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Welding Development W87 Baseline

G. K. Hicken, G. Gibbs, A. Newman

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Sandia National Laboratories

Albuquerque, New Mexico 87185 and Livermore, California 94550

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Welding Development W87 Baseline

G. Ken Hicken, Gordon Gibbs, and Annette Newman
Advanced Manufacturing Technology for Metals Processing
Sandia National Laboratories
Livermore, CA 94550

Abstract

This report covers the development activities used to qualify the Gas Tungsten Arc (GTA) girth weld and the resistance stem attachments on the W87 Base Line (W87BL). Design of experiments was used throughout the development activities.

The stems (two) are attached to the body using a resistance upset welding process. The stems are a 0.120" O D 316L stainless steel tube with a machined foot 0.275" diameter by 0.100" thick. These materials and joints have been used on several other programs with good results.

The girth weld is made using the gas tungsten arc cold wire feed process (GTAWCWF). The part is 2.04 inches in diameter with a wall thickness of 0.350 inches. The final diameter is 1.94" after machining

Welding schedules have been developed which produce welds with an acceptable microstructure and which exceed the pressure requirements for the component.

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Welding Development W87 Baseline

Summary

The development for this program was completed on schedule. The development was demonstrated by fabricating several units for metallurgical testing and six units for overpressure testing. The six burst units exceeded the design requirements.

Discussion

Scope and Purpose

Welding development by Department 8240, Advanced Manufacturing Technology for Metal Processing, was requested by Department 8414, Gas Transfer Engineering. We were asked to develop welding procedures and fabricate 30 units that were war reserve (WR) like and suitable for materials compatibility testing. Each unit has a (GTAW) girth weld and two resistance upset stem attachment welds.

Weld Experimentation Strategy

The objective in development is to meet the new weld requirements with the minimum amount of samples and time. This is accomplished by building on engineers' experience and retained data. Smartweld Advisor¹ contains a database which has weld schedules for many materials, joints, and welding processes. This was used to establish a starting point for the development. A weld schedule called W87 Acorn was used as the starting point for the GTAW parameter development. A prior program called Hogs Head² used stems with the same dimensions and material as those used on the Baseline. Figure 1 plots the results of resistance upset welds made using the same material and configuration as those used in this program.

One to three welds are made using the historical weld schedule to establish a target parameter which produces an acceptable weld. The target parameter is expanded through a designed experiment to demonstrate a range of robustness. The experiment used depends on the number of significant variables in the process and the expected interactions. Finally, once a mean parameter has been developed, a group of welds (ten) are made to show that acceptable welds can be made under any combination of parameters within the developed window of the weld schedule.

Figure 1. Class 1 and Class 2 Welds Made Joining 316L Stainless Steel to 304L Stainless Steel.

Forward Stem

Activity

The forward stem is attached to the forward body using the resistance upset welding process. The weld is made at a reduced atmospheric pressure to improve weld quality. The stem is attached at the counterbore on the flat machined surface on the side of the forward assembly. The reacting force is supplied by the base of the chamber through the fixture. The welding current passes through the part and fixture creating heat at the high resistance weld interface.

Weld Joint description

The stem base is 0.275" diameter by 0.100" thick at the shoulder, Figure 2 shows the stem. The forward body has a counterbore 0.262" diameter x 0.130" deep, Figure 3 shows the stem base weld sample.

Figure 2. 316 Stainless Steel Stem AY456036.

Figure 3. Forward Stem Base Weld Sample. A61395

Weld requirement

The interface between the 316L stainless steel stem and the 304L body is required to be discontinuous and meet the requirements of SB452908² with a weld interface quality of at least Class 2.

Equipment and tooling

Equipment

55kA AC resistance power supply with 10,000 psi cylinder pressure #S574126
Weld computer #S247992
Nicolet Pro 40 # S743486
Miyechi weld checker MM308A
C-Tek displacement gage
Hewlett Packard Multimeter 3478A

Tooling

Electrode # T 001A
Fixture 3 bar # T010A

Figure 4. Three Bar Welding Fixture #T010A and Electrode #T001A.

Weld Experimentation Strategy

Target Experiment

The target experiment consisted of making three welds at different percent heat on the controller. The welds are made on mock-up specimens made from bar stock using the component tooling. Table 1 lists the parameters used to make the welds. The welds are made inside a small vacuum chamber at a pressure of 100 microns using the tools shown in Figure 4. Our objective was to accomplish welds that fell within the range demonstrated by our earlier work see Table 1 that lists the target experiment parameters.

Design of Experiments

An L4 (2^2 factorial experiment)³ was conducted on weld specimens using the production fixtures. The current and force were varied to establish a wide range of machine setting that would produce the desired weld responses. Table 2 lists the machine settings used for this portion of the development.

Weld #	8	9	10
Weld Time Cycles	20	20	20
% Heat	70	72	74
Force (Lbs.)	1800	1800	1800

Table 1. Welding Parameters Used for the Forward Stem Target Experiment.

Weld #	11	12	13	14
Weld Time Cycles	20	20	20	20
% Heat	68	78	78	68
Force (Lbs.)	1600	1600	1800	1800

Table 2. Welding Parameters Used for the Forward Stem L4 Experiment.

Verification

The suitability of the weld schedule was demonstrated by welding actual units with the final weld schedule. These units were destructively evaluated by either cross sectioning or burst testing.

Results and Conclusions

The welds schedules shown in Table 1 and Table 2 list the welding controller settings used in the target and designed experiment welds. All welds had microstructures with a Class 2 or better quality. The actual welding current varied from 16.6 to 18.2 kamp as shown in Table 3.

Weld Identification	8	9	10	11	12	13	14	15
Weld Time Cycles	20	20	20	20	20	20	20	20
% Heat	70	72	74	68	78	78	68	78
Cyl Press (psi)	1800	1800	1800	1600	1600	1800	1800	1600
Time/Cycles	20	20	20	20	20	20	20	20
Full Force (Lbs.)	1650	1730	1780	1550	1620	1795	1798	1584
Peak Current, kA	17.1	17.2	17.8	16.7	18.2	17.8	16.7	16.6
Disp Cold, inches	.009	.011	.011	.008	.010	.008	.012	.018
Disp Hot, inches	.08	.081	.081	.080	.079	.08	.08	.092
Bond Length, inches	.092	.09	.09	.096	.093	.095	.085	
Bond Rating	I	II	II	I	I	I	II	
Unbound Distance, inches	.004	.004	.003	0	.011	.007	.004	

Table 3. Welding Parameters and Results of the Experimental Welds.

An actual part #15 was welded with schedule #12 with a resulting weld current of 16,600 amps. This is well below the 18200 amps values observed on the weld sample. The resulting weld microstructure was acceptable. The decrease in weld current is thought to be a result of a lower resistance in the weld fixture. The percent weld heat was increased to 83 percent to achieve the desired current of 18000 amps. We examined welds made at currents from 16,600 to 18,600 amps all the welds had acceptable microstructure. Figure 5 shows the range of results. There was an approximate difference of 1500 amps between the samples and the actual units. The welding system has a calibration tolerance of +/- 300 amps.

Figure 5. A Graphical Representation for Class 1 and 2 Welds of the Weld Parameters Listed in Table 3.

Accomplishments

A weld schedule was developed and demonstrated that produced acceptable product. Figure 6 shows the cross section of a weld made on a actual forward stem component using the parameters in Table 4.

Cycles	Force lb.	Percent Heat
20	1600	83

Table 4. Production Weld Controller Settings for the Forward Stem.

Figure 6. Cross Section of Forward Stem Attachment Weld on the Forward Cap Using Settings Listed in Table 4.

AFT Stem.

Activity

The aft stem is attached to the aft cap at the pole. A machined boss receives the stem. The boss is threaded into a fixture which provides both location and a reaction to the pressure applied by the stem.

Experimental Procedure

Development welds are made on mock-up specimens made from bar stock using the actual production tooling. The welds are made inside a small vacuum chamber at a pressure of 100 torr. Our objective was to accomplish welds that fell within the range demonstrated by our earlier work, see Figure 1 and Figure 5.

Weld Joint Description

The stem base is a .275 diameter by 0.100" thick at the shoulder the same as for the forward stem shown in Figure 2. The aft cap has a counterbore of 0.262" diameter x 0.130" deep. Figure 7 shows the stem base weld sample. The weld sample or cap is threaded into the adapter T007A which is assembled into the fixture T009A.

Figure 7. Aft Stem Base Weld Sample.

Weld Requirement

As with the forward stem weld, the interface between the 316L stainless steel stem and the 304L body is required to be discontinuous and meet the requirements of SB452908 with a weld interface quality of at least Class 2.

Equipment and Tooling

Equipment:

- 55kA AC resistance power supply with 10ksi cylinder pressure #S574126
- Weld computer #S247992
- Nicolet Pro 40 # S743486
- Miyechi weld checker MM308A
- C-Tek displacement gage
- Hewlett Packard Multimeter 3478A

Tooling:

- Electrode # T 001A
- Fixture 4 column copper #T009A
- Thread Adapter #T007A, & #T007B
- Adapter base #T008A, & #T008B

Figure 8. Resistance Upset Vacuum Chamber and Aft Stem Welding Fixture #T009A.

Target experiment

Prior welding experience has shown that stem attachment weld of the configuration used on the W87BL produce acceptable weld microstructures. These welds have been made with a wide range of parameters as shown in Figure 1 and Figure 5. We targeted for a welding current of 18000 amps with a force of 1600 psi, the same as the forward stem. Our experiments were directed at changing the percent heat to compensating for the resistance changes between the samples and the parts.

Weld # Identification	2/2	3/3	4/4	11/1
Weld Time Cycles	20	20	20	20
% Heat	65	82	82	65
Force (Lbs.)	1500	1500	1700	1700

Table 5. Weld Schedule Used to Weld Aft Stem L4 Experiment.

Design of Experiments

An L4 (2^2 factorial experiment) was used to establish the weld settings for current (percent heat) and force. Table 5 lists the parameters used in this experiment on weld samples. The welding current was varied by 17 percent and the force by 13 percent.

Validation

The welding fixture thread adapter T007A and adapter T008A would not work for the full size parts. The tooling was modified and used as issue B. A group of 4 caps were welded with the modified tooling and only the percent heat changed from 70 to 76 percent. The validation welds made using actual aft caps on the modified tooling resulted in acceptable welds.

Results and Conclusions

The results of the welding experiment showed excellent welds could be made on samples with settings that produced weld heat from 16,300 to 19,600 amps. The higher current welds resulted in some surface melting at one or both interfaces. The stems welded to the caps after tooling modification resulted in acceptable welds at currents near our target of 18000. The results of these welds are shown in Table 6. The actual range of current was varied over 2000 amps which is 7 times the calibration limit of 300 amps.

Weld #	2/2	3/3	4/4	11/1	5/5	6/6	7/7	8/8
Weld Time Cycles	20	20	20	20	20	20	20	20
% Heat	65	82	82	65	76	70	72	72
Cyl Press (psi)	1500	1500	1700	1700	1600	1600	1600	1600
Full Force (Lbs.)	1460	1503	1713	1709	1597	1589	1596	1574
Peak Current Ka	18.63	16.32	19.32	19.62	16.52	19.82	17.42	17.8
Disp. Cold, mils	.007	.012	.013	.012	.009	.013	.013	.012
Disp Hot, mils	.075	.083	.082	.079	.079	.079	.078	.081

Table 6. Stem Attachments Weld Schedule and Results for Samples (2/2, 3/3, 4/4, 11/1) and Parts (5/5, 6/6, 7/7, 8/8).

Figure. 9. Aft Stem Attachment Weld Unit #1297. Weld Made With Production Settings Listed in Table 7. Results 20 cycles, 1605 lbs force, and 18,320A.

Cycles	Force lb.	Percent Heat
20	1600	74%

Table 7. Production Welding Parameters for the Aft Stem.

Weld Acceptance

The stem attachment welds are accepted using process control. The instruments are calibrated to a tolerance of .0005" displacement, 40 lbs force, and 4% for current. The acceptance limits are listed below in Table 8.

Response	Minimum	Mean	Maximum
Time/Cycles	20	20	21
Force (Lbs.)	1500	1600	1700
Current amps	17000	18000	19000
Hot Displacement, mils	.070	.080	.090
Cold Displacement, mils	.007	.013	.016

Table 8. Resistance Weld Acceptance Requirements.

Accomplishments

The suitability of the weld development was demonstrated by welding actual units with the final weld schedules see Table 9. These units were destructively evaluated by either cross sectioning or burst testing. All welds were acceptable. The percent heat settings are different because of the resistance differences in the weld fixtures. Figure 9 is a typical weld cross section.

Stem Location	Cycles	Force	Percent heat
Forward	20	1600	83
Aft	20	1600	74

Table 9. Stem Attachment Weld Schedules.

Girth Weld

Activity

The closure weld on the W87 BL joins the forward and aft subassemblies using the (GTAWCWF) process. GTA welding has many variables that can effect the out come of the weld. These are voltage, amperage, amperage pulse rate and levels, filler wire feed speed, part travel speed, part temperature, tungsten electrode geometry, arc movement and position, and shielding gas composition and flow rate. Prior welding experience is used to minimize the number of weld variables examined during the welding development. Our requirements were to develop WR quality welds and fabricate 30 units for storage and testing. The program Smartweld Advisor's database was used to determine possible starting weld parameters. A recommended starting parameter was used to weld a sample. Two sets of designed experiments were conducted to fine tune the weld schedule and determine optimum root and fill pass parameters. The resulting weld schedule was used to weld 25 storage units and five confirmation parts which were destructively tested.

Material

Bar stock was also used to fabricate the weld samples used on the first two sets of experiments. The chemistry is not overly important since 308L controlled sulfur filler metal which improves weld penetration and reduces cracking is used on this weld. The confirmation experiment parts were machined from the same forgings as was the actual hardware. The forgings were made from stock purchased under specification P-12053⁴ and forged to meet the WR requirements. Table 10 lists the chemistry of the forgings.

The Smartweld advisor suggest that this material is only marginally weldable with a low Cr/Ni equivalent (1.51) and low ferrite (1.71 FN). The controlled sulfur filler wire will resolve any penetration or cracking concerns for the girth fusion weld.

	C	Cr	Mn	Mo	Ni	Ph	Si	S	Ti	N
P12053 Forward & Aft Cap Composiiton	0.021	18.7	1.69	0.079	11.5	0.013	0.49	0.0021	0.05	0.038

Table 10. Forging Chemistry

Components

The component piece parts can be characterized as closed end cylinders. They are called forward and aft caps. The aft cap is symmetric while the forward cap has a large mass increase for about two opposing quarters of the circumference. The initial weld development was conducted on weld samples machined from 304 L stainless steel bar stock. The weld samples were symmetric with a large reinforcing shoulder on the forward sample and a smaller shoulder on the aft component. Figure 10 shows a drawing of the weld samples. The actual parts are machined from forgings.

Weld Joint Description

The weld joint is a modified U groove butt joint. Figure 11 shows the weld joint detail used on the bar stock samples. Copper chill rings are used to control heat build up and aid in the alignment of the parts. The chill ring is butted against the weld reinforcement shoulder on the forward cap. The large width of the shoulder on the aft cap coupled with the fact that it is non-continuous allowed little heat sinking to the part using the customary copper cylinders.

Figure. 10. Welding Samples (1) Represents the Forward Cap, (2) is the Aft Cap

Figure 11. Girth Weld Joint Detail.

Weld Requirement

The girth weld requires complete joint penetration with an underbead that is detectable by X-ray inspection. There can be no cracks in the weld or pores and / or inclusions larger than 0.040 inches in diameter. No more than 3 radiographically detectable voids are allowed in any 1 inch of circumferential length. The sum of all void diameters within any 1/8 inch circle cannot exceed 0.040" total cross section. The weld shrinkage must be repeatable.

Equipment and Tooling

The welding is conducted in a glove box filled with argon. Welding is performed with an oxygen content less than 50 PPM, typically less than 5 PPM.

Equipment

- Amptrack Micro II controller
 - TRX-500 power supply
 - X, Y & Z torch positioner
 - Arc voltage controller
 - Airco M50 torch
 - Wire feeder
 - Wire feed positioner
 - Water cooled three bar fixture
 - Arc oscillator probe

Tooling

The welding fixture includes rotatable water cooled copper cylinders. Copper adaptors are slipped over the part to be welded making contact at the reinforcing shoulder. The adaptor is then inserted into the water cooled fixture. This provides part alignment and heat removal. Care is required to assure copper is not smeared on the joint or area of the heat affected zone which could lead to microcracking.

Experimental Procedure

Target experiment

The target experiment philosophy was to make an acceptable weld with as little expense as possible. The development would then continue through designed experiments to establish a robust weld schedule. The target weld was made using the recommended weld schedule listed in Table 11.

WELD PARAMETER	ROOT PASS	1ST FILL PASS	2ND FILL PASS	COVER PASS
Pulse Time High	.75 sec.	NA	NA	NA
Pulse Time Low	.25 sec	NA	NA	NA
Current High	140 amps	120 amps	130 amps	130 amps
Current Low	75 amps	NA	NA	NA
Rotation IPM	2.7 IPM	2.7 IPM	2.7 IPM	2.7 IPM
Arc Voltage, volts	7.8	8	8	8
Wire Feed IPM	30 IPM	30 IPM	30 IPM	30 IPM
Oscillator Amplitude Settings	NA	45	50	50
Oscillator Dwell Settings	NA	.2 sec	.2 sec	.2 sec
Shielding Gas Flow Rate cfh	20 cfh	20 cfh	20 cfh	20 cfh

Table 11. Starting Welding Parameters.

Design of Experiments

Root Weld

A two-factor two-level (2^2) designed experiment was used varying wire feed speed (22.5 and 30 ipm) and part travel speed (3 and 4 ipm). These were chosen because they have a direct effect on underbead/drop-through and the weld shrinkage which were the primary measured responses. This test matrix is shown in Table 12. The weld samples are shown in Figure 8.

Sample # ID	87G5	87G6	87G7	87G8
Pulse Time High	.75 sec.	.75 sec.	.75 sec.	.75 sec.
Pulse Time Low	.25 sec.	.25 sec.	.25 sec.	.25 sec.
Current High	140 amps	140 amps	140 amps	140 amps
Current Low	75 amps	75 amps	75 amps	75 amps
Rotation IPM	3	4	4	3
Arc Voltage	7.8	7.8	7.8	7.8
Wire Feed IPM	22.5	30	22.5	30
Shielding Gas Flow Rate cfh	20 scfh	20 scfh	20 scfh	20 scfh

Table 12. Experimental Variables Used in the L4 Root Weld Test Matrix.

Fill Pass Experiments

Once the root pass parameters were determined they were used on the fill pass L4 (2^2 factorial experiment) designed experiment. The intent was to define the fill pass parameters without having the influence of heat input variations caused by changes in the root pass parameters. Our main concern was wetting of the weld joint side walls and the proper filling of the groove without melting the shoulders. The welding parameters varied in the experiment were weld current and part travel speed. The current was varied +10 and +20 amps for the first and second fill and 0 and +10 amps for the third fill pass. The speed was 3 or 3.5 IPM for all passes. All other variables were constant per weld schedule Table 13.

Sample No.	Pass 1 weld current change	Pass 2 weld current change	Pass 3 weld current change	Part travel speed all passes
87G9	(-) 130 amps	(-) 140 amps	(-) 130 amps	(-) 3 IPM
87G10	(+) 140 amps	(+) 150 amps	(+) 140 amps	(-) 3 IPM
87G11	(+) 140 amps	(+) 150 amps	(+) 140 amps	(+) 3.5 IPM
87G12	(-) 130 amps	(-) 140 amps	(-) 130 amps	(+) 3.5 IPM

Table 13. Fill Pass Experimental Matrix.

Validation

The validation experiments were made from the same forgings as those to be used on the 30 assemblies. The samples were machined to have the same mass characteristics in the area of the weld joint.

Results and Conclusions

Target

The weld schedule recommended by the Smart weld Advisor (see Table 11) was used to make a weld which produced a radiographically clean weld. This weld is shown in Figure.12.

Figure. 12. Weld Produced Using the Weld Schedule Listed in Table 11 and Recommended by Smartweld Advisor. Weld #87G4.

The weld shoulder width on the joint of the weld sample was too narrow and melted during the last pass. The width of the shoulder was increased to 0.170" and an alignment feature was added as shown in Figure.13 on all samples and ports.

Figure 13. Weld Joint Detail with Alignment Feature.

Designed Experiments

Root Pass

The results of this work showed that our process was robust enough to manage the entire spectrum of changes. It also showed that the high wire speed gave a more irregular appearance and that both the high and low travel speed gave good drop through, but the high travel speed resulted in less heat input and shrinkage. The skewed appearance was not pursued.

These led us to use the low wire feed rate and the high travel speed. Figure 14 shows the cross sections of the root weld samples. The weld shrinkage varied from a low of 0.025 to a high of 0.030. Root pass weld number 87BLG7 was selected to be used for the fill pass experiments.

W89BL G5

W87 BL G6

W87BL G7

W87BL G8

Figure 14. Root Pass Weld Cross Section. Weld Numbers 87BL G5 through G8_.

Fill Passes

Our first test produced a nice looking weld; it was flush to slightly concave. This was one of our slower travel speed welds and a faster travel speeds would produce even more concavity. At this point it was decided to increase the filler wire feed speed on all fill passes to 33 IPM. This would have little effect on the procedure other than increasing the fill. Our completed results showed that the wetting of the weld puddle was not a problem through the variations in our matrix. Faster part travel speed produced acceptable welds, but with a somewhat concave surface which is removed by machining. The final determination was to use the higher weld current and slower part travel speed. The complete final procedure is shown in Table 14.

Confirmation

Using the developed procedure we welded the first of two mockups units which included all of the shape and mass changes. Where the mass was greater the molten weld puddle would wander to the opposite side as expected so we favored the more massive side with the welding torch, but as soon as the torch passed the mass, the edge would melt. It was determined that this was unacceptable and a chill fixture was designed. A copper yoke was used on the non-symmetrical forward part. The yoke compensated for the reduced mass on the part and resulted in uniform part melting. Figure 15 show the copper fixture adapters. The tool number is TA61461.

Figure. 15. Copper Fixture Adapters, (Top) Yoke for the Forward Cap, (Bottom) Aft Cap Holder.

Sectioning the mockups showed less droptrough than observed on the bar stock welds; however, it was still acceptable. We believe this to be an effect of slight material chemistry differences between the samples made of bar stock and forging. Throughout this development and on real parts shrinkage was monitored and determined to be consistently between 0.064” and 0.070”.

WELD PARAMETER	ROOT PASS	1ST FILL PASS	2ND FILL PASS	COVER PASS
Pulse Time High	.75 sec.	NA	NA	NA
Pulse Time Low	.25 sec	NA	NA	NA
Current High	140 amps	140 amps	150 amps	140 amps
Current Low	75 amps	NA	NA	NA
Rotation IPM	4 IPM (.62 RPM)	3 IPM (.46 RPM)	3 IPM	2.7 IPM
Arc Voltage (volts)	7.8	8	8	8
Wire Feed IPM	22.5 IPM	33 IPM	33 IPM	33 IPM
Oscillator Amplitude setting	NA	45	50	50
Oscillator Dwell setting	NA	.2 sec	.2 sec	.2 sec
Shielding Gas Flow Rate cfh	20 cfh Argon	20 cfh Argon	20 cfh Argon	20 cfh Argon

Table 14. Final Weld Schedule.

Conclusions and Accomplishments

The amount of weld drop through was less on the actual units than it was on the bar stock samples. Acceptable welds schedule were developed for the GTAW girth weld on the W87 Baseline assembly. Figure 16. shows the girth weld on an actual unit. The stem and girth welds exceeded the design requirements for the W 87 baseline component.

Figure 16. Typical Cross Section of Final Developed Weld # 12911.

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- 1 (0320A) Allied-Signal Aerospace Co.
Kansas City Division
Attn: LaRoux Gillespie
P.O. Box 419159
Kansas City, MO 64141-6159
- 2 (0320A) Allied-Signal Aerospace Co.
Kansas City Division
Attn: Bruce Alquist
P.O. Box 419159
Kansas City, MO 64141-6159
- 1 (0320A) Allied-Signal Aerospace Co.
Kansas City Division
Attn: B. Keef
P.O. Box 419159
Kansas City, MO 64141-6159
- 1 (0320A) Allied-Signal Aerospace Co.
Kansas City Division
Attn: B. D. Fricke
P.O. Box 419159
Kansas City, MO 64141-6159
- 1 (0320A) Allied-Signal Aerospace Co.
Kansas City Division
Attn: G. P. Miller
P.O. Box 419159
Kansas City, MO 64141-6159

1	(0320A)	Allied-Signal Aerospace Co. Kansas City Division Attn: J. Samayoa P.O. Box 419159 Kansas City, MO 64141-6159
1	(0320A)	Allied-Signal Aerospace Co. Kansas City Division Attn: J. Straub P.O. Box 419159 Kansas City, MO 64141-6159
1	(0470A)	University of California Lawrence Livermore National Laboratory Attn: Jack Robbins, L125 P.O. Box 808 Livermore, CA 94550
1	(0650A)	J.Y.Chiu, 12336, MS0637
1	9001	T. O. Hunter, 8000 Attn: M.E. John, 8100 A. West, 8200 W. J. McLean, 8300 D. L. Crawford, 8900
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