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Integration and Qualification of the HH500 Hand Operated Electromagnetic Riveting System on the 747 Section 11

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ABSTRACT

Hand installation of 3/8”, *5/16”* and 1/4” diameter fatigue head style fasteners is required on some areas of 747 section 11 (center wing). The 3/8” diameter fasteners can require between 45-60 seconds to upset using conventional pneumatic riveting guns. As part of Boeing’s continuing effort to reduce cycle time and improve the factory working environment, a Boeing Quality Circle Team proposed using LVER technology as an alternative to conventional pneumatic percussion riveting hammers The hand operated HH500 system was developed in response to this request. The HH500 single shot upset reduces installation time as well as the noise levels and vibration experienced by the operators. The design of this system and the integration onto the factory floor are presented.

The LVER forming rate is significantly higher than that of conventional pneumatic and hydraulic processes. Verification that this type of fastener formation maintains the integrity of the fastened joint is therefore required prior to introduction of this process into the production environment. Each new application typically requires modification of the riveting die geometry and/or determination of the system parameters to meet the BAG specifications. Preliminary fatigue studies indicated that the HH500 installed fasteners exhibited fatigue lives comparable to conventionally installed fasteners. Statistical design of experiment, D.O.E., studies were then used to further optimize the system parameters. Results from these studies are presented.
To date the HH500 system has been qualified to install approximately 1000 fasteners on the 747 Section 11 and has been in production since March 1992. Work continues on extending the amount of qualified fasteners and on elimination of the coldworking process currently required for all hand installed fasteners on these panels. An update on this work and on experience of using the HH500 in production are discussed.

INTRODUCTION

Over the past few years, Low Voltage Electromagnetic Riveting Technology has gained significant acceptance in the aerospace industry. Four airframe manufacturers are currently using this technology in production in some form. As part of Boeing’s continuing effort to reduce cycle time and improve the factory working environment, a Boeing Quality Circle Team proposed using LVER technology as an alternative to conventional pneumatic percussion riveting hammers on the 747 centerwing assemblies. The hand operated HH500 system was developed in response to this request. The HH500 system has helped to lessen factory noise levels and has decrease the vibration levels experienced by the operator. These ergonomic improvements have led to an increase in worker productivity in the centerwing area. The design of this system and its integration onto the factory floor are discussed below.

The forming rate of the LVER process is different from conventional pneumatic and hydraulic installation methods. Qualification of LVER fastened joints therefore typically requires non conventional approaches to meet process requirements. Optimal system forming parameters, such as voltage levels and forming die geometries, need to be identified. A procedure using statistical design of experiment methods, DOE, has been developed to simplify the optimization process. A case study is presented to illustrate this procedure.

The HH500 system has currently been qualified to install approximately 1000 fasteners on the 747 Section 11 and has been in production since March 1992. Work continues on extending the amount of qualified fasteners and on elimination of coldworking process currently required for all hand installed fasteners on these panels.

APPLICATION

The lower section of the Boeing 747 center wing consists of five panels. The upper section consists of three panels. Plate 1 shows typically panels in the Floor Assembly Station (FAS). Wing skin to stringer assembly is performed at the Boeing plant in Wichita, Kansas. The panels are then shipped for final assembly to the Boeing plant in Everett, Washington. The center wing lower skins are machined from 2324-T39 aluminum. The upper skins are machined from 71 50-T651 aluminum. Lower stringers are machined from 2224-T351 1 aluminum extrusions and the upper stringers are machined from 71 50-T651 1 aluminum extrusions. Stringers are fastened to the skins using 3/8” and *5116”* 2024 in the W-condition **(Nice** box”) and 1/4” 7050-173 fatigue head (FH) rivets. A schematic of the FH rivet is shown in Figure 1. FH rivets are installed in countersunk holes. Hand installation is required for all rivets located on uneven and tapered areas, where the autoriveters are unable to install fasteners.

The 747 center wing is a fatigue rated structure. Pneumatic rivet installation alone is unable to consistently provide the hole expansions necessary to meet the minimum fatigue life requirements. The holes are therefore cold worked prior to rivet installation to insure adequate compression levels are achieved. Coldworking reduces the minimum interference requirements, while maintaining the integrity of the joint. Coldworking however adds an additional step to the assembly process.

Pneumatic hand installation of these large fasteners requires between 45 to 60 seconds with a 9X riveting gun and approximately 15 lb bucking bar. A great deal of stamina is required to perform this operation. This leads to premature worker fatigue and a subsequent drop in productivity. The noise levels generated by the repeated impacts of the pneumatic hammers are amplified further by the panels themselves. The high decibel levels created in the surrounding shop have a detrimental effect on the general morale of the shop floor personnel.

These issues prompted a shop floor request from a Boeing Quality Circle Group, the 147 Ear Jammers”, for an alternative installation method. At the project initiation, LVER technology had recently been qualified for production on the 767 automatic spar assembly tool. Boeing engineers felt that LVER offered the potential to improve the operational ergonomics and reduce the factory noise levels, while at the same time reduce the installation time for these fasteners. Preliminary studies also indicated that LVER installed fasteners could meet the required expansion levels without coldworking. One of the ultimate goals for this system was therefore to be able to eliminate the coidworking requirement and thereby, reduce the panel assembly time. This initiative lead to the development of the HH500, a handheld LVER system.

HH500 DEVELOPMENT

The HH500 is a one shot hand operated low voltage electromagnetic riveter. LVER technology is based on capacitor discharge. Two actuators are typically employed on either side of the rivet. Energy stored in capacitor banks is discharged through pancake coils In the opposing actuators. An intense magnetic pressure between the coils and an adjacent copper plate develops. The copper plates are attached to steel shafts which transfer the force to the rivet. The force output of the HH500 is in the form of a narrow high intensity impulse, which results in only a small amount of recoil transferred to the operator. Proper sizing of the actuator mass further reduces the recoil force in its inertia. The HH500 actuators weight approximately 180 lbs. and can be comfortably operated at force levels exceeding 30,000 lbs.

The HH500 has been ergonomically designed for operator comfort. The handle is angled to match the natural position of the operator's wrist. LVER impulse forming reduces the installation time from 45-60 seconds to under one second. The vibration and noise levels experienced by the operator are corresponding reduced. Both of these factors reduce the wear and tear on the riveters and help to create a more pleasant working environment. Further, the electronic nature of the HH500 provides a highly controllable means of fastener installation. With automatic voltage compensation for the change in coil temperature, the HH500 force pulse has been shown to be repeatable within 1.0%. (1, 2)Two additional features were incorporated into the HH500 system which have received excellent feedback from shop floor and manufacturing personnel.

1) A preset switch allows the manufacturing engineer to present the LVER system control parameters prior to releasing the system control to shop floor personnel. The system parameter for each rivet type are assigned a code or a switch position. The operator is then only required to position one dial to the appropriately labeled position. This feature simplifies the system's operation. The ultimate control of the system is therefore retained by qualified personnel.

2) A sensor system termed "smart gun" is used to insure both operators are on the same fastener prior to allowing the units to fire. In hand riveting of large panels, there has been a concern about potential damage if opposing handheld EMRs are pushed up against two adjacent rivets and discharged. The smart gun system address this concern.

In the conventional EMR system both EMR guns fire at the instant both triggers, one on each actuator, are pulled. A small "smart" capacitor bank, 5% of the main bank, discharges through one of the actuators. A small force pulse results which takes about 0.5 millisecond to travel from the transmitting EMR coil, down the drive shaft, through the rivet and down the opposing EMR drive shaft to be resolved in the second EMR coil. A thin film piezoelectric force transducer is positioned behind the second coil. If the force signal transmitted to this load cell exceeds a settable threshold value in an adjustable time period the main EMR banks are allowed to discharge and the rivet is formed. The adjustable period reflects the speed of sound and the driver lengths for the particular EMR gun. The small smart discharge is so short that it is undetectable by the operator if the main banks fire. If the two actuators are not on the same fastener, the signal picked up by the piezo film will not reach the threshold value and the main banks will not fire. In this case the operators will notice a small tap, which indicates to them that they are positioned on adjacent rivets.

In the current practice, the smart gun transmitter is selected to be on the tail side of the fastener. This choice is made so that the smart gun pulse is not transmitted out to the wing panel rather than along the rivet to the opposing gun. (4)

POSITIONING SYSTEM

A permanent floor assembly station (FAS) was constructed for the HH500 system integration. The FAS consists of three bays each large enough to hold one panel. The panels are held vertically in these bays by removable clamps with the stringers running horizontal. A rubber cushion is attached to the base of the FAS and the panels are placed on this cushion using an overhead crane. The unloaded FAS is shown in Plate 2. Two scissors lift platforms travel on inverted V-rails on either side of the panels. (Plates 2) This provides two axes of motion, horizontal and vertical, such that the entire FAS envelope can be serviced. Sixty feet of horizontal and twelve feet of vertical travel is provided. This arrangement maximizes the use of the HH500 system. LVER riveting is performed either before or after the panels have been through the autoriveter depending upon the machine scheduling. The platform position is controlled from a four position thumb switch conveniently located in the HH500 handle. This allows the operator to position the actuator without disrupting the installation flow.

The HH500 actuators are cable suspended from jib booms mounted on each platform. The actuators can therefore be positioned on the rivet or rotated completely out of the work area. Operation of these actuators is shown in Plates 3 and 4. The HH500 control box is mounted on one of the platforms with easy access for the operator to either change the settings or visually monitor the system operation. Power cables exit the bottom of the actuators and run to capacitor boxes also mounted on the platform. A **220** foot control cable provides a communication link between the two actuators. All electrical and air lines are contained on tension reels attached to each platform.

GENERAL LVER QUALIFICATION

The qualification process insures acceptable joints are consistently produced by the installation equipment. Parameters used to access a riveting process include joint shear and tensile strength, rivet microstructure and rivet-hole interference levels. Interference levels have been shown to be strongly correlated to joint fatigue lives and therefore are a primary means to qualify a particular riveting process. Through years of experience and experimentation acceptable levels of interference have been developed. Typically, formed rivet head dimension are used as a visual indication that a rivet has been properly installed. Due to the different nature of LVER formation, the conventional correlation between formed head dimensions and interference levels developed for the pneumatic and hydraulical processes do not universally hold. Typically, some experimentation is required to develop a set of criteria which better characterizes a well formed LVER fastener. Once these parameters have been determined, the LVER process has been shown to be extremely repeatable.

LVER systems such as the HH500 exhibit much higher forming rates than conventional processes. Small resistances and/or concentrations to the flow of the rivet material are significantly magnified in the LVER time domain. Die geometry and rivet alloy therefore becomes critical to achieving the desired results. The geometry is dictated by the specific installation, i.e. rivet material, rivet type and substrate material. Forcing LVER bucktails to meet existing hydraulic and pneumatic dimensional standards can sometimes actually compromises a joint’s quality. Therefore, optimization of the LVER process typically requires that new upset head geometries need to be adopted.

Figure 2 illustrates the flow characteristics of a FH style rivet when using different die geometries. Formation of the bucktail with a tight constraining die (Figure 2, Die A) forces more material down the hole by limiting the radially expansion of the rivet. A tight die has the tendency to increase the hole expansion. Tight die geometries are typically used with hard fasteners, e.g. 7050 and hard substrate materials, e.g. 7150. With softer rivet materials, a tight die can cause excessive expansion of the hole. An open die (Figure 2, Die B) allows more of the material to flow radially thus reducing the interference levels. Hole fill is further controlled by the amount of volume of the forming cup. A typical rule of thumb is the higher the volume the more the hole fill. In severe cases, more exotic shapes are necessary to achieve the required interference. (Figure 3).

With FH rivets it is important that the die on the head side is centered on the head prior to upset. Centering the die on the rivet is a trivial task for most autoriveters and the low energy multiblow pneumatic hammer is somewhat forgiving to off center formation. The HH500 however is a one shot device and there is little margin for error. All handheld LVER dies are therefore designed to be self-centering. The minor diameter of the cup or containment dies closely matches the diameter of the rivet. This allows the operator to “feel” the rivet seat in the die prior to firing. With flat or convex dies such as those required on the head side of an FH fastener, a compliant centering sleeve is employed. This sleeve fits tightly onto the head of the rivet. When the rivet is formed the die moves forward and the sleeve expands radially out of the way.

LVER IMPLEMENTATION METHOD

LVER is a relatively new technology to the aerospace industry, which has been using essentially the same fastener installation methods for the past forty years. Boeing engineers therefore recognized that a framework needed to be developed to expedite the implementation of this technology into production. This method is described below, followed by an example of its use.

1) Identify candidate areas:

Shop personnel play a key role in the determination of which areas would most benefit from LVER alternatives. Quality improvements, time savings and worker fatigue concerns are the important aspects used to assess the priority level for the system integration into specific areas.

2) Study engineering drawings:

Once the candidate area have been identified, the part geometries are obtained to establish tooling requirements. Manufacturing personnel are consulted for material and dimensional data, i.e. minimum and maximum stack-up and corresponding rivet grip lengths. Engineering drawings are studied to determine the required joint specifications.

3) Prepare test specimens:

Representative test specimens are prepared to simulate the areas where the fasteners are installed. The standard test specimens are 6 inches by 15 inches. Special preparation is sometimes required to duplicate the actual geometry of the production panels, e.g. test specimens are tapered or radius to match runout areas. The test coupons are representative of the aircraft structure in thickness. The coupons are initially bolted together to prevent shifting. Rivet holes are then drilled and cold worked, reamed and countersunk if required.

4) Measure and Document Hole Geometry:

Rivet holes are measured with a bore gauge and checked for ovality. Countersinks are measured using a countersink gauge. Each hole is labeled and the data is tabulated. (see Table 3)

5) Parameter Prescreening:

An educated guess is made for the initial LVER system parameters based on qualification personnel's past experience or on the manufacturer's suggestions. The parameters include die geometries, capacitor bank voltages and firing delay times. The prescreening procedure is used to determine which parameters have a distinguishable effect on the results. Interference levels and the formed button geometries are used to access the variable effects. The extent of preliminary testing Identify candidate areas: required is largely determined by the knowledge base previously developed for similar installations.

6) Design of Experiments (DOE):

Once the prescreening has been completed, the data is used to determine the variable ranges which encompass the Study engineering drawings: experimental space. Die commonality is preferred and therefore, this factor is weighted in the experiment. A test matrix is established based on a statistical method called D-Optimum Design. This method is used rather than classical factorial methods due to the large number of potential variable interactions.

Once the test matrix has been determined, fasteners are shot in groups of two or three through the voltage ranges with Prepare test specimens: different die geometries. The fasteners are then cut out of the coupons and interference measurements are taken at D1, D2, D3 and D4. (see Figure 4) This data is then analyzed. D-optimal design provides a means by which specific information about the response variable dependency on system parameters is clarified. This is accomplished by performing a regression of the data for each response variable. The system variables and the response variable for these studies are given in Table 1. Interference levels are more heavily weighted since the button dimensions are referenced to them. Typically, the target interference and formed button geometries Measure and Document Hole Geo are set in the middle of the specification ranges to establish a confidence factor. A multi-property optimization routine is then run using the regression model results to predict the optimal system parameters. If more than one setting is derived a second test matrix is designed and the process is repeated.

7) Confirmation Tests

Confirmation coupons are prepared with the minimum and maximum stack thicknesses. Fifty holes are drilled and measured in each specimen. Rivets are installed with the derived optimal LVER parameters. Button heights and widths are measured and documented. The rivets are then cut out and interference is measured and documented. Results are compared with the predicted values for verification.

8) Microscopic analysis:

The formed rivets are then submitted to the metallurgical laboratory to be sectioned and polished. Metallurgical engineers then examine the polished specimens for microstrutural abnormalities. Photomicrographs are taken to document these results.

9) Qualification Document:

All test data is tabulated and a short description of the test procedure is prepared. This document is then submitted to Engineering and Stress for LVER system approval. Provided the testing supports existing requirements, stress engineers then define allowables and make the appropriate drawing changes for integration of the LVER into production. At the present time, each case is analyzed independently. As the knowledge base for LVER implementation is further developed, more general LVER specifications will likely be developed.

CASE STUDY

The primary application for the LVER HH500 handheld system on the 747 center wing is the installation of fasteners in areas where autoriveting is not possible. One of these areas is in radiused sections on the lower panels where due to the non-parallel nature of the opposing surfaces, autoriveters are unable to clamp up. (See Figure 5) The panel material is 2324-T39 and the stringer material is 2224-T351 1. The rivets are 5/16" diameter -17 grip length 2024-T39 "ice box" fasteners. All holes are cold worked with a solid mandrel, ream and countersunk prior to rivet installation.

Specimens were machined to match the panel curvature and thicknesses. Initially, three possible head die geometries, three possible tail die geometries and approximate voltage levels were recommended by the LVER manufacturer. Preliminary screening reduced the system parameters to two head and one tail geometries (see Figure 6), a head voltage range between 255 and 315 volts and a tail voltage range of between 240-300 volts. One of the preliminary head dies was rejected since it was unable to produce a consistently favorable witness line around the countersink. The two tighter geometry tails dies were eliminated due to overexpansion of the hole at D4. Six factors therefore required optimization. The preliminary data was analyzed using the D-Optimal method and yielded the test matrix with twenty different trial combinations. Table 2 illustrates this matrix. Two to three rivets were shot at each setting. The rivets were then sectioned and measured. Since the holes were cold worked, the important interference levels were at DI and D4 to maintain the integrity of the seal plane. Regressions were performed for these response variables. Regressions for the formed button geometries were performed as well. A multi-property optimization routine was run with the regression results. The DI and D4 values were more heavily weighted in the optimization routine than the button geometries.

This analysis indicated that the optimal system settings for this application were the head die 10-45, tail die 10-115, a head side voltage of 275 V and a tail side voltage of 300 V. Thirty rivets were then installed with these parameters to verify that the derived results. A compilation of these tests are presented in Table 3. A histogram of the D1 data is presented in Figure 7. The D1 and D4 results fall well within the required .0015" to .012" range. Since the holes were precoldworked, D2 and D3 interference were only required to be positive. One interesting note was that the form button geometries which yield the optimal D1 and 04 interference levels do not meet the existing pneumatic specifications. Some of the LVER formed heads did fall below this maximum, however many did not. This data was submitted to Boeing Engineering and the system was subsequently approved for production with a drawing change which raised the allowable maximum button height for LVER installed fasteners.

CONCLUSION

The HH500 hand operated electromagnetic riveting system provides a viable alternative for the installation of large diameter rivets. The one shot operation of this system has been shown to significantly reduce installation time as well as the noise and vibration levels experienced by the operator compared to pneumatic percussion riveters. Exploiting the power of D-Optimal Design statistical methods has been effectively employed to expedite the optimization of the LVER system parameters.

To date the HH500 system has been qualified to install approximately 1000 fasteners, 3/8”, 5/16” and 1/4" in diameter on the 747 Section 11. The system has been in production since March 1992. Work continues on extending the amount of qualified fasteners and on elimination of the coldworking process currently required for all hand installed fasteners on these panels.

REFERENCES

1. Zieve, Peter B., “Low Voltage Electromagentic Riveter”, FASTEC WEST ‘86, Anaheim, October, 1986.

2. Hartmann, John and Zieve, Peter, “Rivet Quaility in Robotic Installation,” FASTEC ‘89, Arlington, October, 1989.

3. Hartmann,John, “Development of the Handheld Low Voltage Electromagnetic Riveter”, SAE Aerospace Automated Fastening Conference, Long Beach, October, 1990.

4. Zieve, P. et al., “Advanced EMR Technology”, SAE Aerospace Automated Fastening Conference, Seattle, October, 1992.

TABLE 1: DOE VARIABLES

System Variables	Response Variables
Head side capacitor voltage	DI Interference Level
Tail Side capactitor voltage	D2 Interference Level
Head side dies	D3 Interference Level
Tails side dies	D4 Interference Level
Head/Tail Timing Delay	Formed Rivet Button Height
	Formed Rivet Button Diameter

TABLE 2: DOE TEST MATRIX

Test #	Stack Thickness 1-max 2-min	Head Die	Tall Die	Head Voltage	Tail Voltage	Time Delay (+ head first) (-tail first)
1	2	45	115	315	280	0
2	2	45	115	295	260	0
3	2	45	115	315	240	-250
4	2	45	115	255	300	0
5	2	45	115	295	300	-250
6	2	45	115	255	240	-250
7	2	504B	115	315	240	0
8	2	504B	115	315	300	-250
9	2	504B	115	255	280	-250
10	2	504B	115	275	300	0
11	1	45	115	315	240	0
12	1	45	115	315	300	-250
13	1	45	115	275	280	0
14	1	45	115	255	240	-250
15	1	45	115	255	300	-250
16	1	504B	115	315	260	0
17	1	504B	115	275	260	-250
18	1	504B	115	295	280	-250
19	1	504B	115	255	300	0
20	1	504B	115	255	240	0

TABLE 3: 5/16" Confirmation Data Sheet

Low Voltage EMR Test Results

Settings: Head Gun: Voltage: 275 Volts | Tail Gun: Voltage: 300 Volts | Bias: 0

Head Die: 10-45 | Tail Die: 10-1 15

Rivet Diameter: 5/16" | Length: -17 | Alloy: 2024

Part "A ": AL2324 T39 0.422"-0.237" Max Tail Height: 0.2140" Max Tail Dia: 0.4520"
Part "B": AL2224 T351 1 0.252w Min Tail Height: 0.1900" Min Tail Dia: 0.4350"

Fastener #		D1	D2	D3	D4	Tail Height	Tail Dia.
30 Shot Avg.		***0.0050***	***0.0013***	***0.0043***	***0.0095***	***0.2042***	***0.4449***
	Rivet Dia.	0.3229	0.3186	0.3215	0.3260		
1	Hole Dia.	0.3 168	0.3168	0.3168	0.3168	0.2040	0.4390
	Interference	***0.0061***	***0.0018***	***0.0047***	***0.0092***		
	Rivet Dia.	0.3223	0.3182	0.3206	0.3244		
2	Hole Dia.	0.3167	0.3167	0.3167	0.3167	0.2010	0.4480
	Interference	***0.0056***	***0.0015***	***0.0039***	***0.0077***		
	Rivet Dia.	0.3213	0.3182	0.3206	0.3245		
3	Hole Dia.	0.3168	0.3168	0.3168	0.3168	0.2020	0.4410
	Interference	***0.0045***	***0.0014***	***0.0038***	***0.0077***		
	Rivet Dia.	0.3214	0.3182	0.3214	0.3257		
4	Hole Dia.	0.3167	0.3167	0.3167	0.3167	0.2040	0.4350
	Interference	***0.0047***	***0.0015***	***0.0047***	***0.0090***		
	Rivet Dia.	0.3210	0.3180	0.3197	0.3251		
5	Hole Dia.	0.3168	0.3168	0.3168	0.3168	0.2080	0.4450
	Interference	***0.0042***	***0.0012***	***0.0029***	***0.0083***		
	Rivet Dia.	0.3214	0.3180	0.3215	0.3264		
6	Hole Dia.	0.3168	0.3168	0.3168	0.3168	0.2110	0.4400
	Interference	***0.0046***	***0.0012***	***0.0047***	***0.0096***		
	Rivet Dia.	0.3229	0.3189	0.3226	0.3276		
7	Hole Dia.	0.3171	0.3171	0.3171	0.3171	0.2040	0.4480
	Interference	***0.0058***	***0.0018***	***0.0055***	***0.0105***		
	Rivet Dia.	0.3219	0.3 183	0.3214	0.3270		
8	Hole Dia.	0.3168	0.3168	0.3168	0.3168	0.2070	0.4490
	Interference	***0.0051***	***0.0015***	***0.0046***	***0.0102***		
	Rivet Dia.	0.3224	0.3 186	0.3215	0.3278		
9	Hole Dia.	0.3171	0.3171	0.3171	0.3171	0.2080	0.4470
	Interference	***0.0053***	***0.0015***	***0.0044***	***0.0107***		
	Rivet Dia.	0.3216	0.3181	0.3211	0.3273		
10	Hole Dia.	0.3170	0.3170	0.3170	0.3170	0.1980	0.4500
	Interference	***0.0046***	***0.0011***	***0.0041***	***0.0103***		

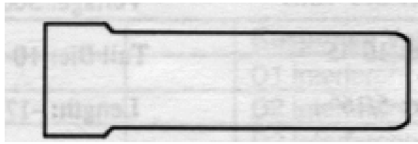


Figure 1: Fatigue Head rivets proflie

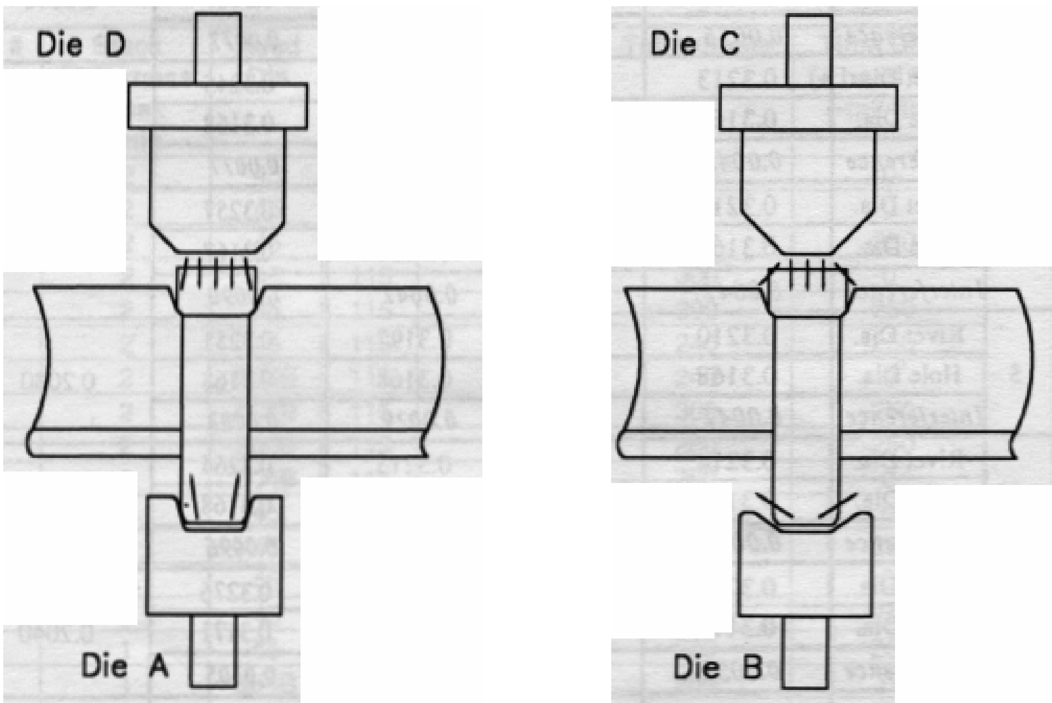


Figure 2: Die geometries and related flowlines

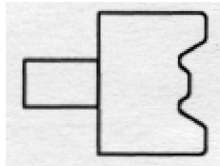


Figure 3: Example of exotic die.

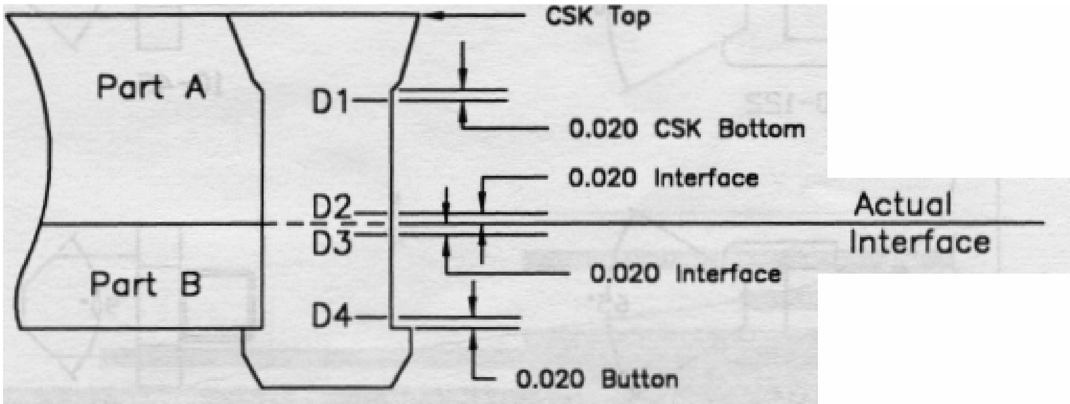


Figure 4: Location of rivet interference measurement

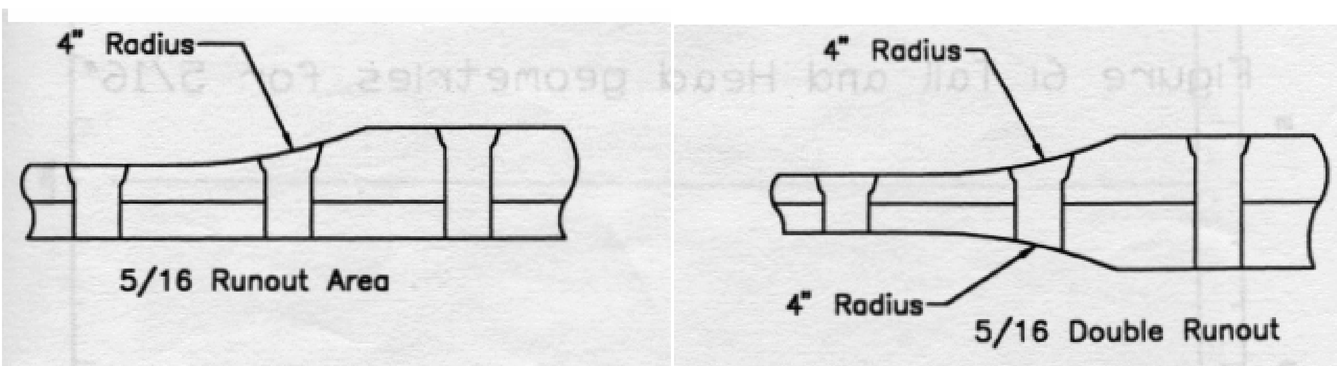
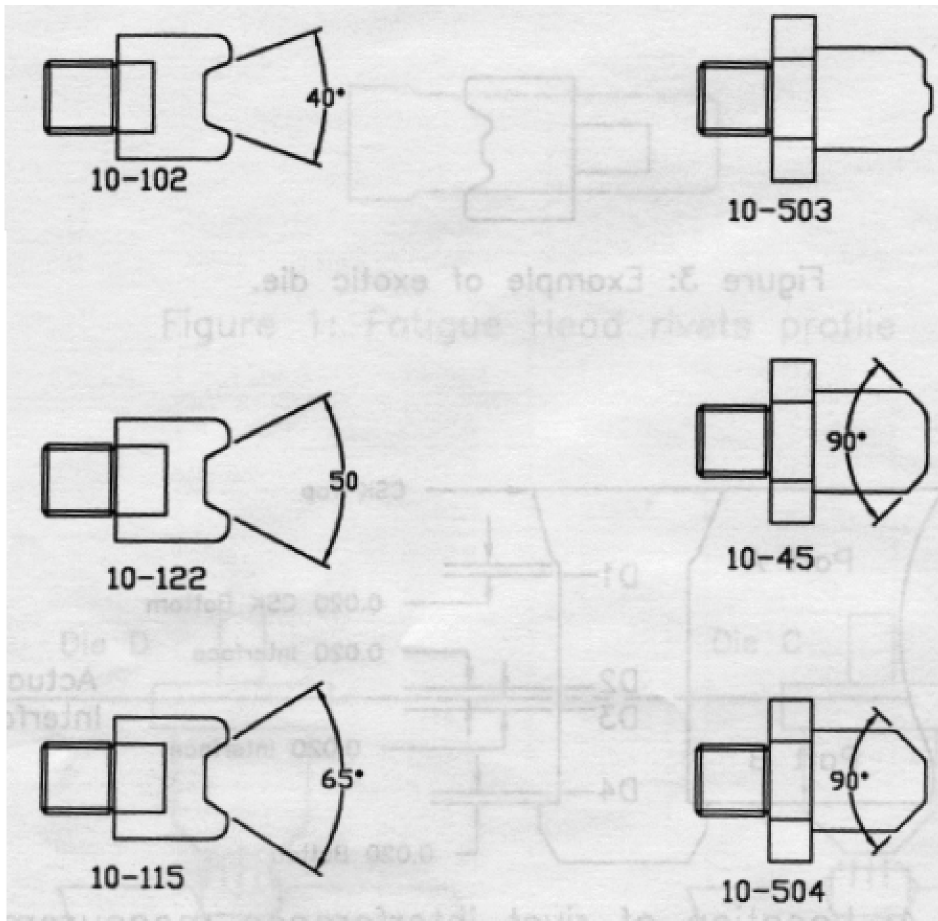


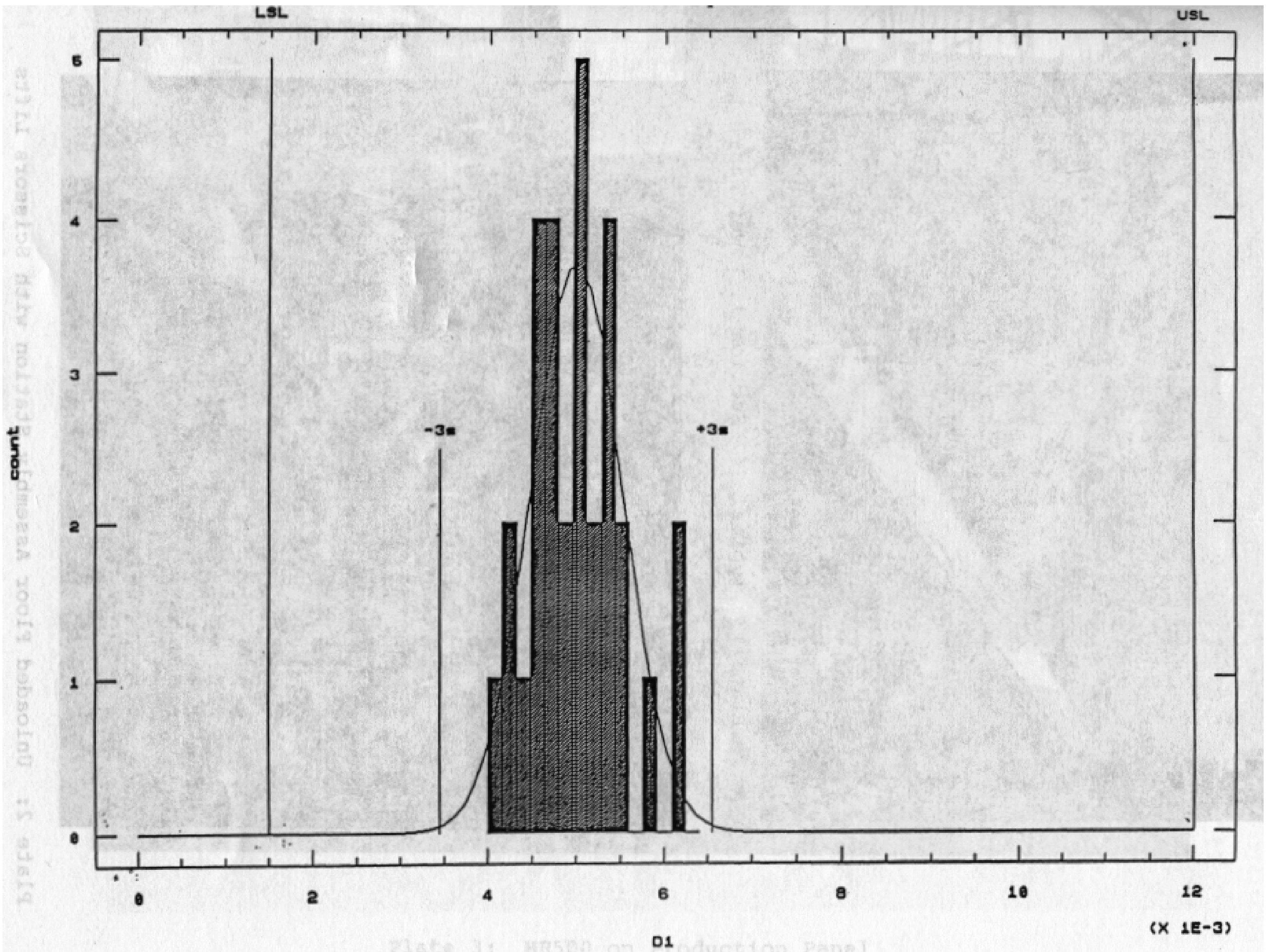
Figure 5: Runout Areas



Tail Dies Head Dies

Figure 6: Tail and Head geometries for 5/16"

Figure 7: D1 Interference



Minimum Coupon Stack

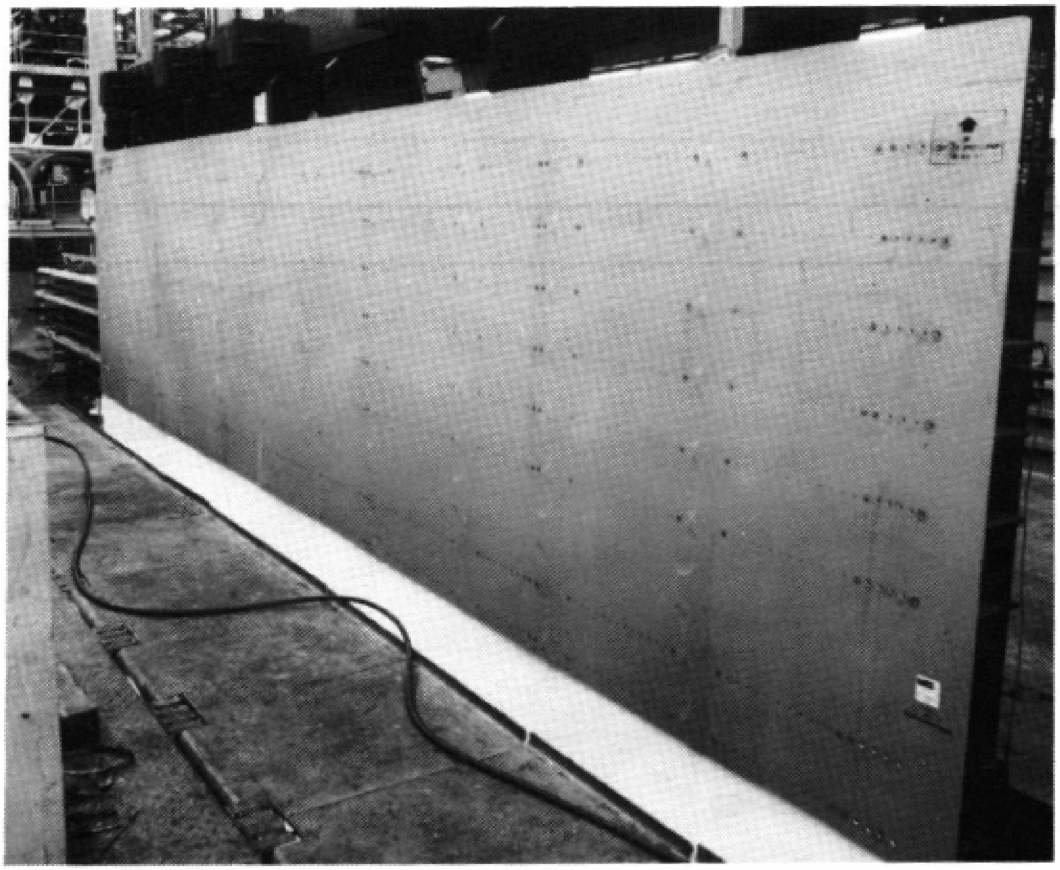


Plate 1: Typical 747 Section 11 Lower Panel

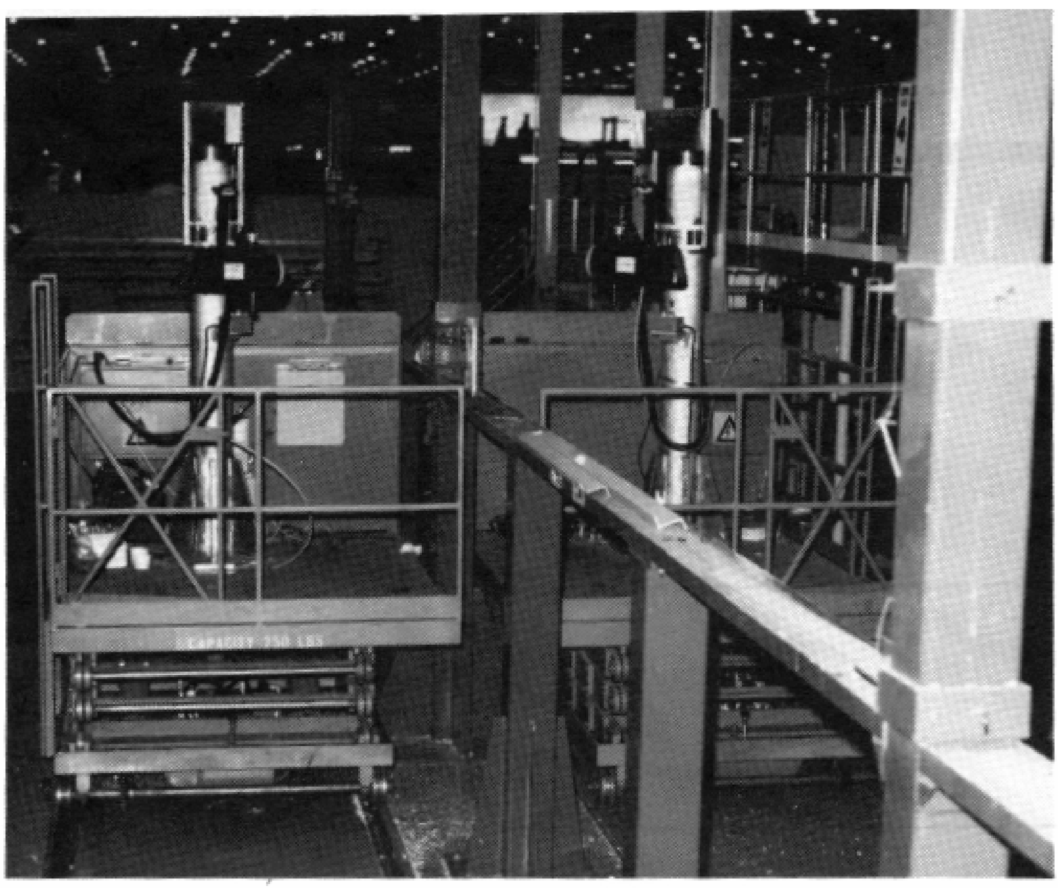


Plate 2: Unloaded Floor Assembly Station with Scissors Lifts

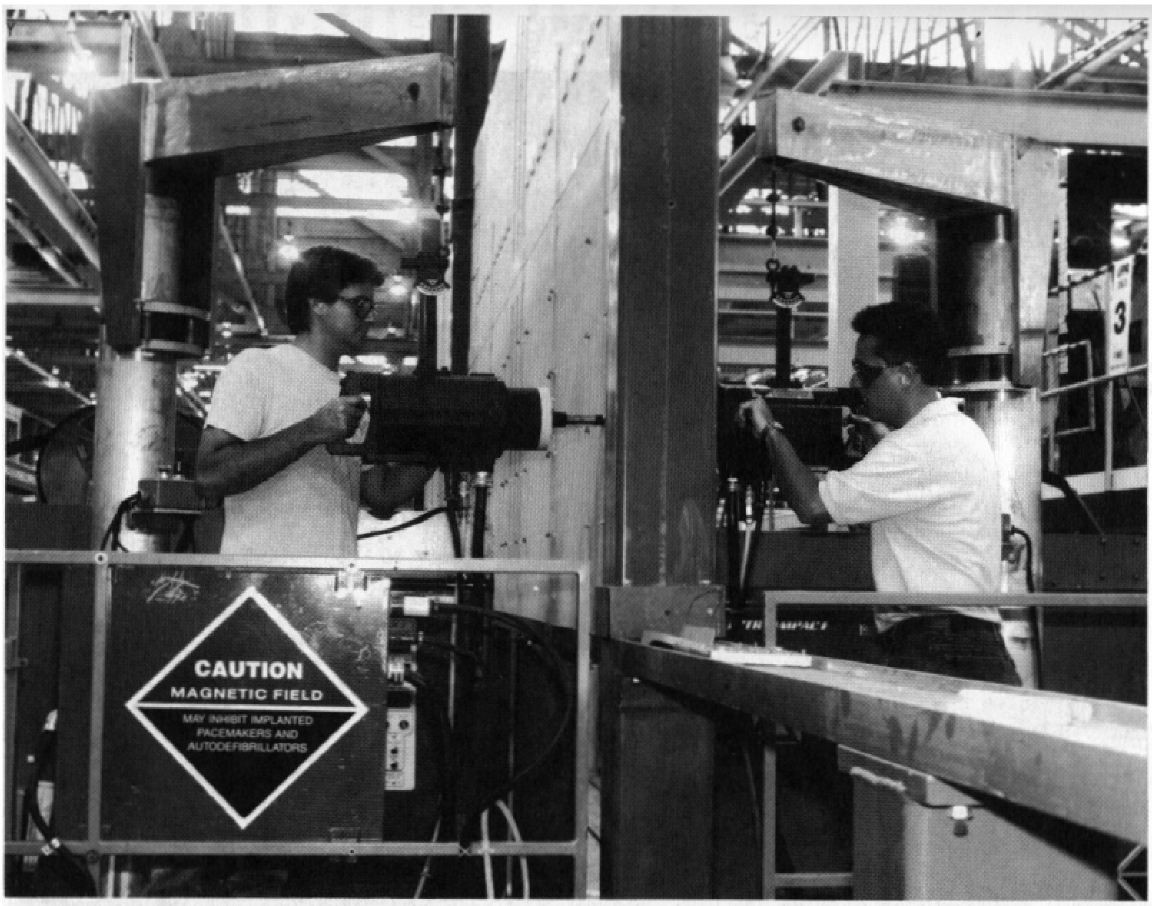


Plate 3:   HH500 on Production Panel

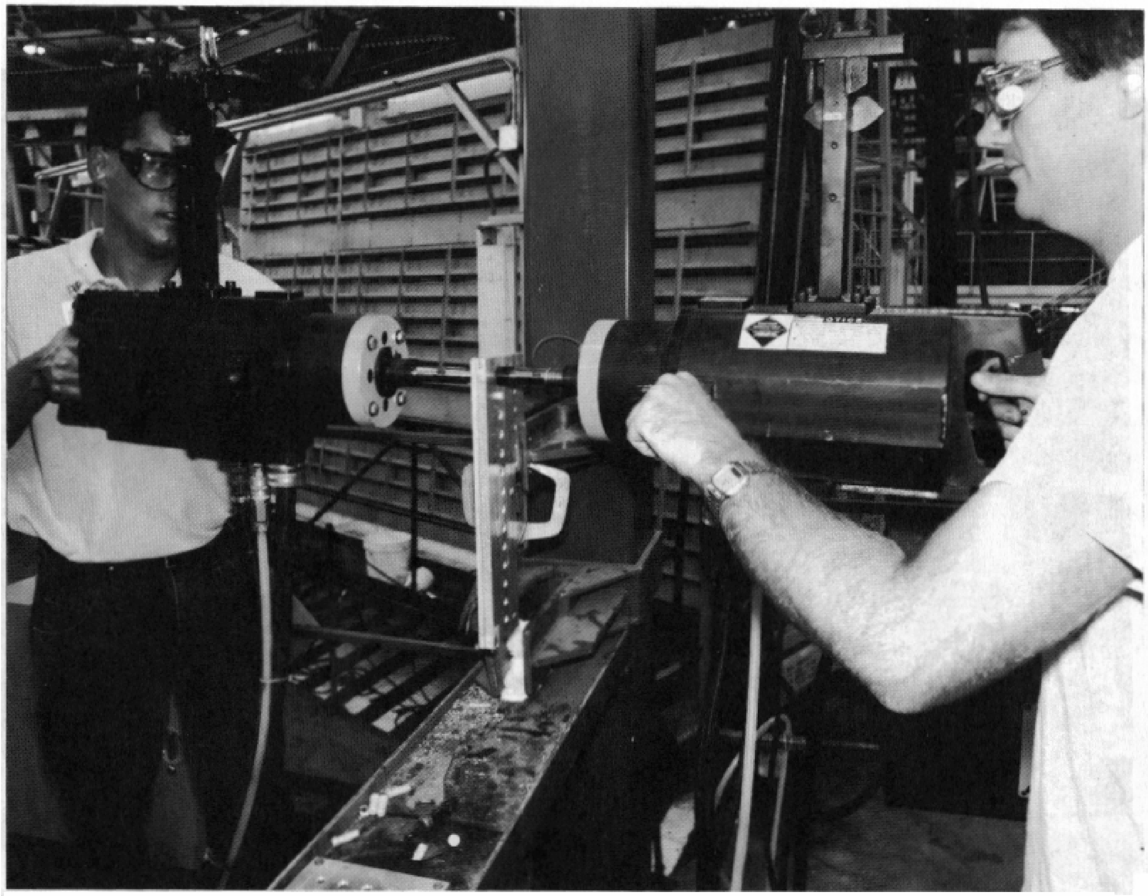


Plate 4: HH500 on Test Coupon