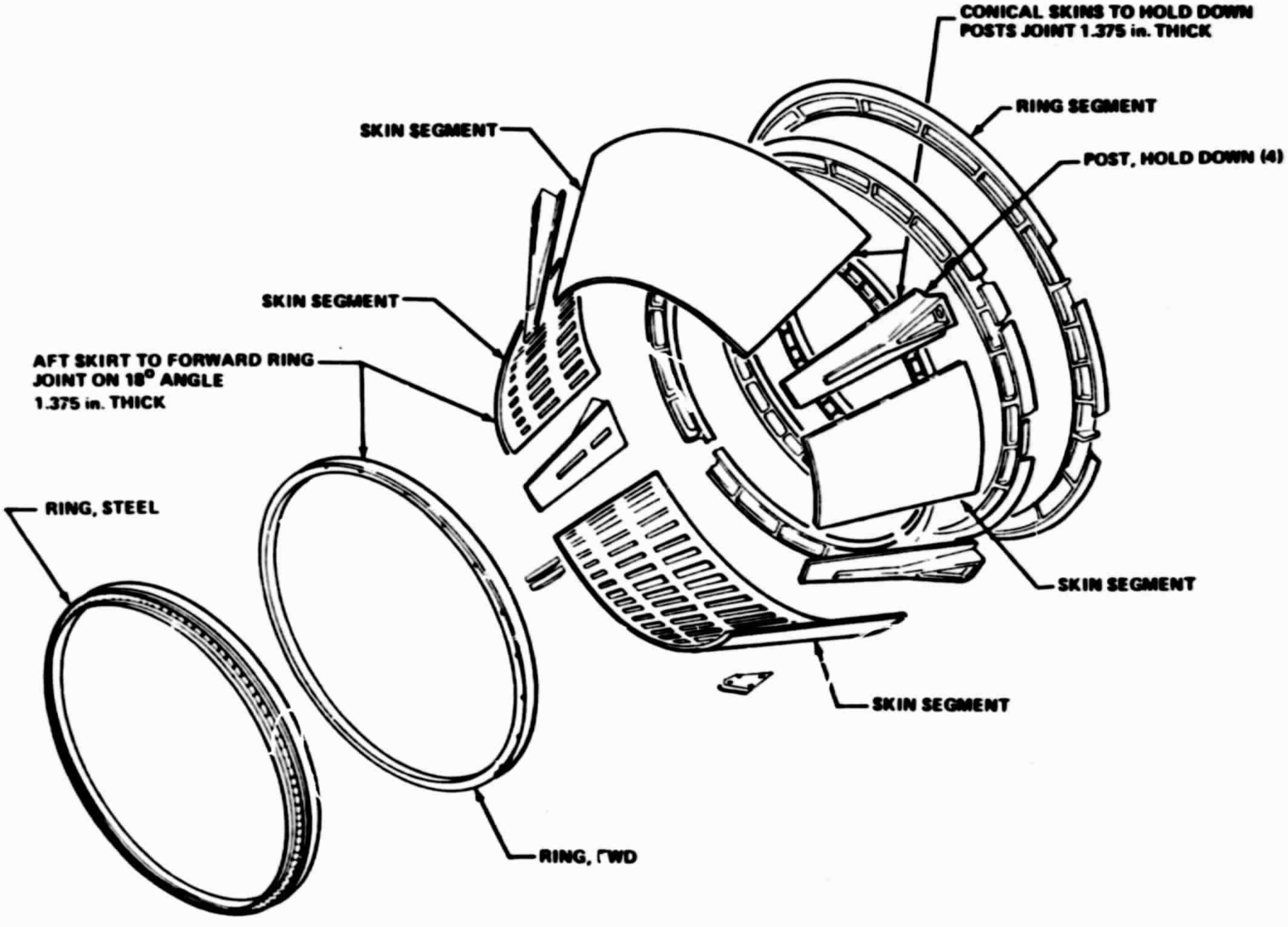

Figure 3. Aft skirt.

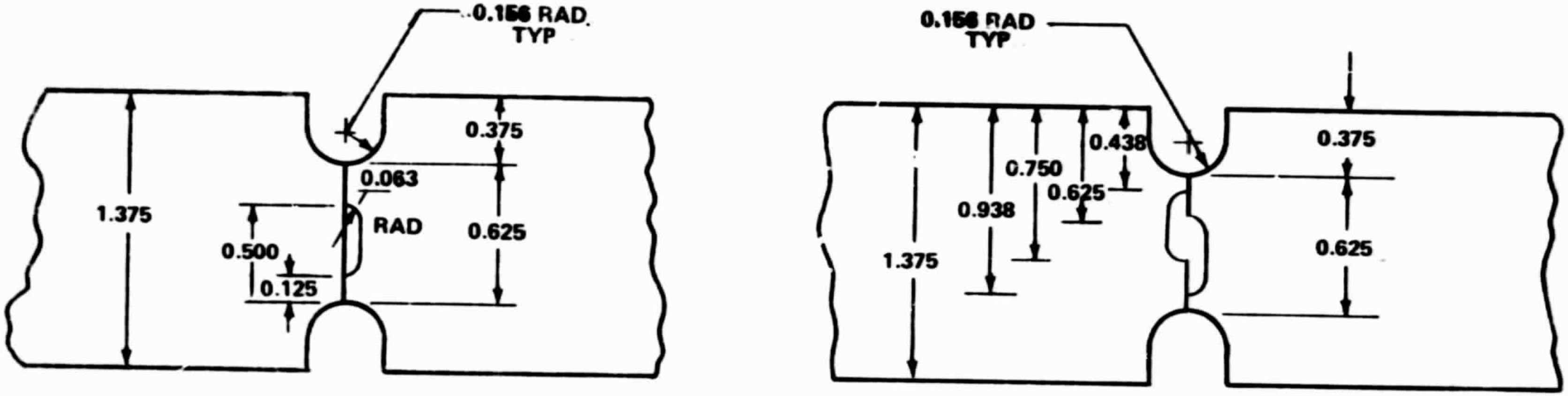

Figure 4. Witness groove.

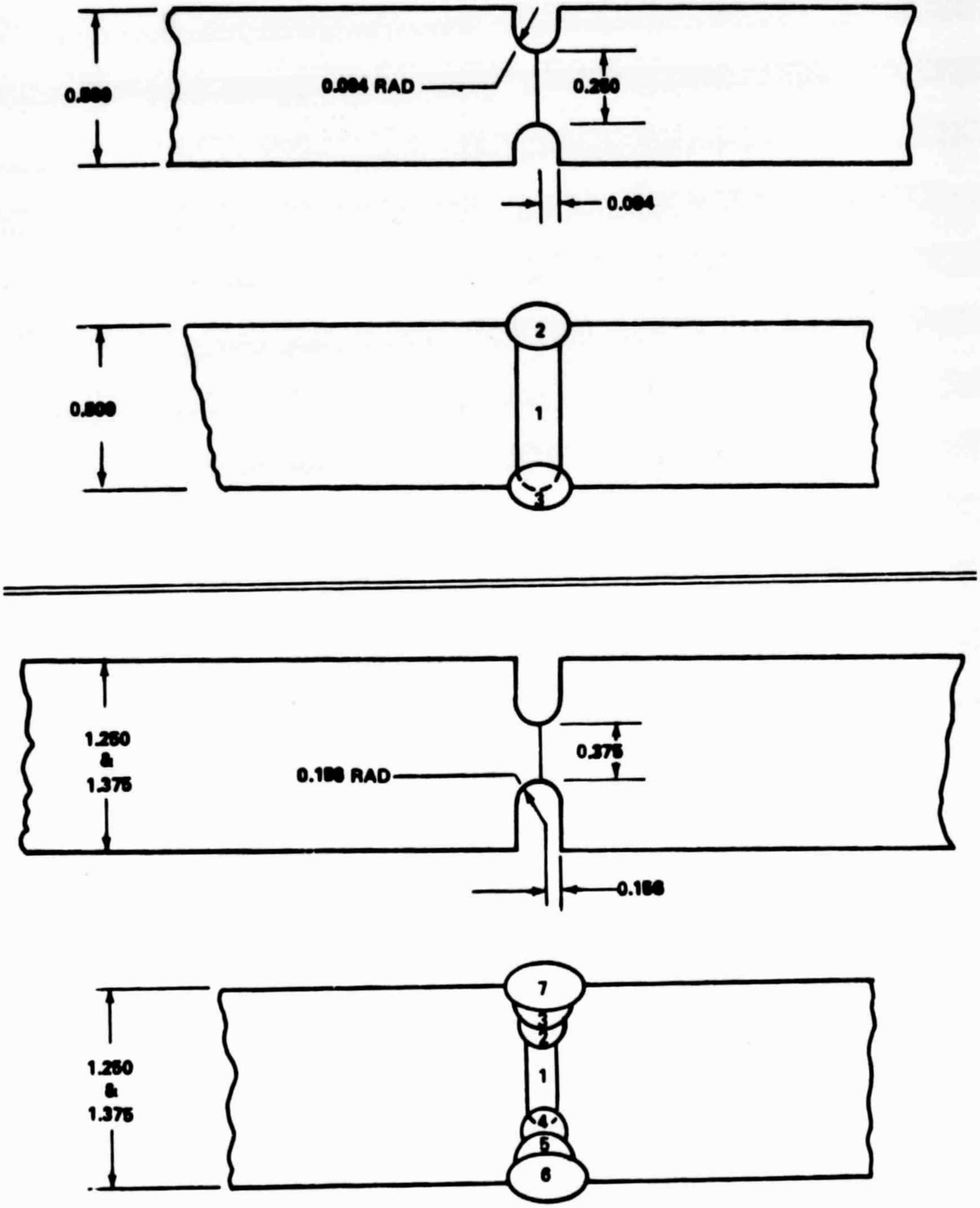

Figure 5. Joint detail and pass sequence.

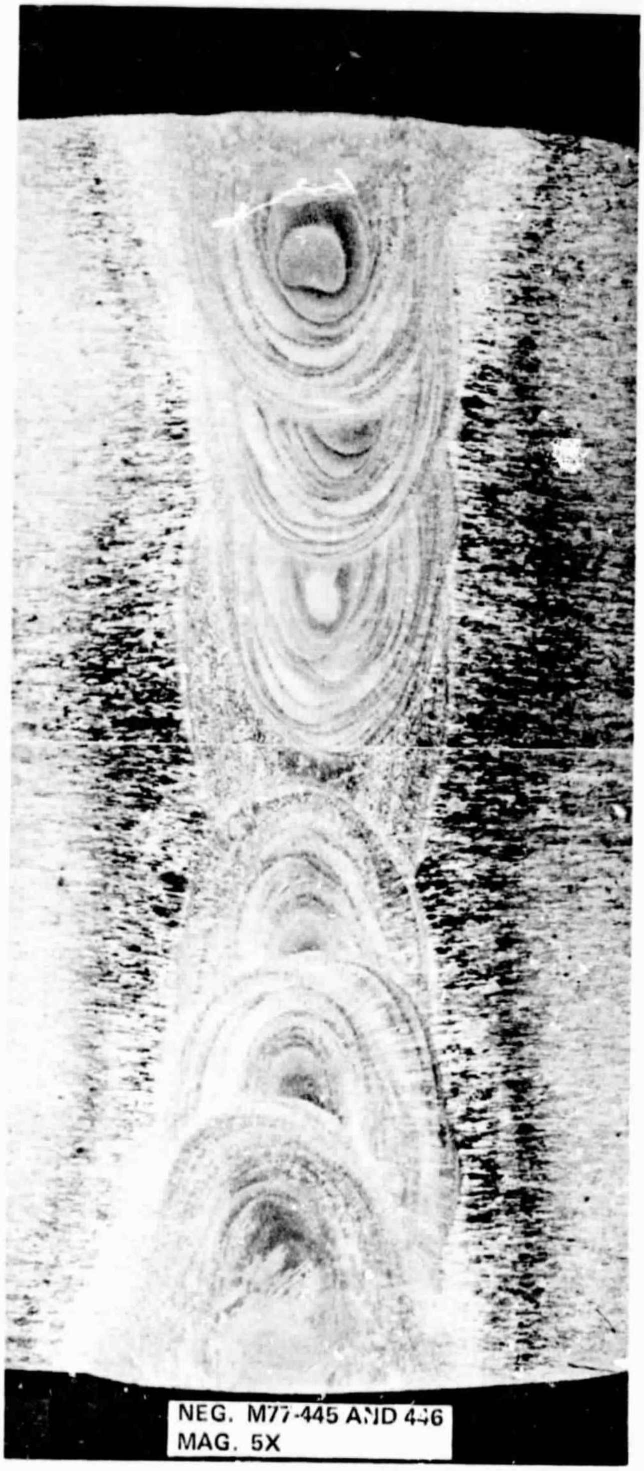

Figure 6. Micrograph of weld No. 7VP (1.250 in. plate).

Figure 7. Micrograph of weld No. 9VP (1.375 in. plate).

APPROVAL

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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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