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DEVELOPMENT OF AN ADVANCED HIGH-TEMPERATURE FASTENER SYSTEM FOR ADVANCED AEROSPACE VEHICLE APPLICATION

By F.R. Kull

Prepared Under

Contract NASI-13283

by

STANDARD PRESSED STEEL CO. LABORATORIES

Jenkintown, Pennsylvania

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

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DEVELOPMENT OF AN ADVANCED HIGH-TEMPERATURE FASTENER SYSTEM FOR ADVANCED AEROSPACE VEHICLE APPLICATION

F. R. Kull
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1. SUMMARY

This report documents the results of a program to develop a lightweight high temperature reusable fastening system for aerospace vehicle thermal protection system applications. This feasibility program resulted in several fastener innovations which will meet the specific needs of the heat shield application. The results indicated that a lightweight, reusable, high temperature fastening system can be developed for aerospace vehicle application.

In the course of this program, a survey was conducted in which all available aerospace and commercial type fastener designs were reviewed and considered as candidates in the program. It was apparent after this review that new designs with adoption of some present fastening technology could satisfy the requirements of the heat shield application.

Eleven fastener designs were generated from which three were selected for evaluation. The designs selected consisted of three basic methods of permanently fastening a grooved stud to the vehicle sub-structure, which were welding, clinching, and caging. The means of retaining the heat shield to the sub-structure with disassembly from the outside of the vehicle were by a crimped collar or by a split ring assembled in the stud groove with special tooling. All test fasteners and test joints were fabricated from Haynes Alloy No. 188. The fastener shank diameter was .350 cm (.138 in.), representative of a nominal number 6 size threaded fastener.

For this study acceptable reusability of each fastening system required successful completion of 100 simulated mission cycles with disassembly and assembly every 10 cycles. The reusability evaluation was conducted on a test joint representative of aerospace vehicle structure. Part of each fastener type evaluated remained in the test structure for 100 cycles, while the externally removable part of the fastener was removed and replaced with a new part every 10 cycles. All three fastener types evaluated performed without failure in the simulated shuttle cycling. In the simulation, test parts were subjected to a load, temperature vs. time profile of a reusable space vehicle during ascent and re-entry. The results showed no significant reduction of fastener strength properties. The fasteners were readily assembled and disassembled with special tools from the heat shield side of the test structure. There was no damage to the heat shield during the assembly and disassembly procedure.

Tests were also conducted to characterize the mechanical strength properties of the fastener. These were ultimate shear and ultimate tensile tests. Modified shuttle cyclic loading was included in both the shear and

tensile tests before determination of the ultimate failure loads. The results of these tests indicated failure loads exceeding the ultimate design loads required at room and 1200K (1700°F).

An important objective of this program was to develop fastener systems lighter than a conventional aerospace fastener. An anchor nut and protruding head bolt was used for comparison since it is used in blind applications where only one side of the structure is accessible at assembly. This is similar to the heat shield requirement. The weight comparison showed that the three types of fasteners evaluated were 46 to 98% of the weight of the conventional fastener.

All measurements made in conducting the work in this program were made in the customary United States system of units. (Pounds, Degree Farenheit, Inches) In reporting the results, the customary units were converted to SI units which are stated first. The customary measurement values are stated afterwards in parenthesis. Conversion factors used were:

To Convert From	To	Multiply By
Farenheit (F)	Kelvin (K)	$t_k = \frac{5}{9}(t_f + 459.67)$
Inch (in.)	Centimeter (cm)	2.54
Pound Force (lbf)	Newton (n)	4.448

2. INTRODUCTION

The need for a lightweight reusable fastener for thermal protection systems has been recognized in several evaluations of metallic heat shields in NASA programs[1,2]. Due to the particular requirements of heat shields such as light weight, reusability, temperature and vibration resistance, conventional fasteners are inadequate. Since the metallic heat shield is being considered as a candidate thermal protection system for advanced aerospace vehicles, a program was initiated to extend fastener development into this particular area.

The objective of this program was to design and evaluate fastening systems that would meet the requirements of metallic heat shields operating at temperatures to 1255K (1800°F).

Haynes Alloy No. 188 was chosen for the application as the most suitable material since it combines the high temperature strength of L-605 with the oxidation resistance of Hastelloy X. Haynes Alloy No. 188 material is compatible with present fastener and aerospace vehicle fabrication techniques, lending itself to economical production methods now in existance.

Problems with conventional fasteners have been identified in several areas, and it is toward the solution of these problems that this program was directed:

Weight - Excessive weight of conventional fasteners is due in part to heat shield designs in which the threaded section must be eliminated from the high temperature zone. Because of high contact stresses between nut and bolt threads, diffusion-bonding occurs making it imposible to disassemble structure components. To facilitate disassembly, the fasteners must be made long enough to keep the threaded section out of the high temperature zone.

Structure - Since the feasible thickness of a metallic heat shield is about .025 cm (.010 in.) to .063 cm (.025 in.), a greater number of small diameter fasteners must be used to effectively hold the shield in place. This dictates the placement of the thread in the high temperature zone.

Reusability - Heat shields must be removable for refurbishment. Since small fasteners must be used in the high temperature zone, removal of the fastener or a portion of a multi-part fastener, must be accomplished externally and in an economical manner. A conventional rivet could be used but would require excessive time to remove by drilling, with possible damage to the heat shield.

Vibration Resistance - The heat shield on a space vehicle is subject to intense vibration. Since the metallic heat shield requires small, short, conventionally threaded fasteners, the thread is in the high temperature zone. For vibration resistance, the thread would require an elastic locking element such as deformed threads. Locking methods of this type relax at high temperature and are only usable for one cycle. High stresses in threaded locking elements also cause problems as a result of diffusion-bonding, making fastener disassembly impossible.

3. FASTENER DESIGN AND SELECTION

A review of present technology for fasteners that would meet the requirements of the heat shield application was conducted by study of existing heat shield models at Langley Research Center and extensive discussions with cognizant NASA personnel. During the discussion the following items were covered:

1. Sub-structure design.
2. Present metallic heat shield designs.
3. Type of formed sections in the sub-structure.
4. Sheet thickness variables.
5. Expansion problems.
6. Dimpling of the heat shield or sub-structure.
7. Heat shield temperature.
8. Fastener grip accommodation.
9. Required clamp load.
10. Vibration resistance.
11. Preferred type of fastener drive.
12. Riveting and welding to sub-structure
13. Use of special tools to install or remove fasteners.
14. Fastener evaluation: load, time, temperature.
15. Fastener selection criteria.

An extensive survey of commercial and aerospace fasteners was performed of available fastening techniques for heat shield application. With this background of information, a number of fastening methods were conceived as shown in Figures 1 through 11. These designs were evaluated using fastener design criteria, Table 1 considered pertinent to high temperature heat shield applications.(1) Each design criterion was rated from 0 to 5, which was in turn multiplied by a relative importance weighting factor of 1, 2, or 3. The fastening systems considered more responsive to the design criteria would have the higher score. The results of the design evaluation are given in Table 2.

The three fastener systems with the highest scores were:

1. Clinched stud with crimped retaining collar, Figure 1.
2. Welded stud with split retaining ring, Figure 7.
3. Caged stud with crimped retaining collar, Figure 11.

These three designs do not have threads, thereby avoiding diffusion-bonding and vibration problems associated with threaded fasteners in high temperature applications. Each of these studs are permanently attached to the sub-structure and utilize a grooved design to retain the crimped collar or split ring retainer. The crimped collar and split ring are the external fastener components which are replaced when heat shields are disassembled and assembled. Special tools are needed to assemble and remove the collar or the ring from the grooved studs.

Selection of all three fastening systems for evaluation provided data on three different methods of attaching a grooved stud to the sub-structure (clinching, welding, and caging) as well as data on two distinct methods of fastening the heat shield to the sub-structure (crimped retaining collar, and split retaining ring).

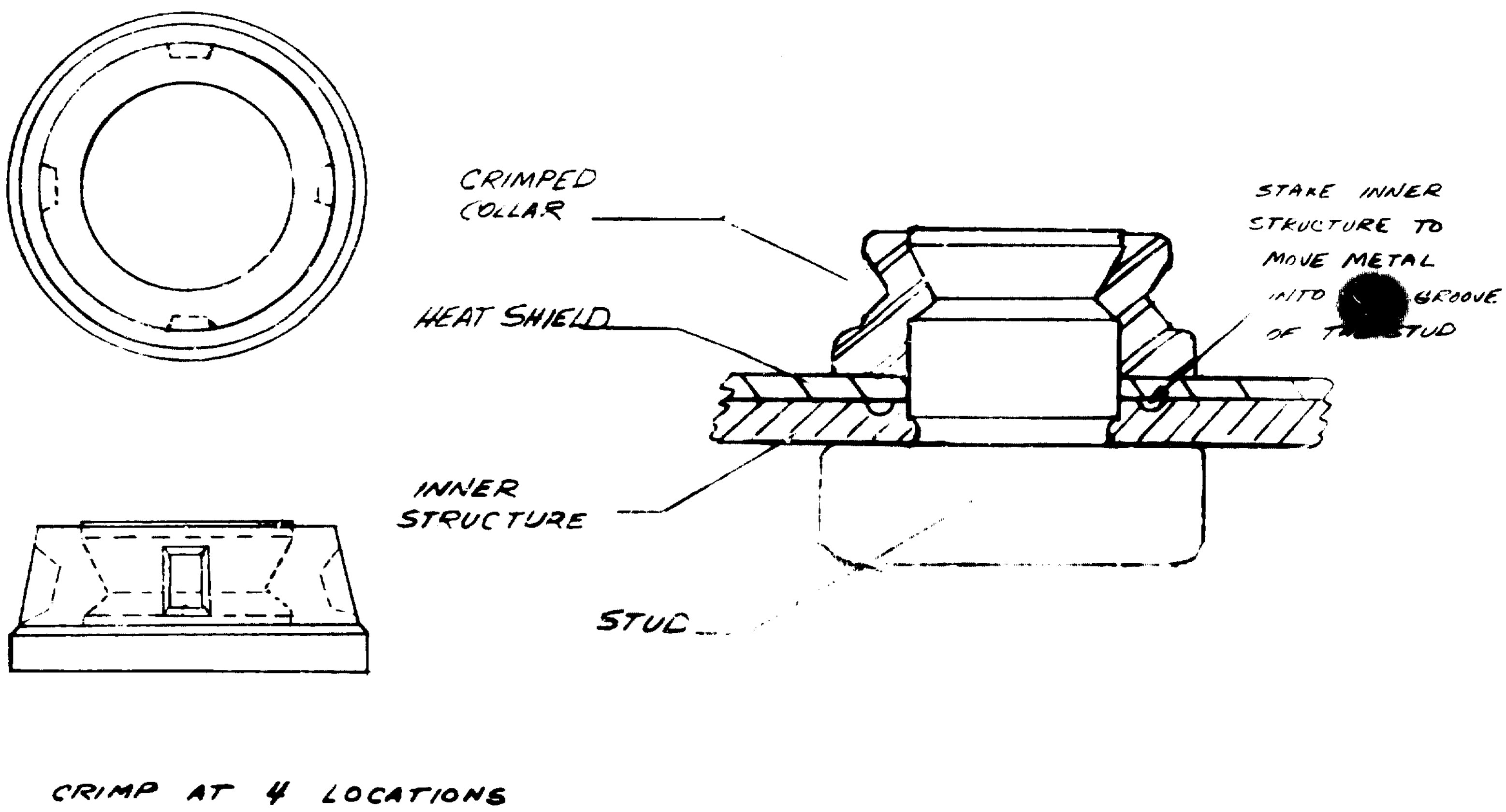


Figure 1. Clinched Faste

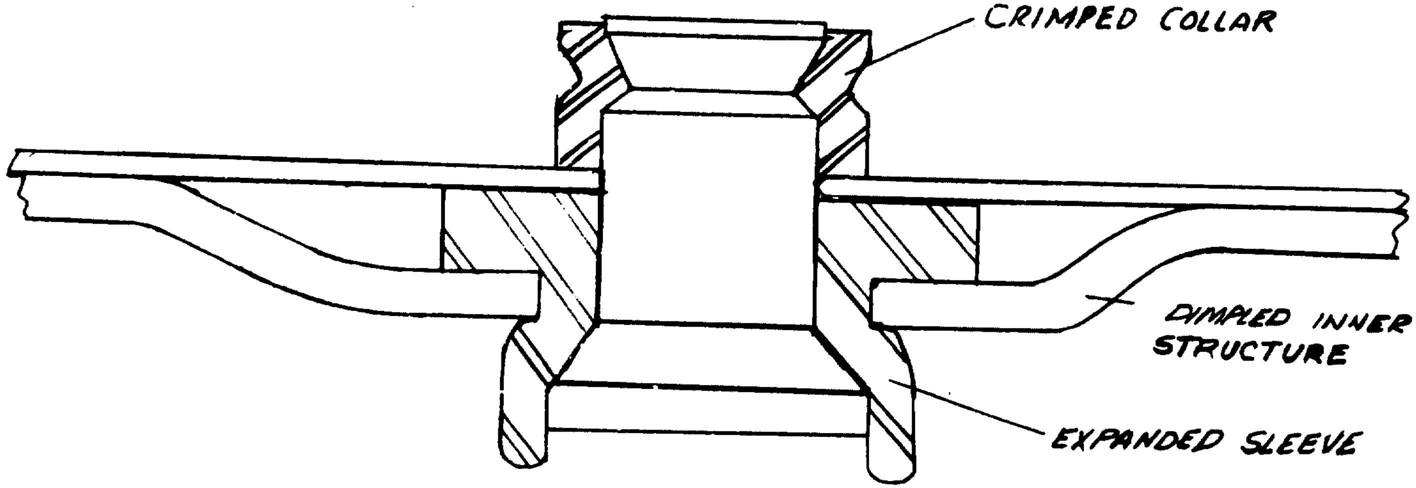


Figure 2. Expanded Sleeve Stud Retainer with Crimped Collar

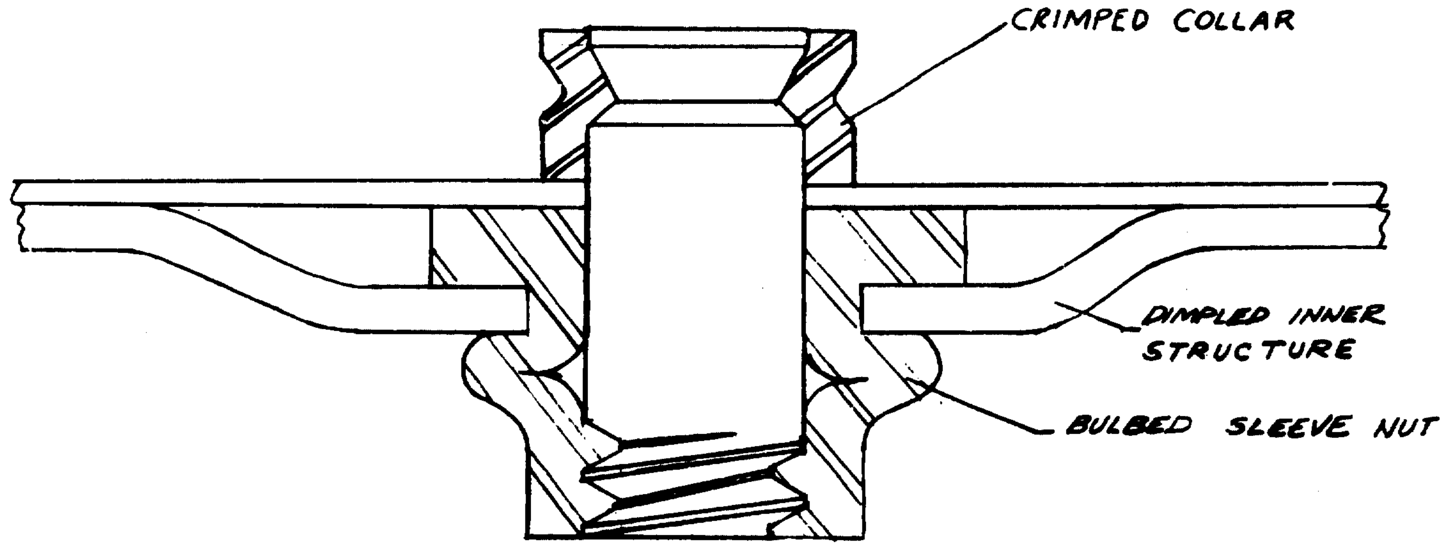


Figure 3. Bulbed Sleeve Stud Retainer with Crimped Collar

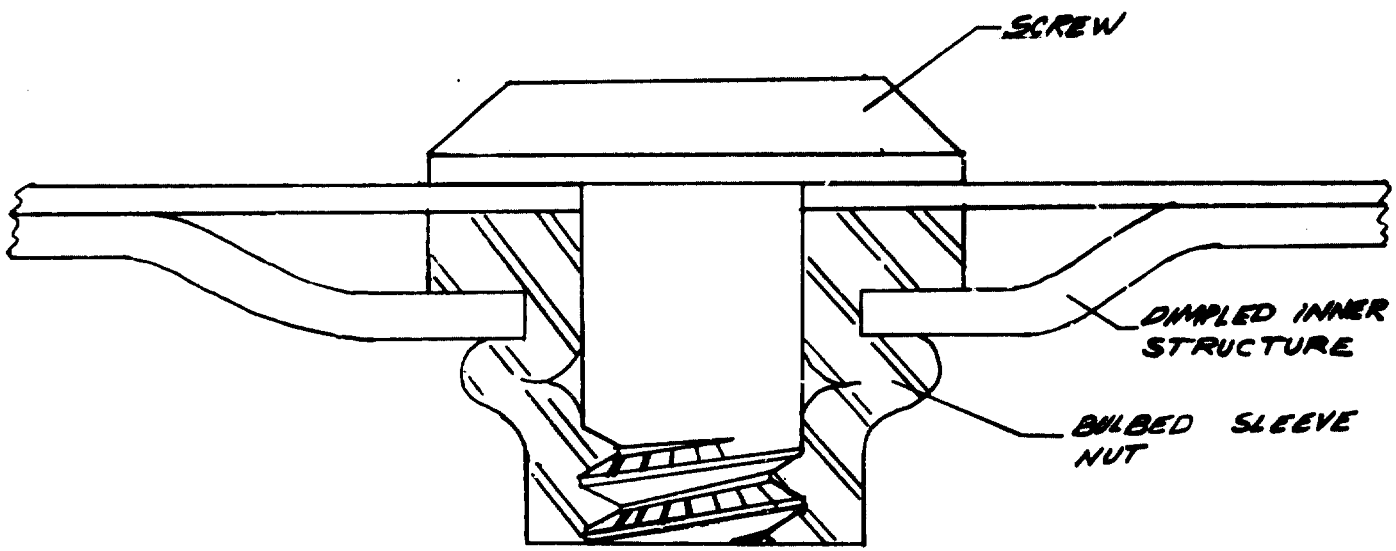


Figure 4. Serrated Flank Screw with Bulbed Sleeve Nut

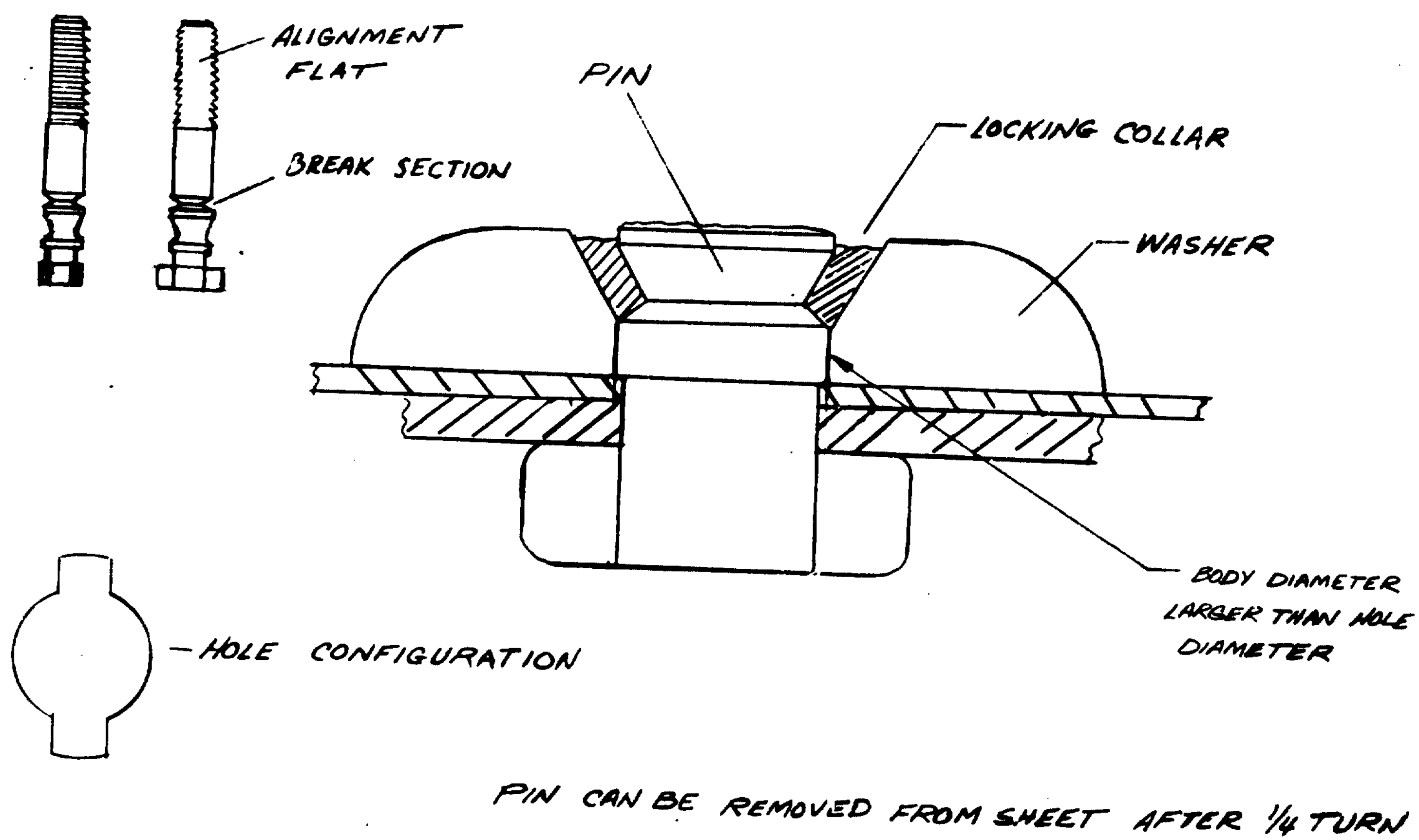


Figure 5. Removable Pull Type Pin

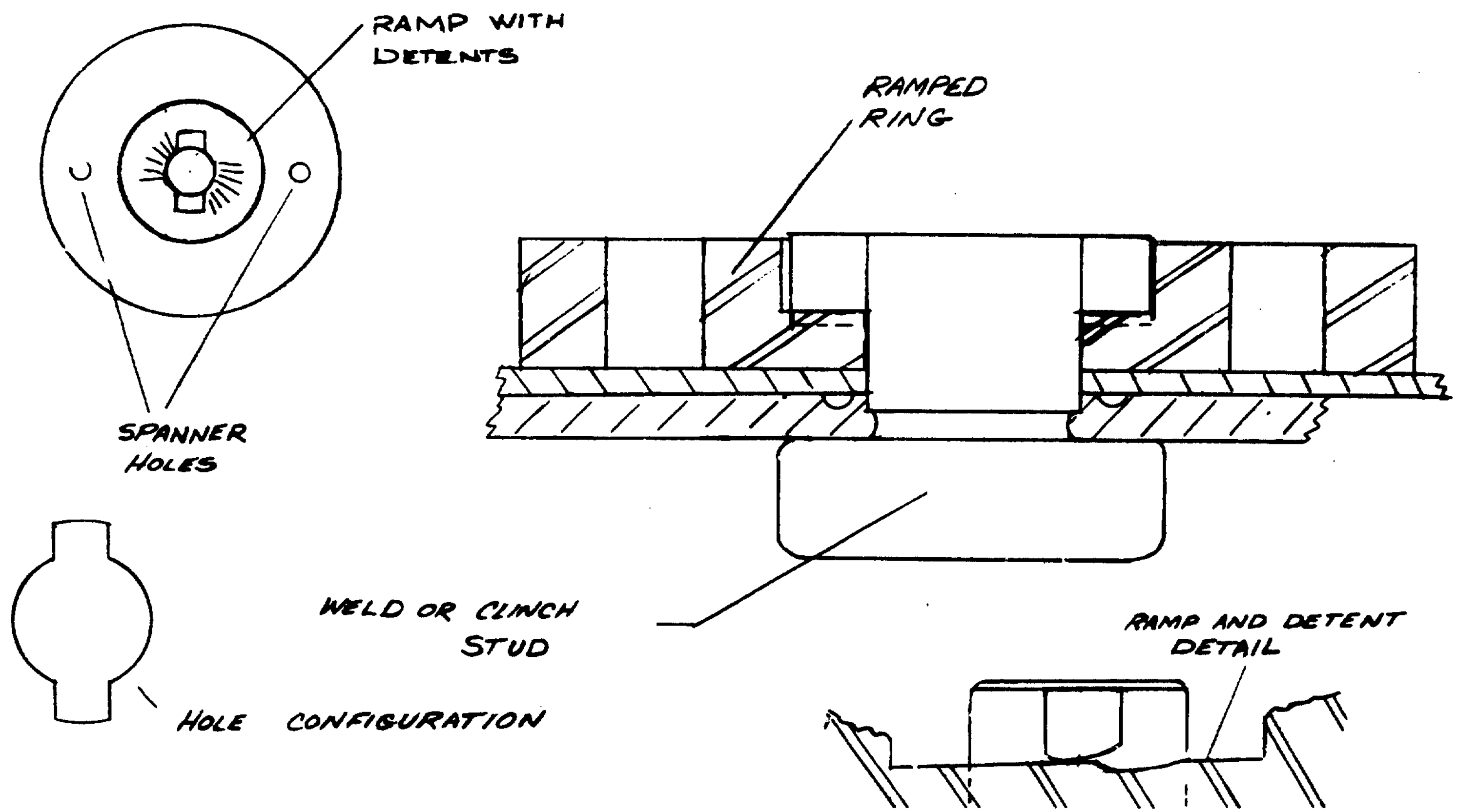


Figure 6. Quarter Turn Ring

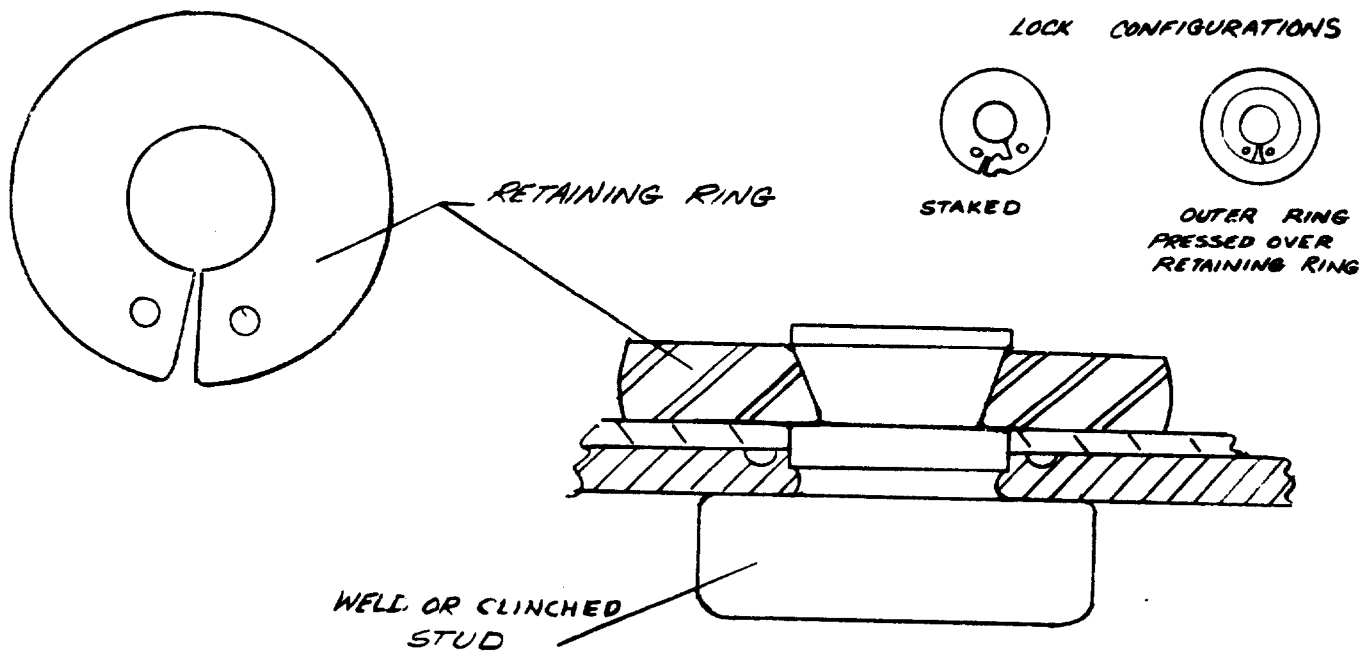


Figure 7. Fastener with Split Retaining Ring

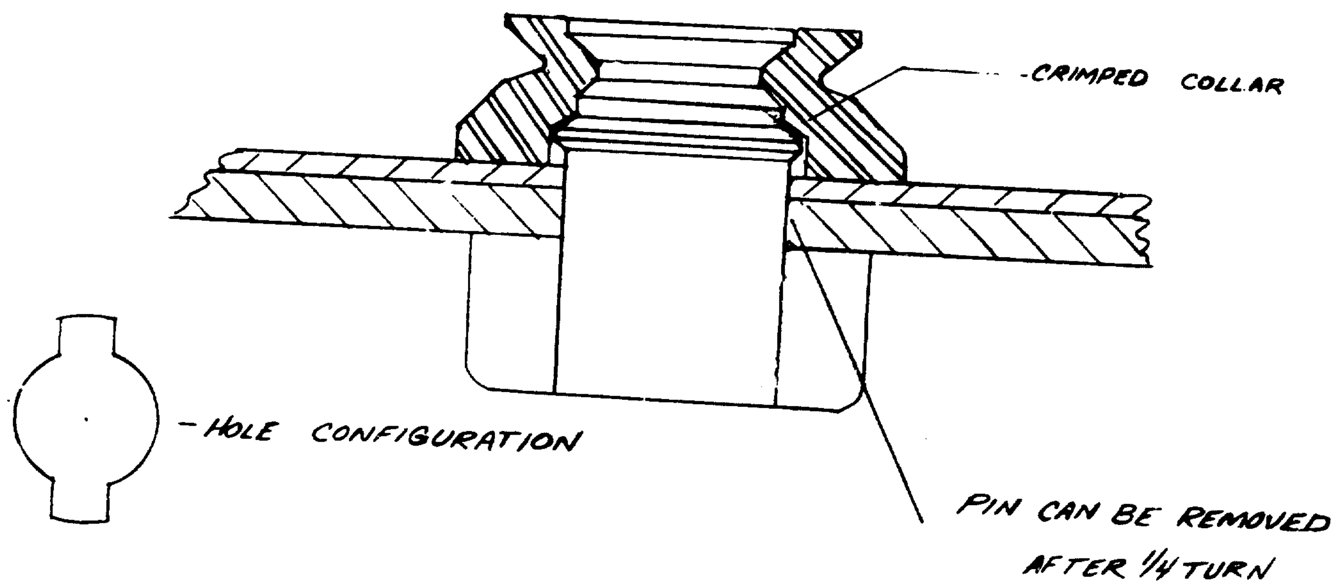


Figure 8. Quarter Turn Pin with Crimped Collar

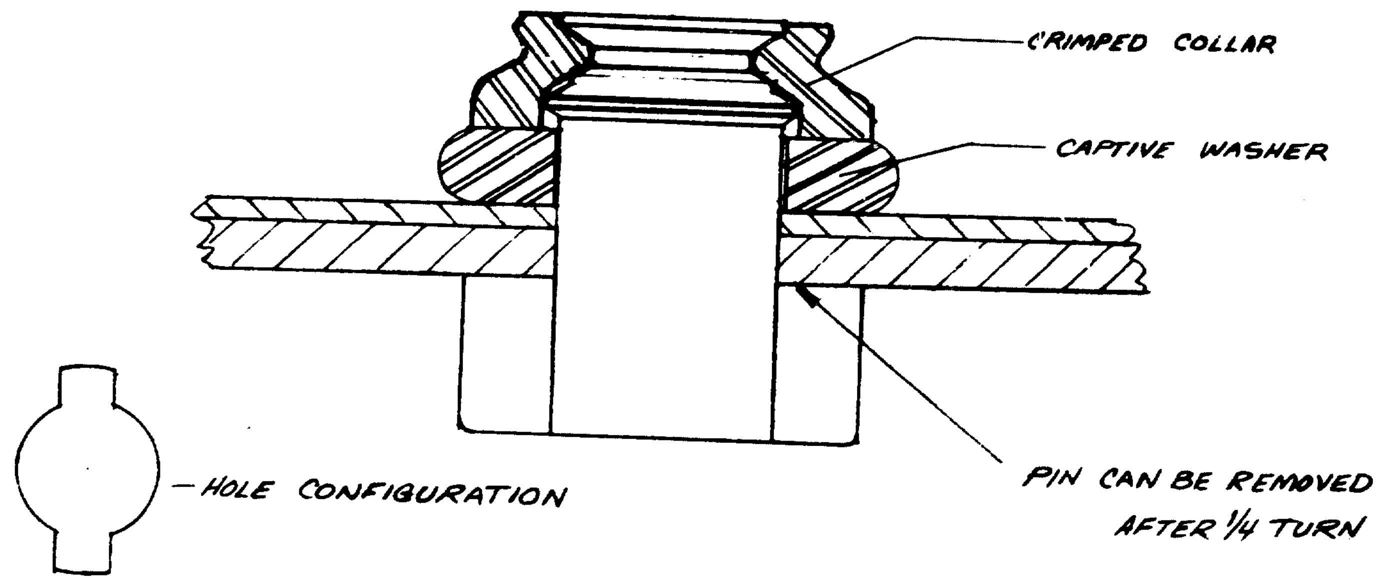


Figure 9. Quarter Turn Pin with Crimped Collar and Captive Washer

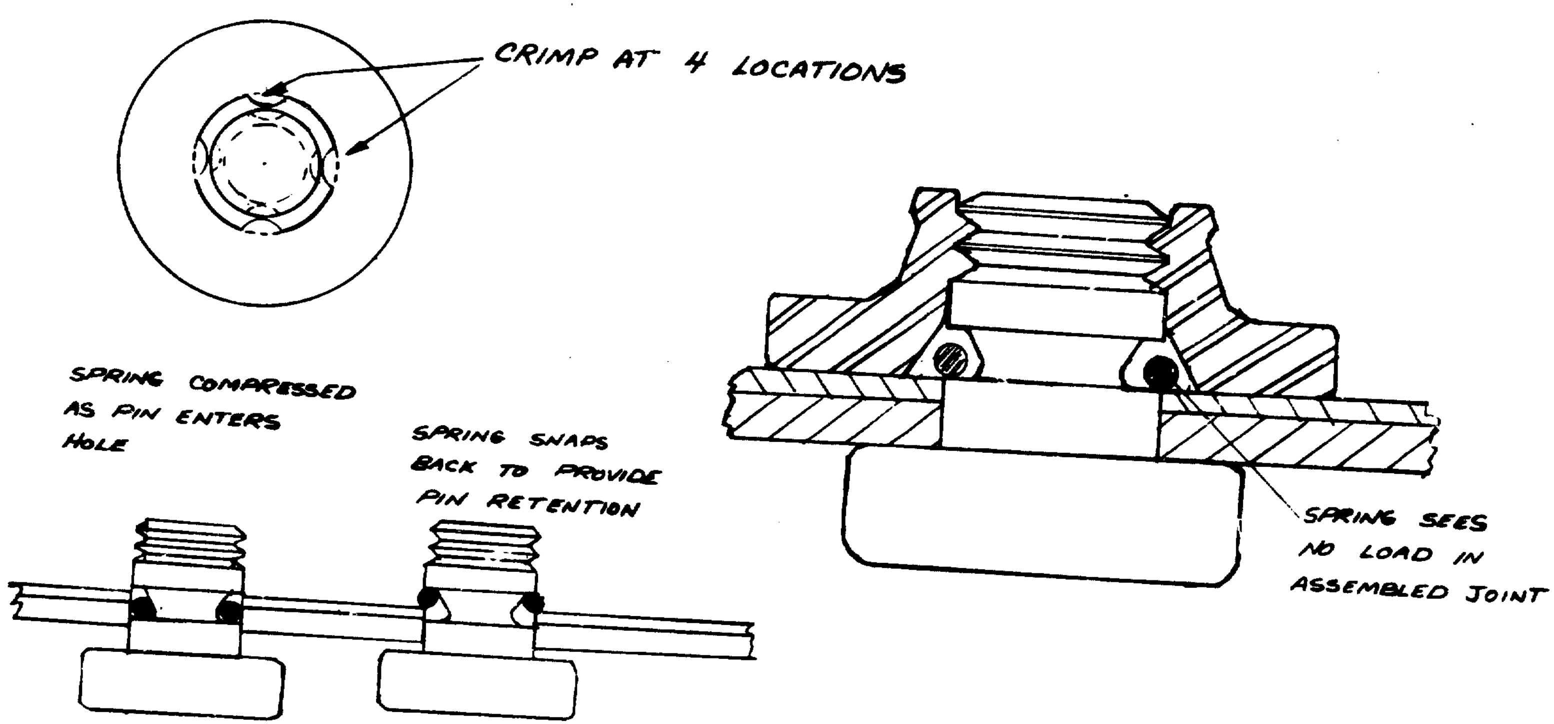


Figure 10. Crimped Collar with Positive Locking Pin

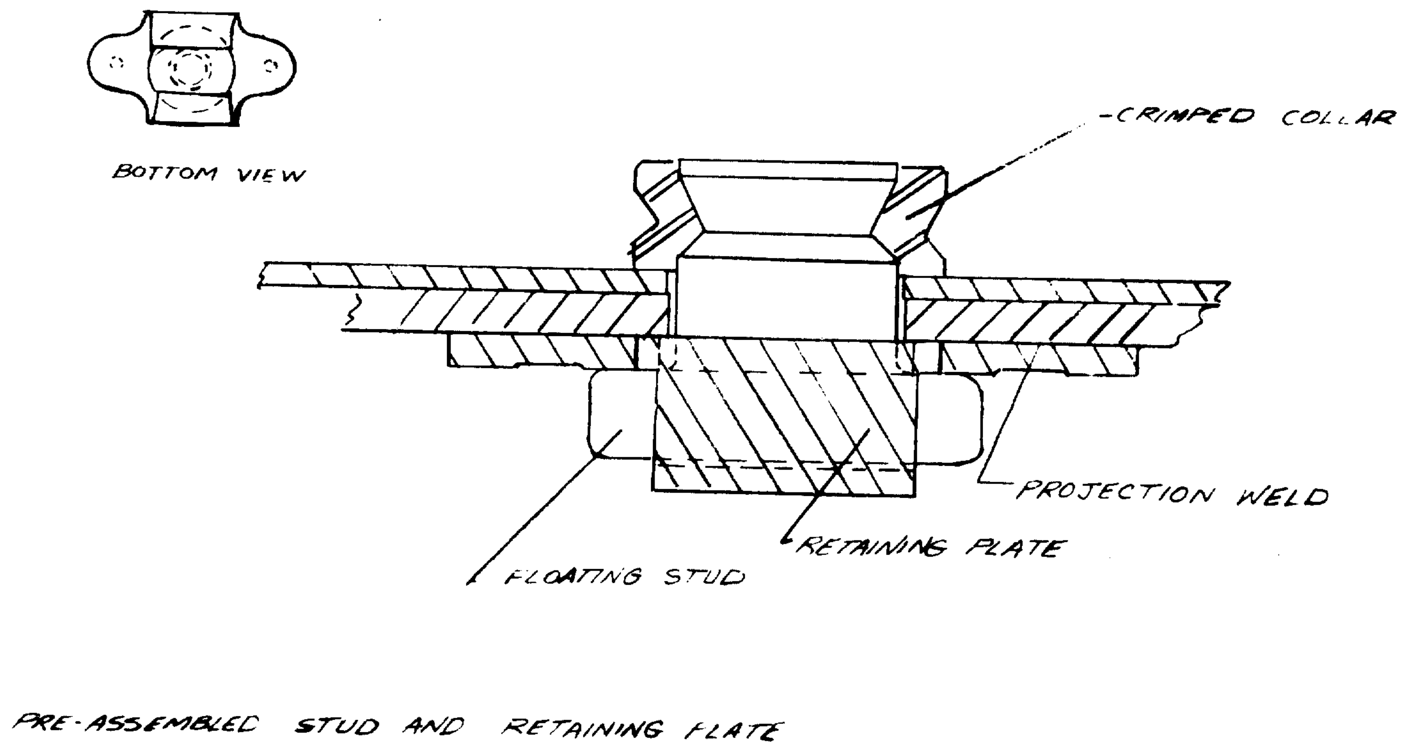


Figure 11. Caged Fastener

TABLE 1

Fastener Design Criteria

ITEM:

1. Reusability and-or replaceability

   A. Complete
   B. Partial
   C. Replaceable with new fastener

2. Cost

   A. Fabrication
   B. Present technology
   C. Assembly and disassembly (tools and time)

3. Weight

   A. Size
   B. No. of parts

4. Vibration Resistance

   A. Locking features
   B. Pull-up and clamp loads
   C. Heat Effects

5. Fabricability

   A. Machining, forming, etc.
   B. Size

6. Ease of Assembly and Disassembly

   A. Tools
   B. Damage tolerance
   C. Operator skill
   D. Time
   E. Misalignment

7. Simplicity of Design

   A. No. of parts
   B. Fastening complexity

TABLE 1 - Continued

Fastener Design Criteria

8. Geometry of Installed Fastener

   A. Stress risers
   B. Exposed areas
   C. Gas sealing
   D. Contact stresses
   E. Heat effects

9. Inspectability

   A. Misalignment
   B. Preload

TABLE 2

Comparative Score Sheet
Summarizing Results of Fastener Selection

Item No.		Design Identification (Figure No.) 1	2	3	4	5	6	7	8	9	10	11	Relative Importance Factor
1.	Reusability or Replaceability	6	6	6	2	8	4	6	10	10	4	8	2
2.	Cost	8	4	4	6	2	0	6	2	2	4	6	2
3.	Weight	15	6	6	6	12	9	15	15	12	12	3	3
4.	Vibration Resistance	12	9	3	3	3	6	6	3	3	15	15	3
5.	Fabricability	5	4	4	4	1	1	4	1	1	3	4	1
6.	Ease of Assembly or Disassembly	3	2	2	3	1	1	3	2	2	1	4	1
7.	Simplicity	4	2	2	3	2	2	4	3	3	2	2	1
8.	Geometry	2	2	2	3	3	1	4	2	1	1	2	1
9.	Inspectability	4	1	1	4	2	4	6	2	2	4	6	2
	Total	59 *	37	31	34	34	29	57 *	40	36	46	50 *	

* Designs selected for evaluation

Note: Each score is the value of item (on a basis of 0 to 5) multiplied by the relative importance factor.

4. FINAL FASTENER DESIGN AND FABRICATION

The degree of fastener design refinement was constrained to a feasibility demonstration. Development of the selected fastener systems was carried to a point which was considered sufficient to demonstrate that the fastener designs were lightweight with a multi-mission reuse capability. A description of the important design features of each type follows.

<u>Caged Type Stud with Crimped Retaining Collar</u> - Figure 12 shows an assembly view of the caged stud with the crimped retaining collar in place. The stud has been previously assembled to the cage in the manufacturing operation, making the stud and cage an integral unit. For application, the unit can then be either spotwelded or riveted to the sub-structure.

A principal purpose of the cage type design is to allow the stud to "float", facilitating heat shield assembly. Also, there is enough float in the design to allow the stud to bear against the sub-structure when sustaining joint shear loads, this feature prevents the cage from experiencing principal joint stress.

Detailed design of the stud for the caged type fastener is shown in Figure 13. Of particular interest is the 60° groove located near the top of the stud shank. The main purpose of the groove is to retain the collar, Figure 14, when it is crimped in the assembly operation. The 60° ramp in the stud groove also serves the purpose of creating clamp load in the joint when the collar is crimped. This occurs when deformed material in the base of the collar contacts the ramp surface and forces the collar against the heat shield.

<u>Clinch Type Stud with Crimped Retaining Collar</u> - The clinch type stud design is shown in Figure 15. Clinching is defined as the operation of swaging or forcing structure material around a hole into the clinch groove. The clinch groove was proportioned to assure an adequate volume of the structure material in the groove to prevent the stud from loosening when subjected to the simulated mission stress and temperature environment. This method of retaining a stud in a structure requires close control of the hole size to assure adequate retention in application. The design of the retaining groove to accept the retaining collar was the same as described above for the caged stud.

<u>Weld Type Stud with Split Ring Retainer</u> - Figure 15 shows detailed dimensions of the welded type stud design. In application, the head is spotwelded to the sub-structure for permanent retention of the stud. The 60° retaining groove on the stud is designed to accept the split ring retainer shown in Figure 17. The split ring is assembled into the groove by means of a tool to squeeze on the outside diameter of the ring. When the ring is squeezed, the inner surface of the ring contacts the 60° ramp, forcing the ring against the heat shield.

A design limitation was imposed on the maximum protrusion of the fastening systems above the heat shield surface of .317 cm (.125 in.) For the three types of fasteners evaluated, the actual protrusion was:

1. Caged Stud with Crimped Retaining Collar: .310 cm (.122 in.)
2. Clinched Stud with Crimped Retaining Collar: .310 cm (.122 in.)
3. Welded Stud with Split Retaining Ring: .190 cm (.075 in.)

Fastener Fabrication - Fabrication of all fastener members was accomplished with tooling and equipment now normally used in fastener manufacture. No special or undeveloped techniques were required. Machining properties of the Haynes 188 material was comparable to other high temperature alloys such as Waspaloy. Forging operations on the caged type stud head were accomplished at 1255 K (1800°F). The Haynes Alloy No. 188 sheet was formed and trimmed with no excessive difficulty when fabricating the cage for the stud. Tool life was reduced, and machining time increased, as compared to that for carbon or alloy steels.

Photographs of manufactured parts of each type of fastener are shown in Figures 18, 19, and 20.

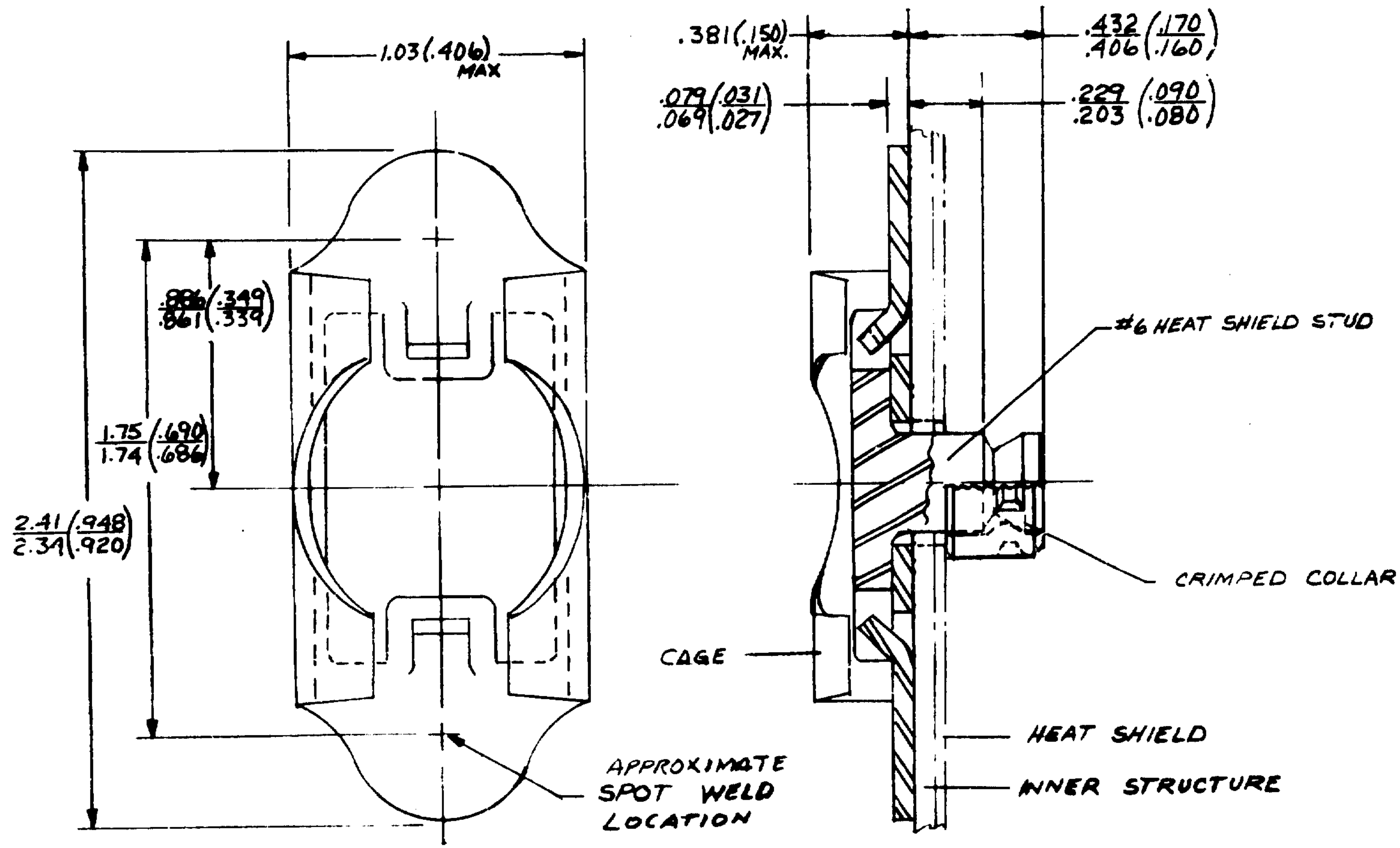


Figure 12. Caged Type #6 Fastener with Collar Retainer, Assembly. Dimensions in cm (inches).

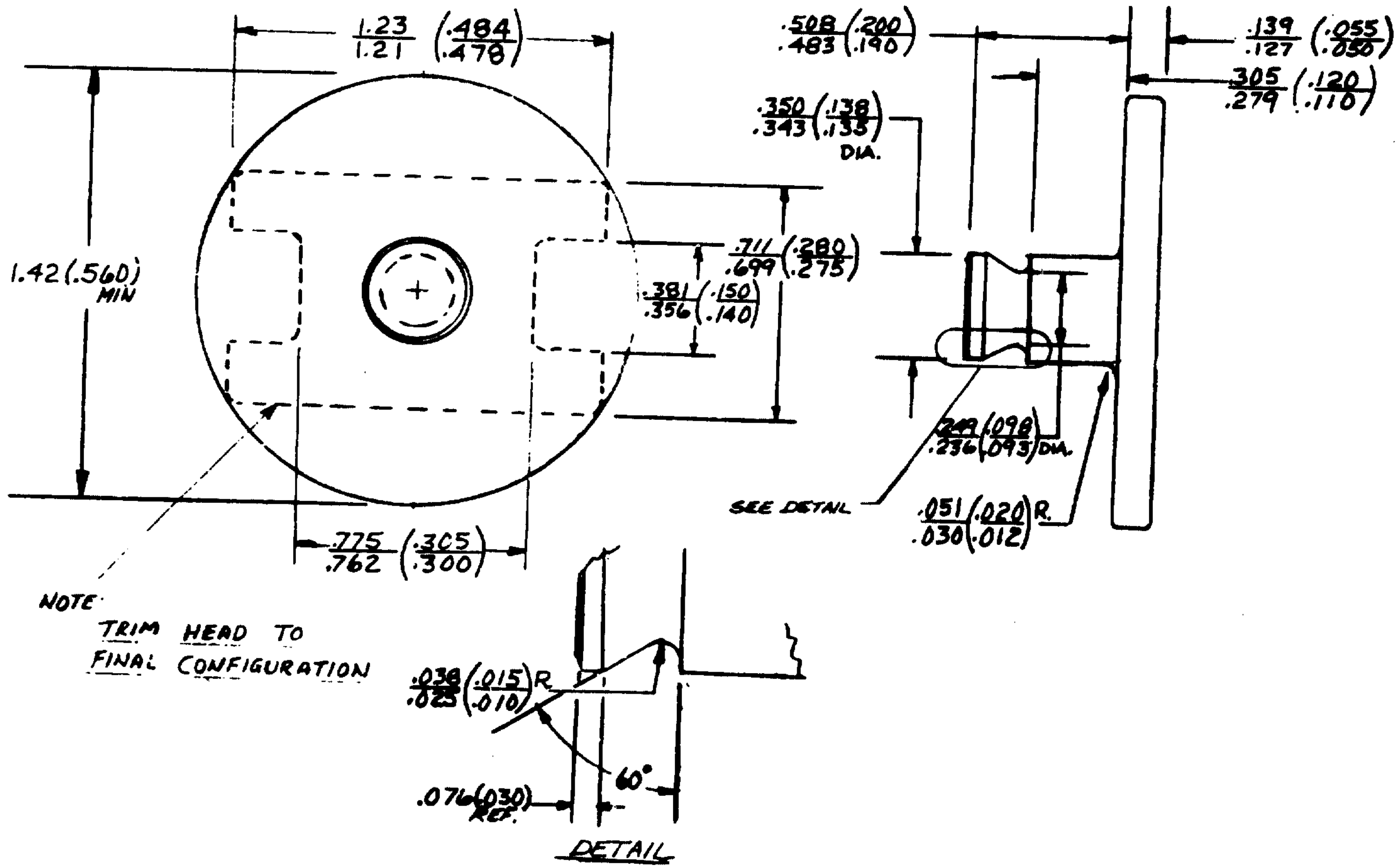


Figure 13. Caged Type #6 Fastener, Stud Detail Dimensions in cm (inches).

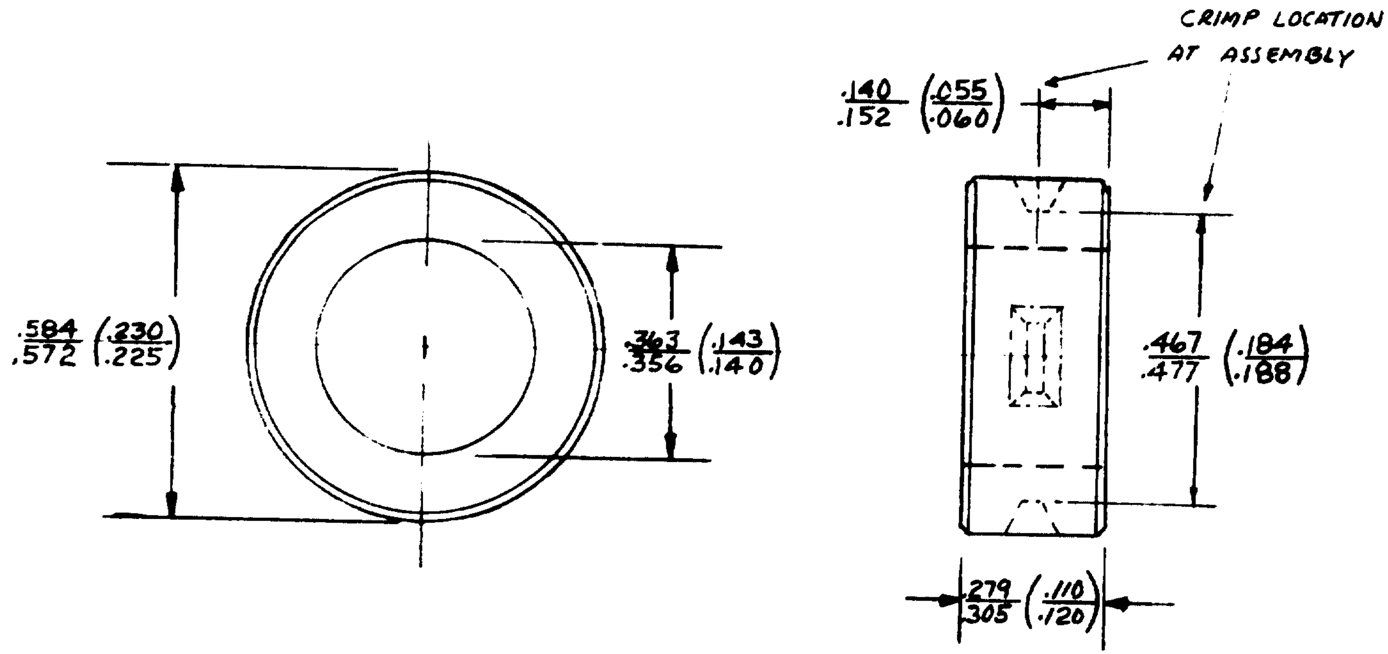
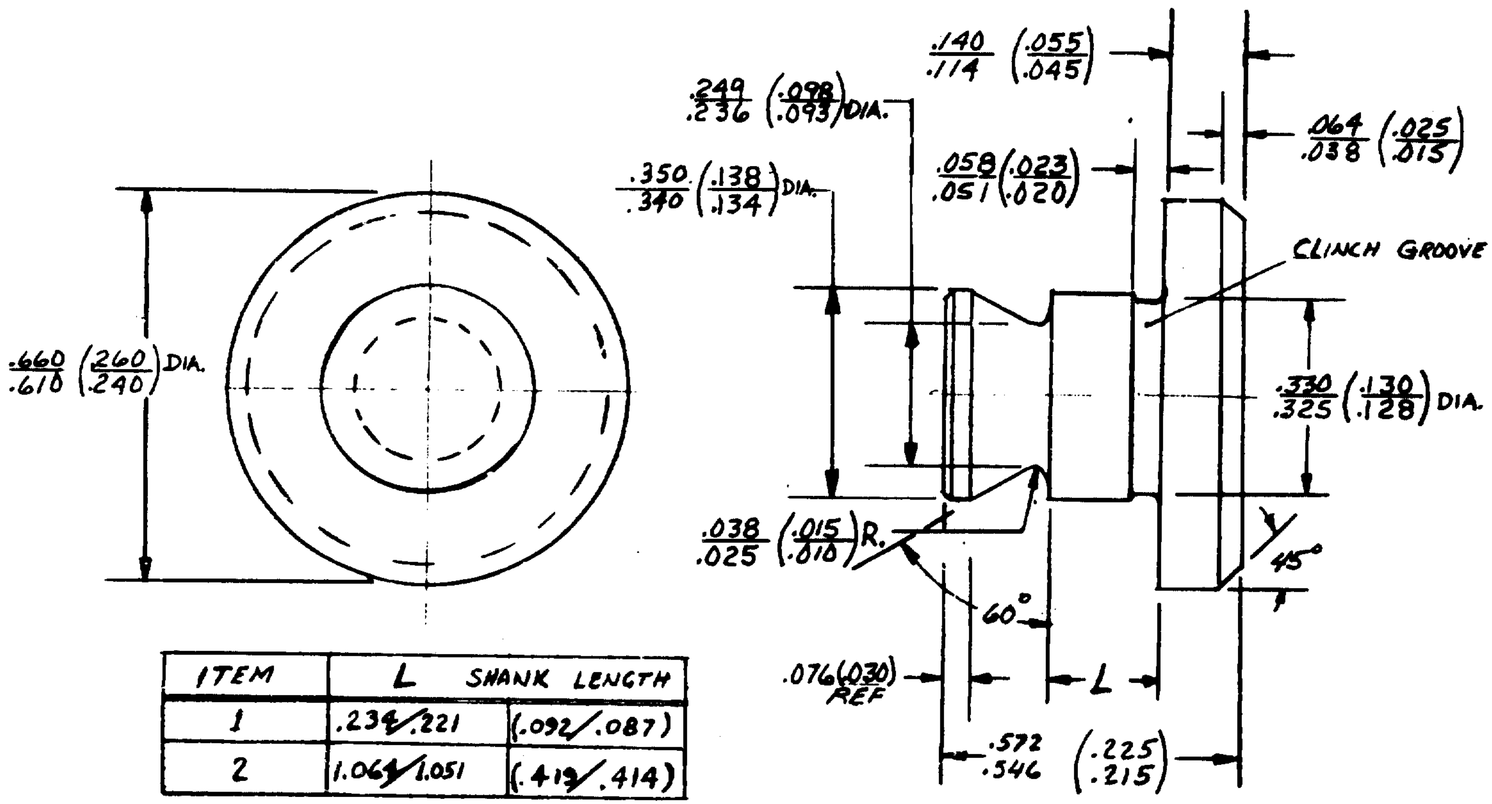


Figure 14. #6 Crimp Type Collar Retainer Dimensions in cm (inches).



ITEM	L	SHANK LENGTH
1	.234/.221	(.092/.087)
2	1.064/1.051	(.419/.414)

Figure 15. Clinch Type Fastener
Dimensions in cm (inches).

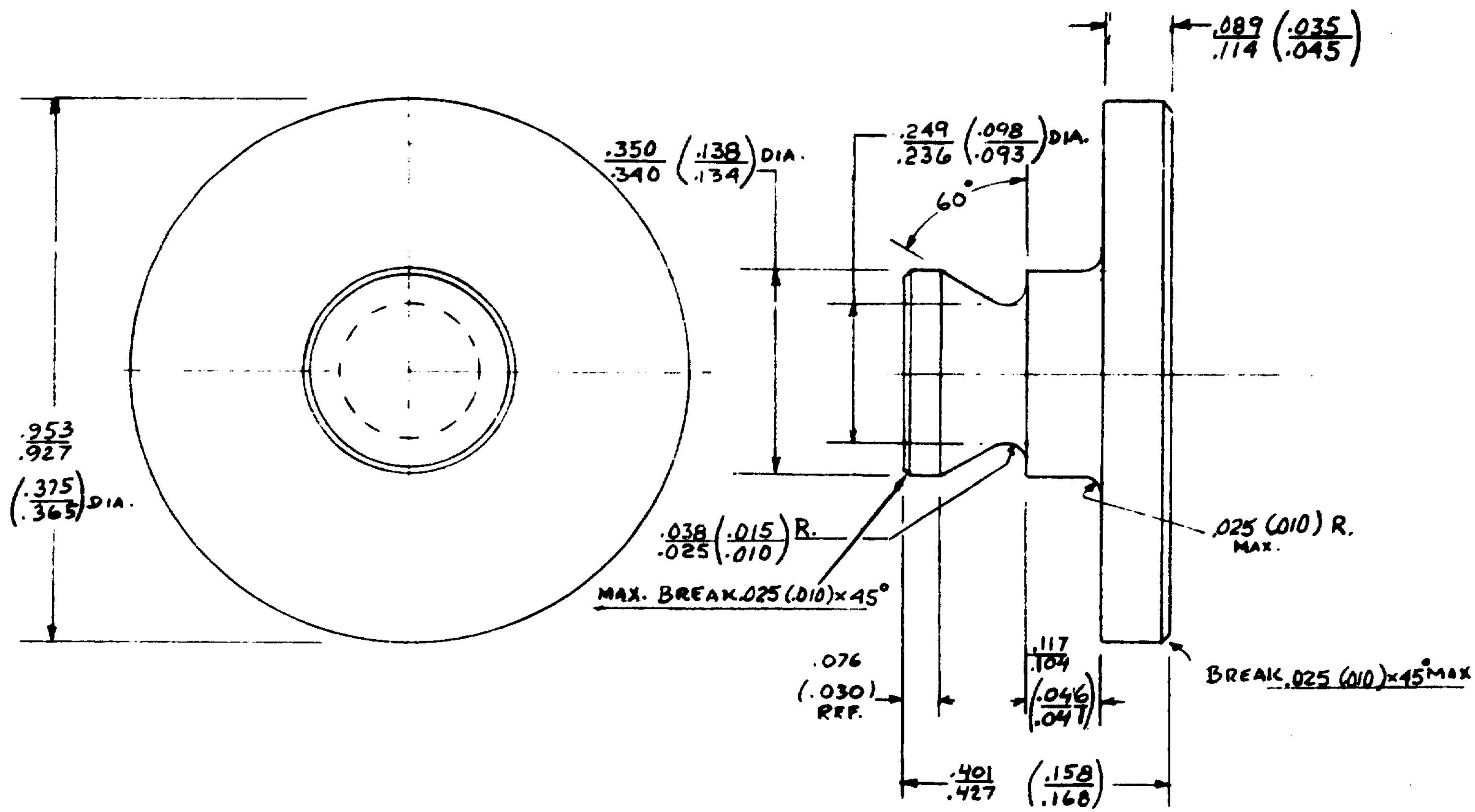


Figure 16. Weld Type Fastener
Dimensions in cm (inches).

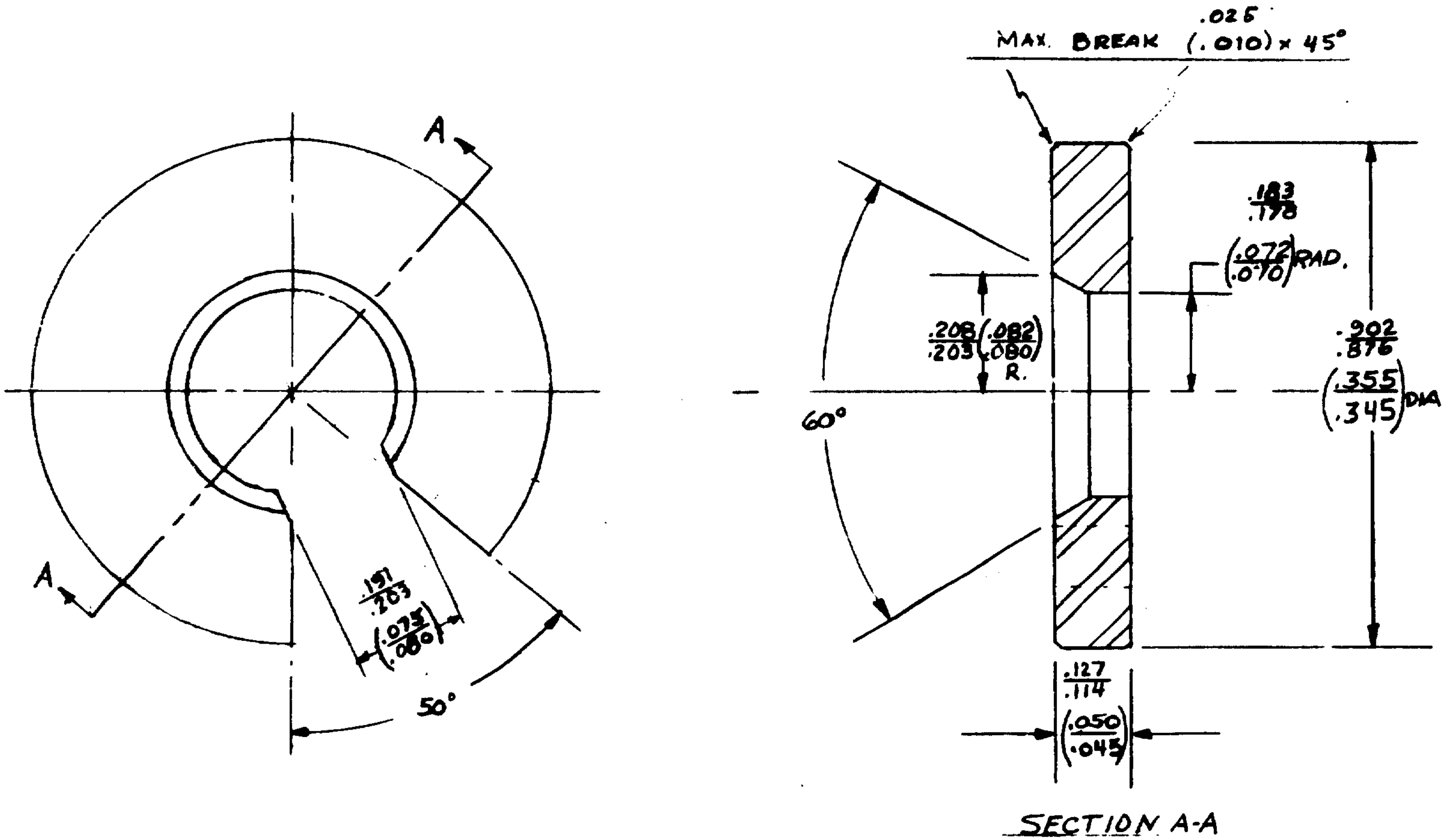


Figure 17. #6 Split Ring Retainer
Dimensions in cm (inches).

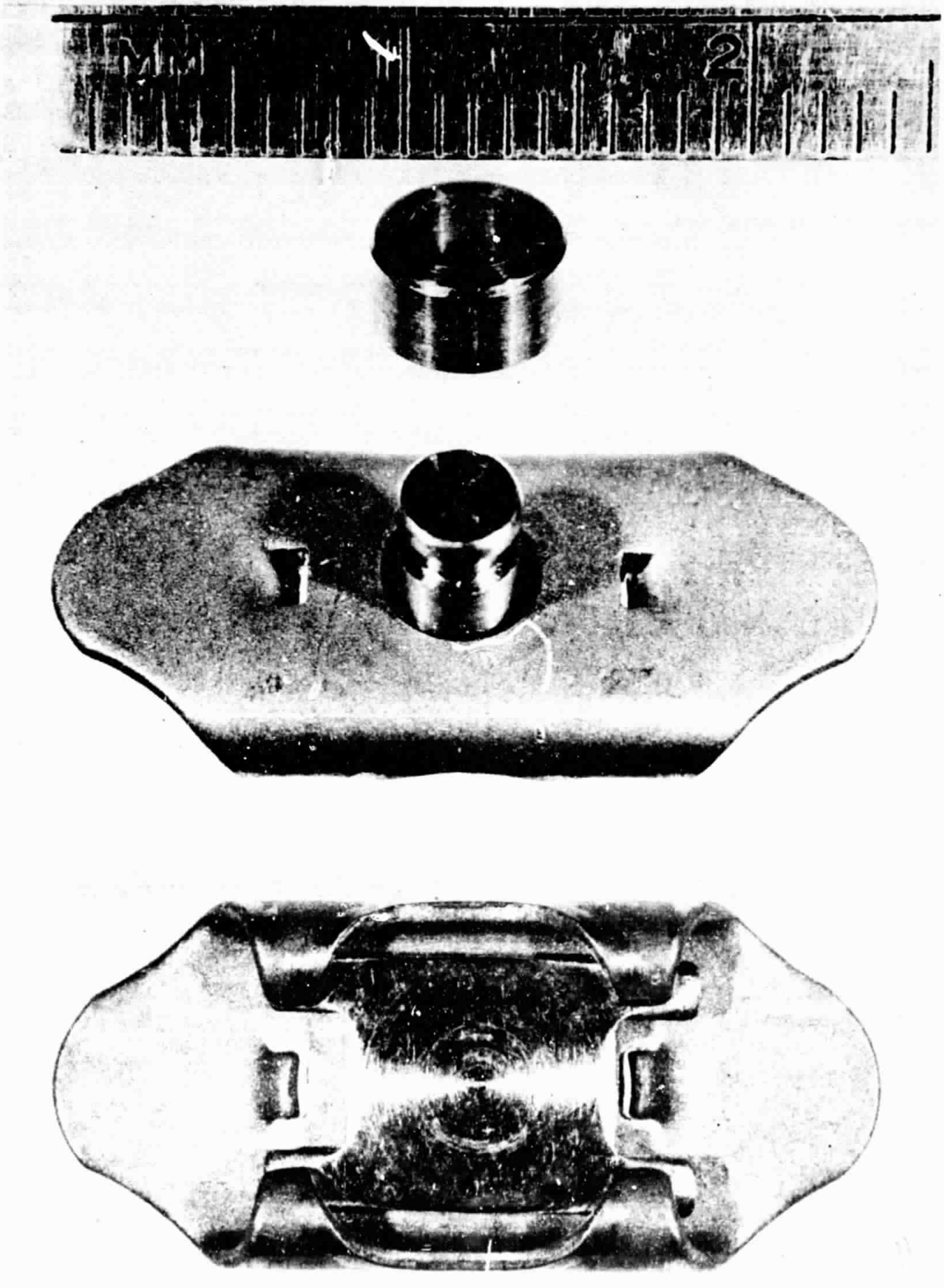


Figure 18. Cage Type Fastener with Collar Retainer

Figure 19. Clinch Type Fastener with Collar Retainer

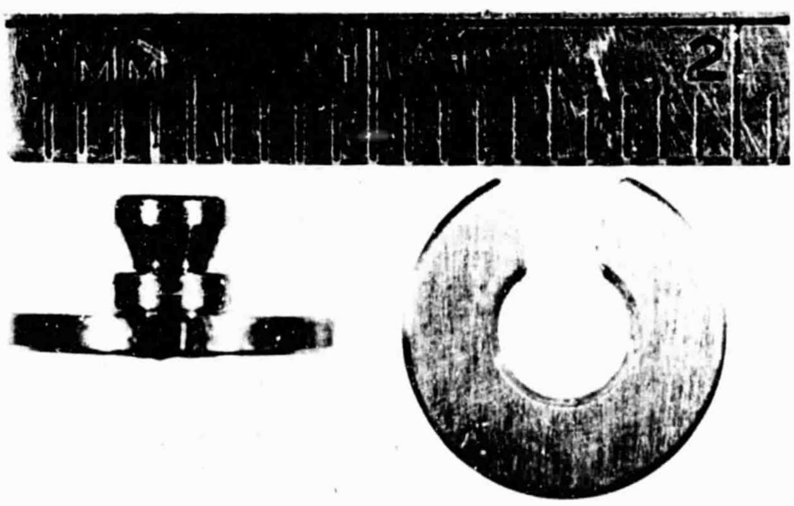


Figure 20. Weld Type Fastener with Split Ring Retainer

5. FASTENER ASSEMBLY AND DISASSEMBLY METHODS

Assembly and disassembly of the fasteners evaluated required some special tooling. Since the program was directed at feasible fastener designs for the intended application, tools to assemble and disassemble were of a simplified nature to minimize design cost and time. However, production tools based on the methods used to complete this program can be readily developed fo a specific fastener application.

Stud Assembly Methods - The three types of fasteners were assembled into joints representative of a fastening point between heat shield and sub-structure. The heat shield was represented by a 2.54 cm (1.00 in.) wide by .048 cm (.019 in.) thick strip of Haynes 188 material. The sub-structure was represented by a 2.54 cm (1.00 in.) wide by .073 cm (.029 in.) thick strip of the same material. The two sections were assembled with a 2.54 cm (1.00 in.) overlap to form a lap shear specimen for joint strength determinations.

Figure 21 shows the assembly operation of spotwelding the cage type stud to the sub-structure material. Care was taken in positioning the cage to prevent the shank of the stud from bearing against the sub-structure hole which would induce loads in the cage during spotwelding. The spotwelding equipment was a Unitek machine Model No. 1-132-02 with the current density reading of 100 watt seconds when the welds were made. An alternate method of fastening the cage to the structure would be by means of riveting.

Figure 22 shows the method of assembling the clinch type stud to the sub-structure material. A clinching tool, Figure 23 was used to clinch the sheet material into the groove located under the head of the stud. As seen in Figure 22, the stud was inserted through the sheet. The head of the stud was supported on a flat surface, the staking tool placed over the stud shank and a force of 13344 N (3000 lbf.) applied to the assembly in a tensile machine. The pushout force to remove the stud from the sheet after assembly, was 364 N (82 lbf.) to 890 N (200 lbf.) for five tests. This amount of pushout proved to be adequate since no studs loosened in the cyclic tests described in Section 6.

Figure 24 shows the method of fastening the weld type stud to the sub-structure material. The Unitek machine was again utilized for this operation with the current density reading at 120 watt seconds at the time of welding. The head of the stud was welded at four equally spaced spots approximately .078 cm (1/32 in.) from the edge of the head.

Retainer Assembly Methods - Assembly of the crimp type collar retainer to the cage and crimp type studs, was accomplished by use of a collet mechanism powered by a hydraulic cylinder. When the collet was retracted into the tapered sleeve, Figure 25, the jaws, (detail in Figure 26), crimped the collar in four places to a root diameter of .473 cm (.186 in.). Care was taken to have the collar in contact with the sheet before crimping.

Assembly of the split-ring type retainer to the weld type stud was again by means of a collet type arrangement. A standard 5C lathe type collet size .912 cm (.359 in.) was used to squeeze the ring to an assembly diameter of .818 cm (.322 in.). See Figure 27 for a photograph of the tooling arrangement.

Disassembly Methods - Disassembly of test joints was accomplished by the removal of the collar and the split-ring retainers. Removal of these retainers allowed the removal of the .048 cm (.019 in.) strip, representing heat shield disassembly.

Removal of the collar type retainer was accomplished with a splitting tool arrangement. Two cutting tools with a 45° included angle cutting edge were mounted in a machinists' vise and pressure applied to split the collars. See Figure 28 for a photograph of this operation.

Removal of the split-collar retainer was also accomplished with the aid of the machinists' vise. For this method, a blunt wedge tool with a wedge angle of 90° was forced into the split section of the retaining ring. A support tool was positioned opposite the wedge to sustain the resultant wedging force. Figure 29 illustrates the disassembly operation.

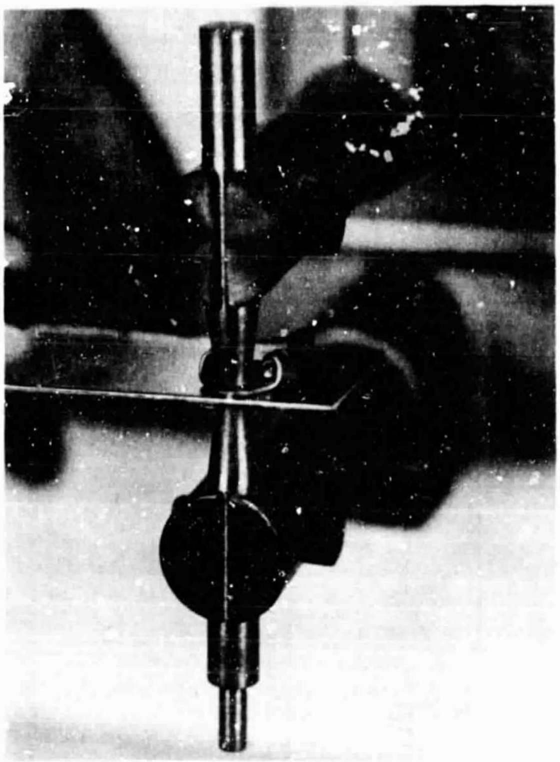


Figure 21.

Assembly of Cage Type Stud to Sub-Structure Material

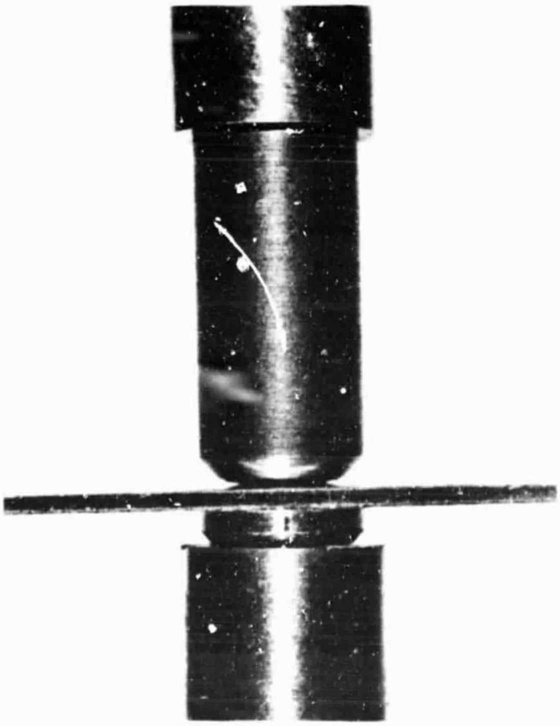


Figure 22.

Assembly of Clinch Type Stud to Sub-Structure Material

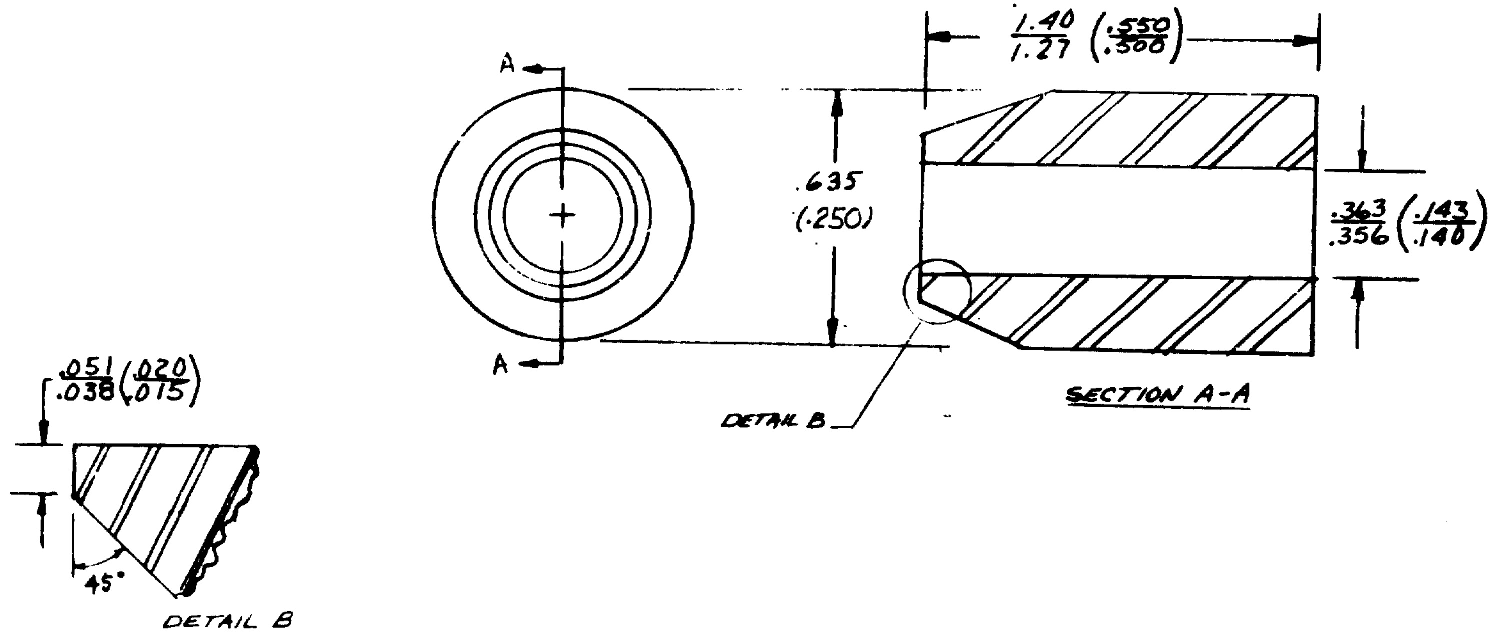


Figure 23. #6 Heat Shield Fastener Clinching Tool Dimensions in cm (inches).

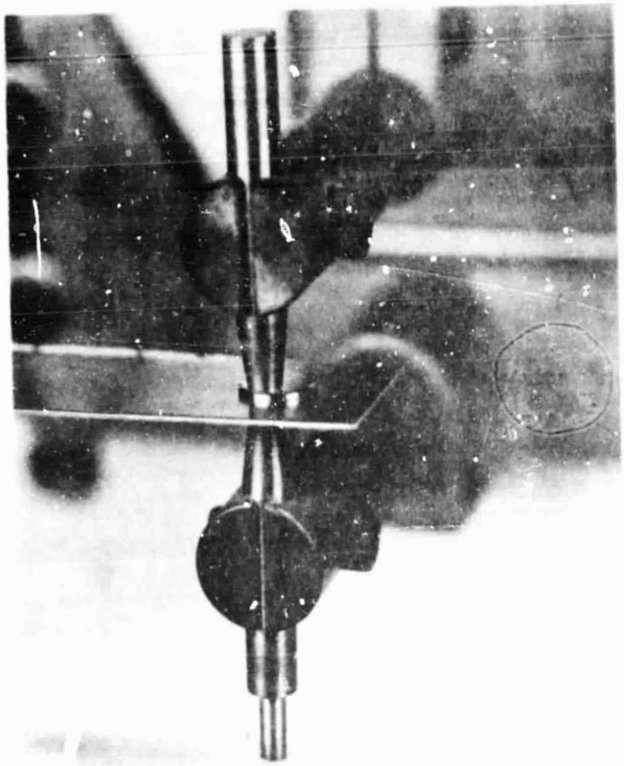


Figure 24.

Assembly of Weld Type Fastener to Sub-Structure Material

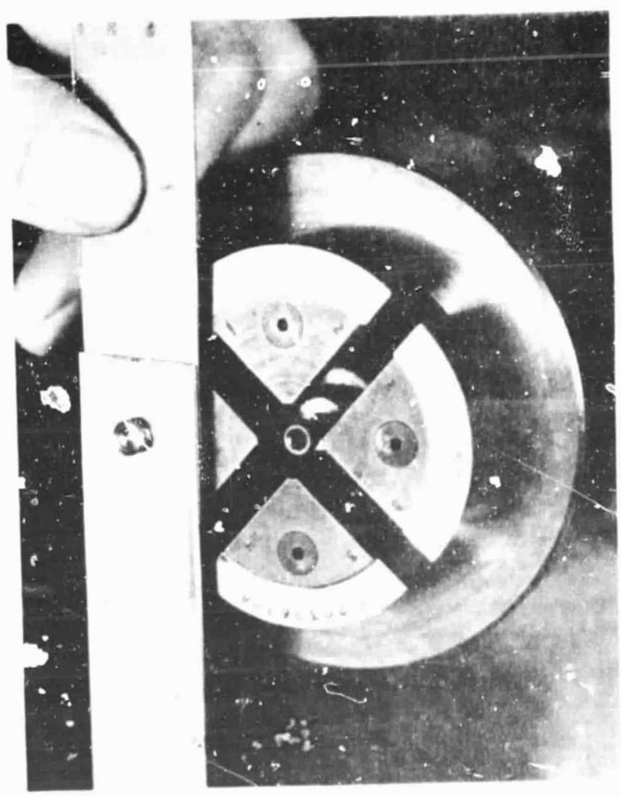


Figure 25.

llar Retainer Crimping Tool

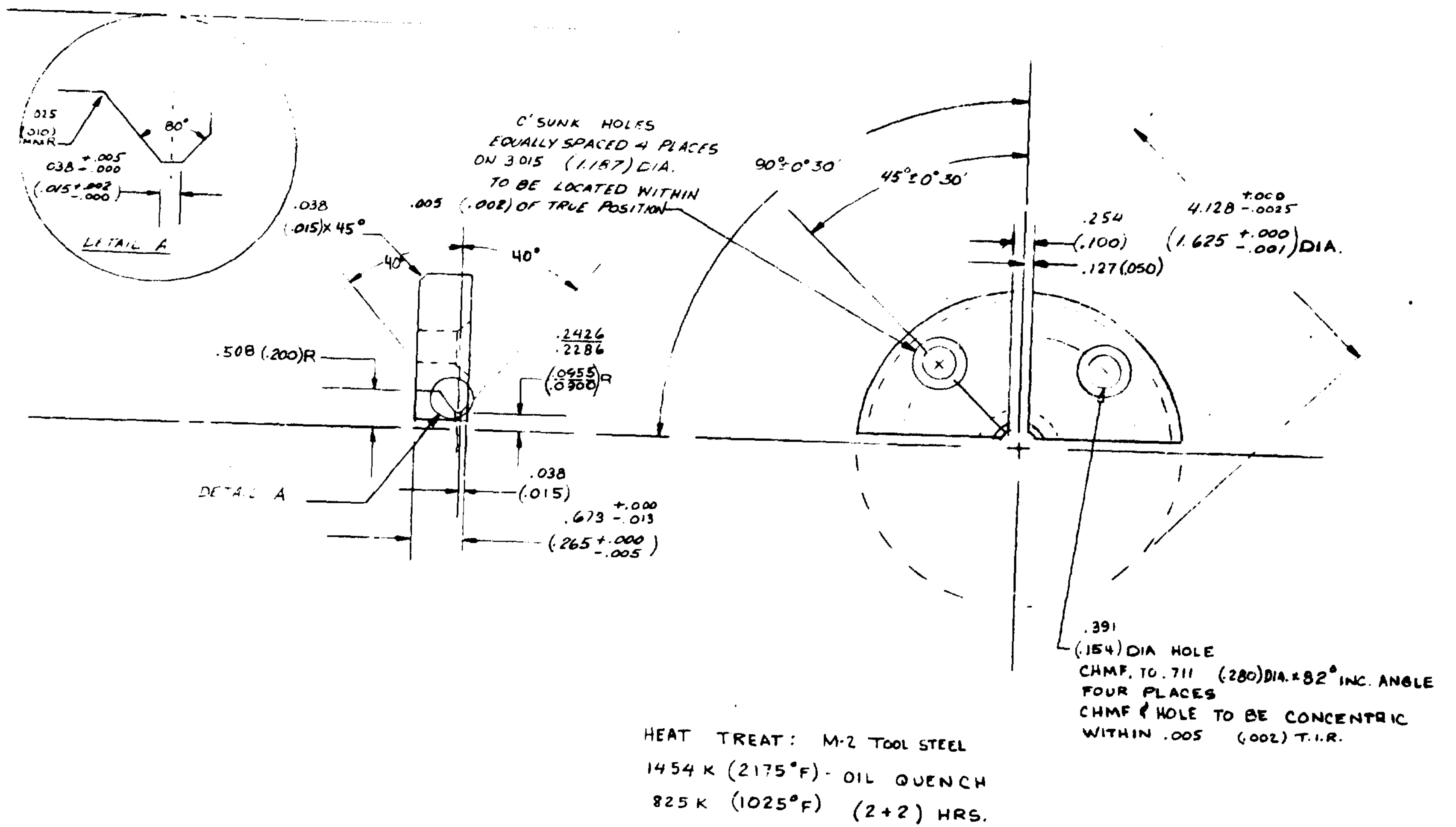


Figure 26. Matched Set of Crimping Inserts for #6 Crimp Type Collar Dimensions in cm (inches).

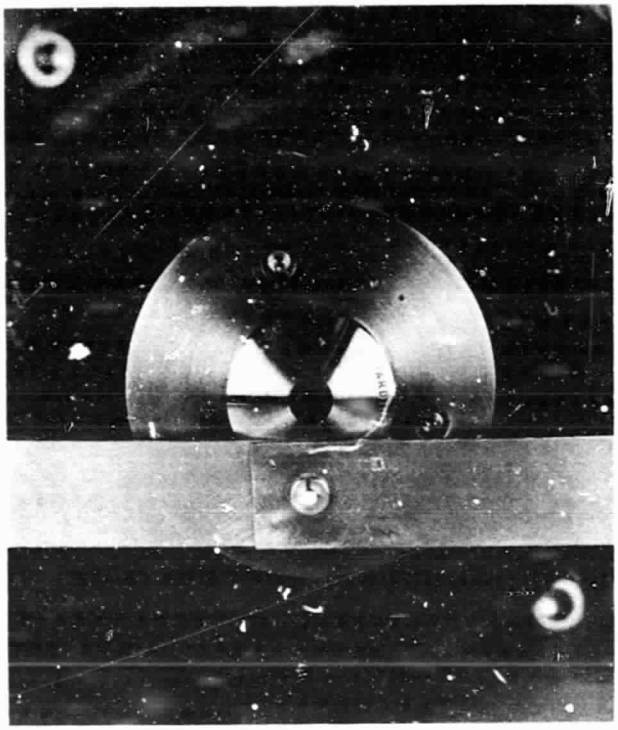


Figure 27. Split-Ring Squeezing Tool

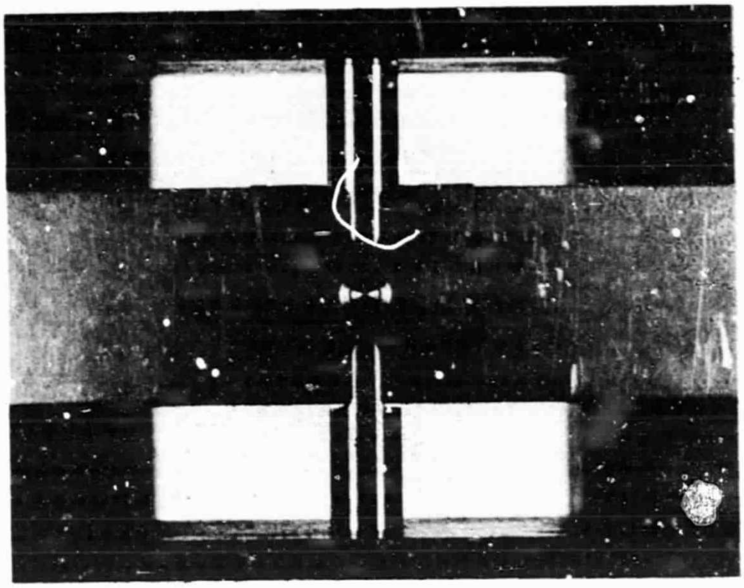


Figure 28. Disassembly of the Collar Type Retainer

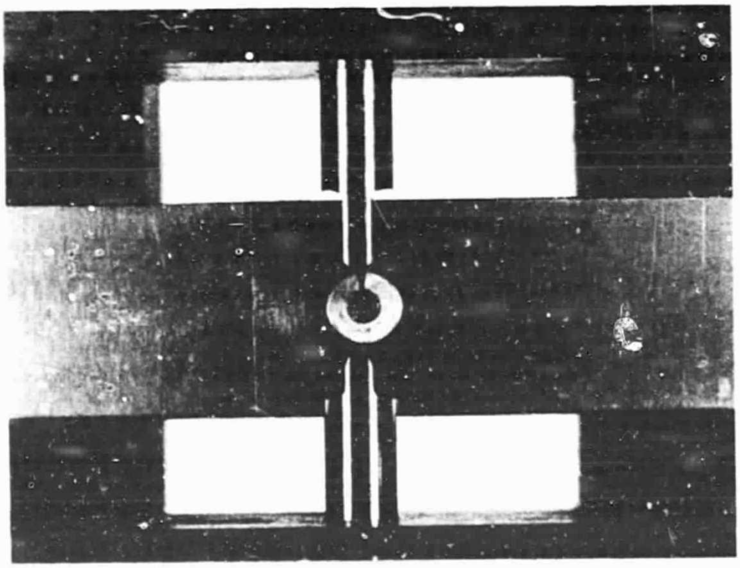


Figure 29. Disassembly of the Split-Ring Type Retainer

6. TESTING PROCEDURES AND EQUIPMENT

Strength determinations of the fastening systems necessitated two types of tests to obtain the type of data required. The tests were classified as joint strength and fastener strength tests. The joint strength tests indicated the performance of the fasteners in a simulated aerospace vehicle structure. The fastener strength tests indicated the mechanical strength properties of the fastener irrespective of joint design. This procedure was essential since the simulated vehicle structure was not of sufficient strength to cause fastener failure.

Joint Strength Tests - The simulated vehicle structure test joint is shown in Figure 30. The joints were fabricated from 2.54 cm (1.00 in.) wide strips of Haynes 188 material. Strip thicknesses were .073 cm (.029 in.) and .048 cm (.019 in.) representing sub-structure and heat shield respectively. The strips were overlapped 2.54 cm (1.00 in.), and a drilled .355 - .363 cm (.140 - .143 in.) hole centered in the overlapped section to receive the test fastener. The 1.27 cm (.500 in.) hole provided at each end of the test joint was provided for mounting in the test machine fixtures. The overall length of the test assembly was 60.9 cm (24 in.).

Simulated mission cycle, and ultimate joint strength tests were conducted with the test joints described above. A typical test arrangement on an Instron Universal Testing Machine is shown in Figure 31. The furnace was an R I Quad Elliptical Radiant Heating Chamber Model E4-5. In the particular setup shown in Figure 21 a survey of the temperature in the fastener test area was in process. A temperature survey is shown in Figure 32. Thermocouple No. 1 placed on the fastener was used for control.

For the simulated mission cycle testing the Instron machine was programmed to produce a cyclic 60 minute load-temperature profile. A sensitive load cell at the upper end of the specimen mount and a thermocouple in contact with the fastener under test were utilized in a closed loop control system during the tests. Figure 33 shows a block diagram of the control system.

The temperature/load profile used to simulate the mission cycle is shown in Figure 34. This profile was reproduced with the control system as shown on a tracking record in Figure 35. Some deviation is noted at temperatures below 477 K (400°F) due to the cool-down rate of the test specimen and furnace. Critical points in the test program are noted in Table 3 where actual readings of load and temperature are listed for a typical one hour simulated mission cycle.

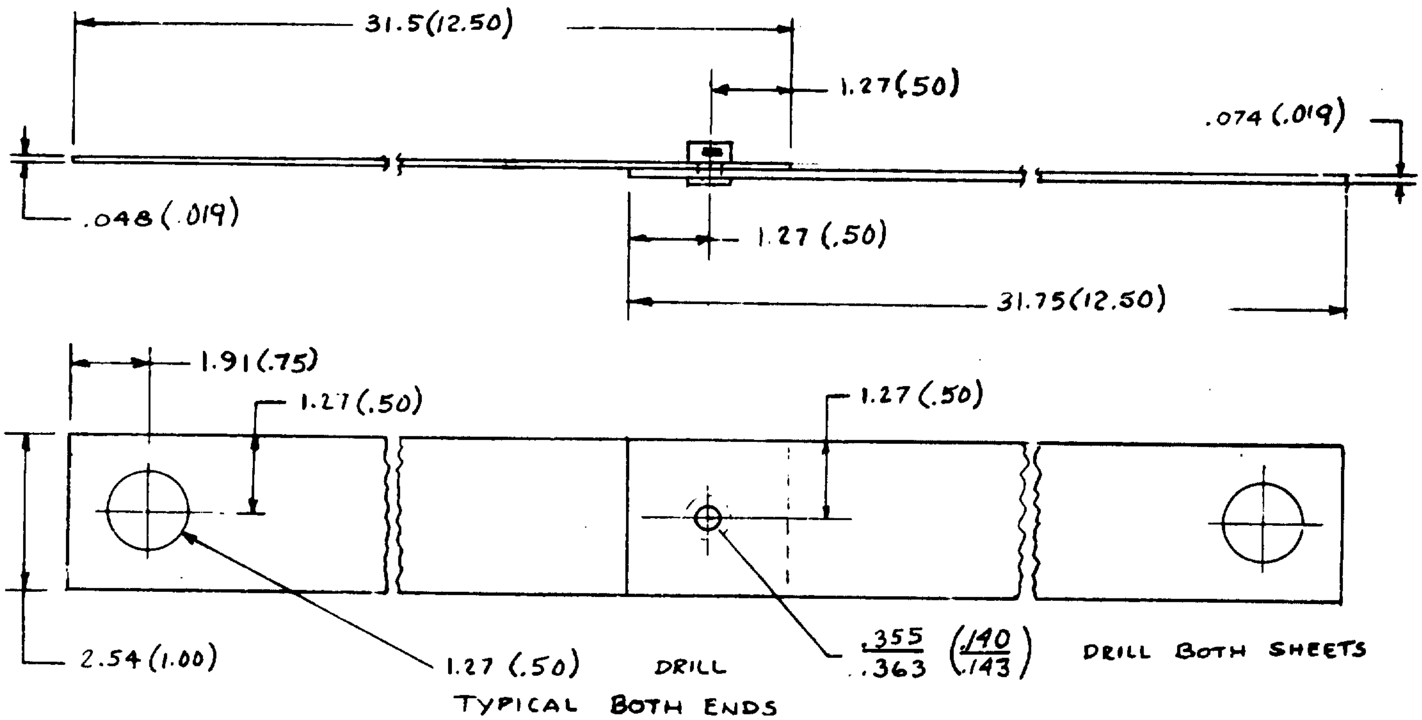


Figure 30. Simulated Vehicle Structure Test Joint
Dimensions in cm (inches)

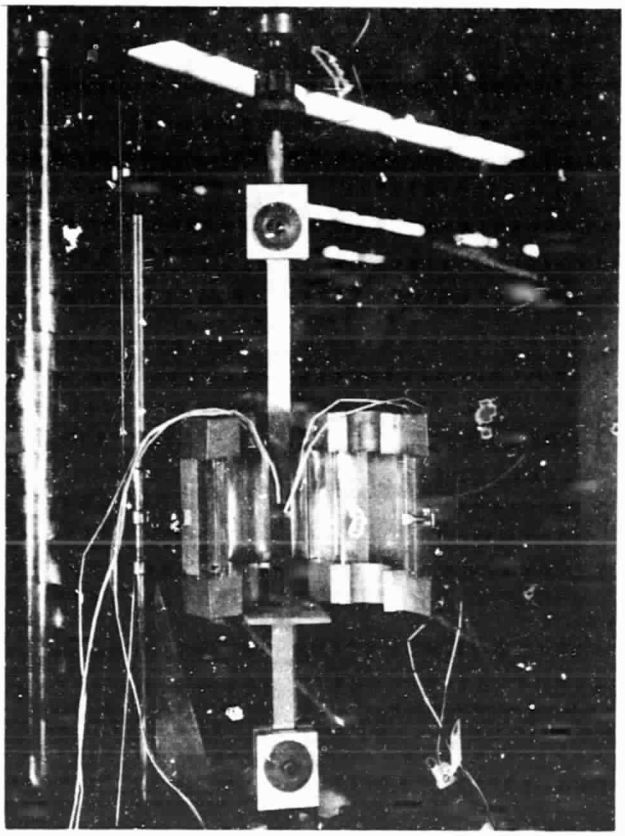
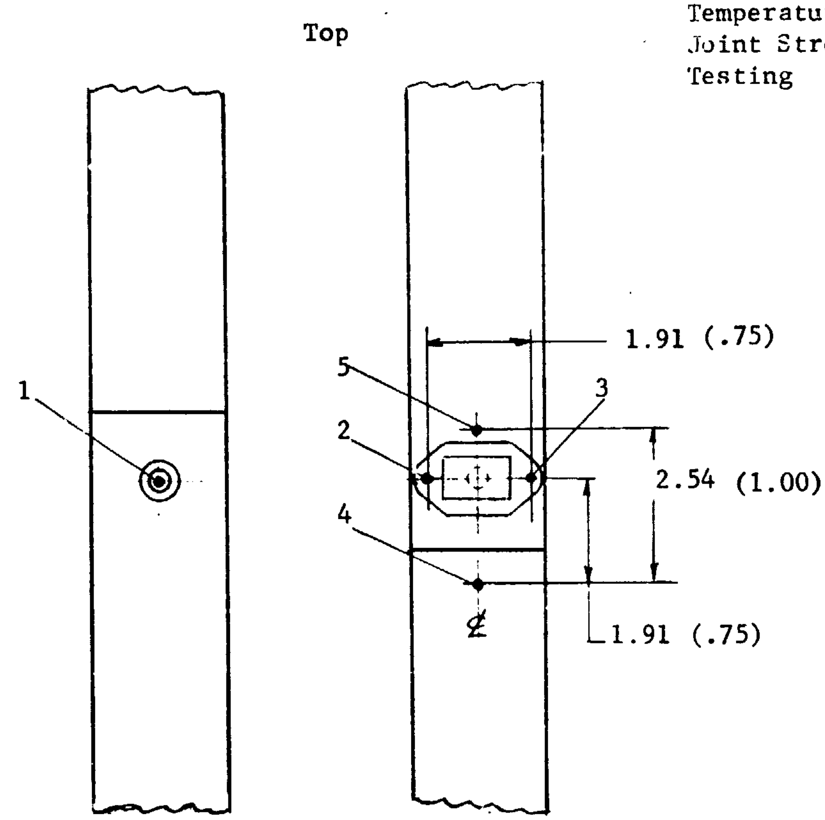


Figure 31. Typical Test Arrangement for Cyclic Testing

Figure 32

Temperature Survey, Joint Strength Cyclic Testing



Thermocouple No.	Temperature		
1 (Control)	702 K (804°F)	1088 K (1500°F)	1255 K (1800°F)
2	701 K (803°F)	1087 K (1497°F)	1250 K (1790°F)
3	703 K (806°F)	1096 K (1515°F)	1261 K (1810°F)
4	697 K (795°F)	1088 K (1500°F)	1255 K (1800°F)
5	705 K (810°F)	1094 K (1509°F)	1257 K (1804°F)

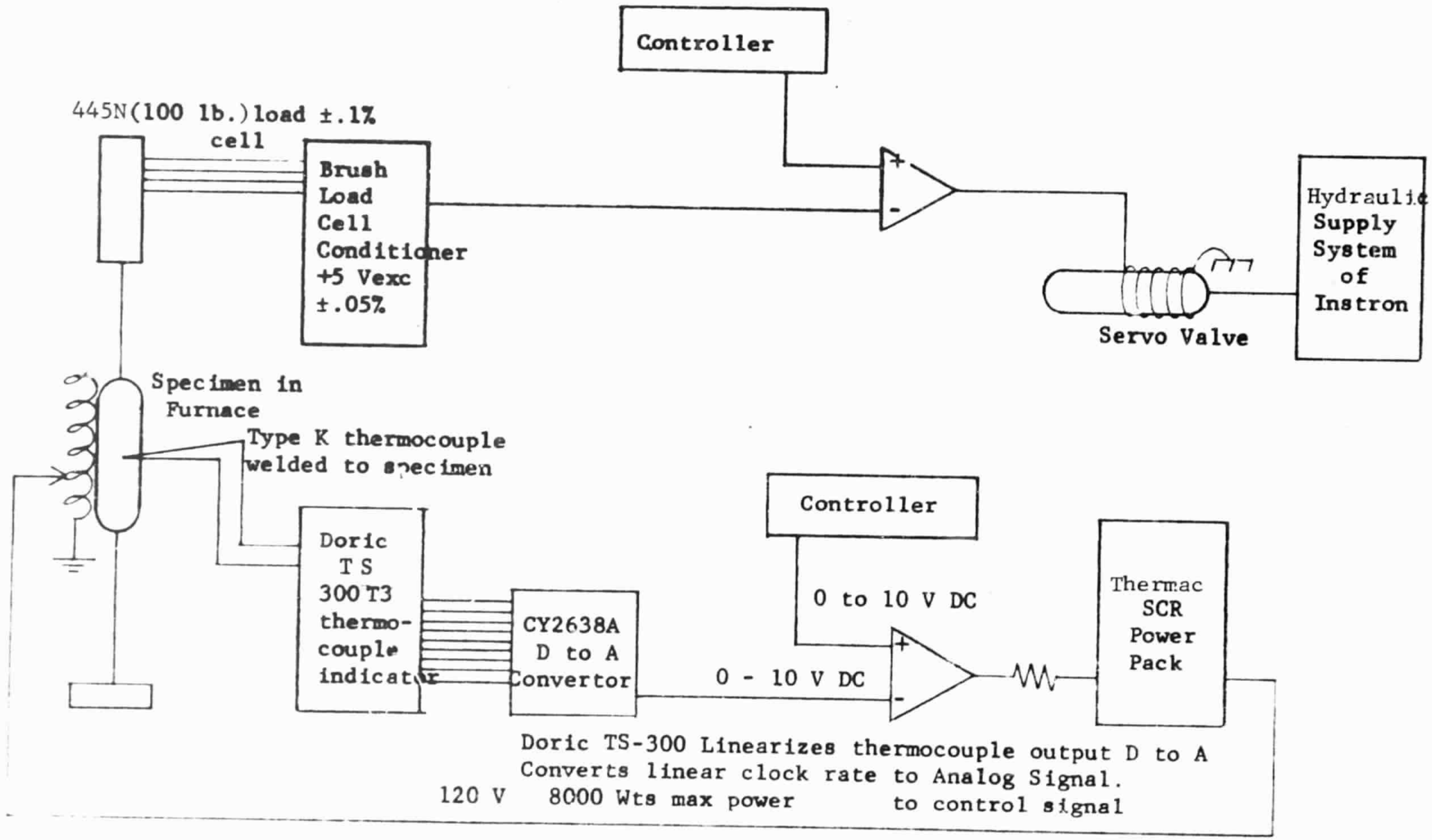


Figure 33. Block Diagram of Load and Temperature Control Systems

Heat Shield Panel - Cyclic Test Profile

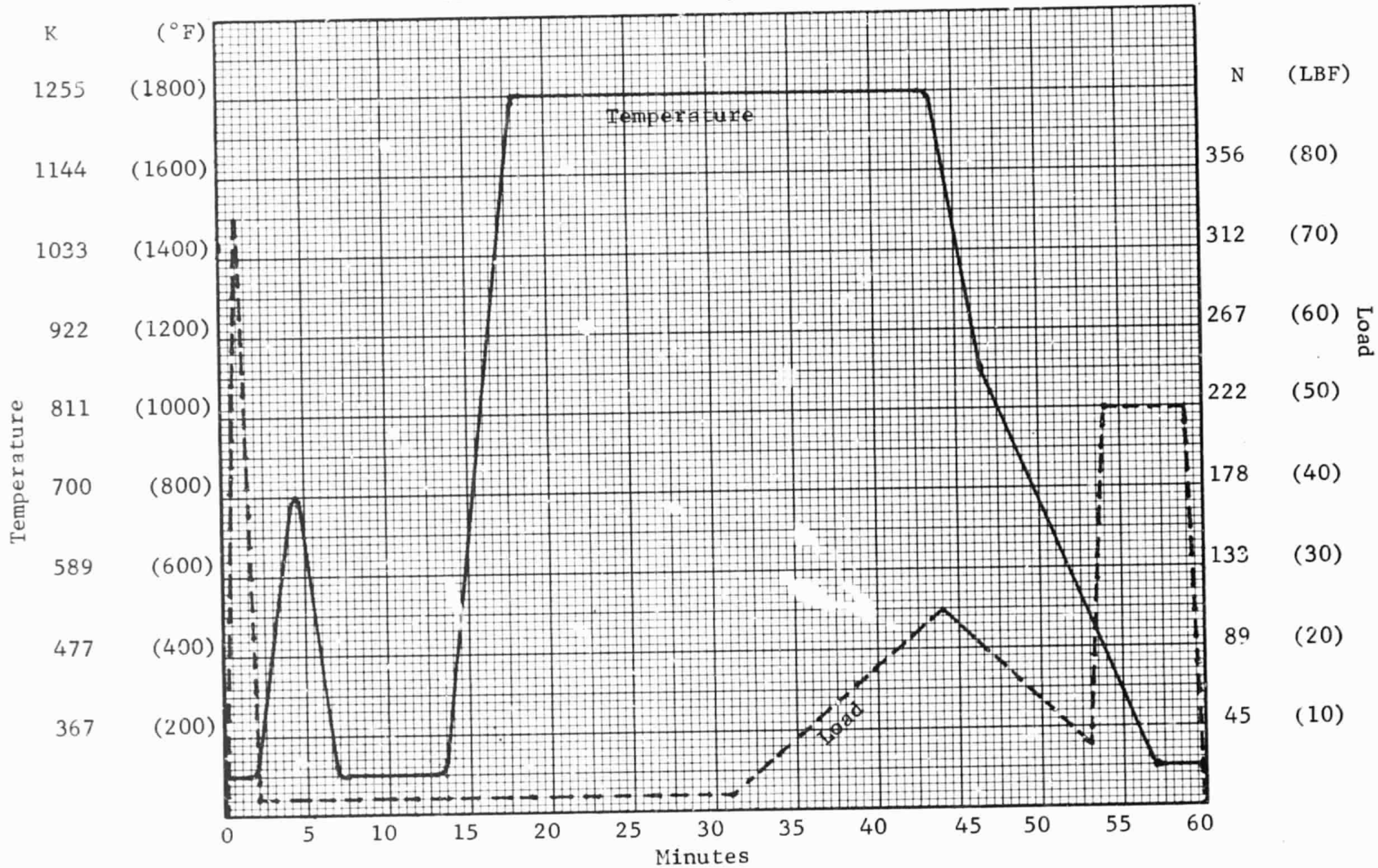


Figure 34. Temperature/Load vs. Time Profile

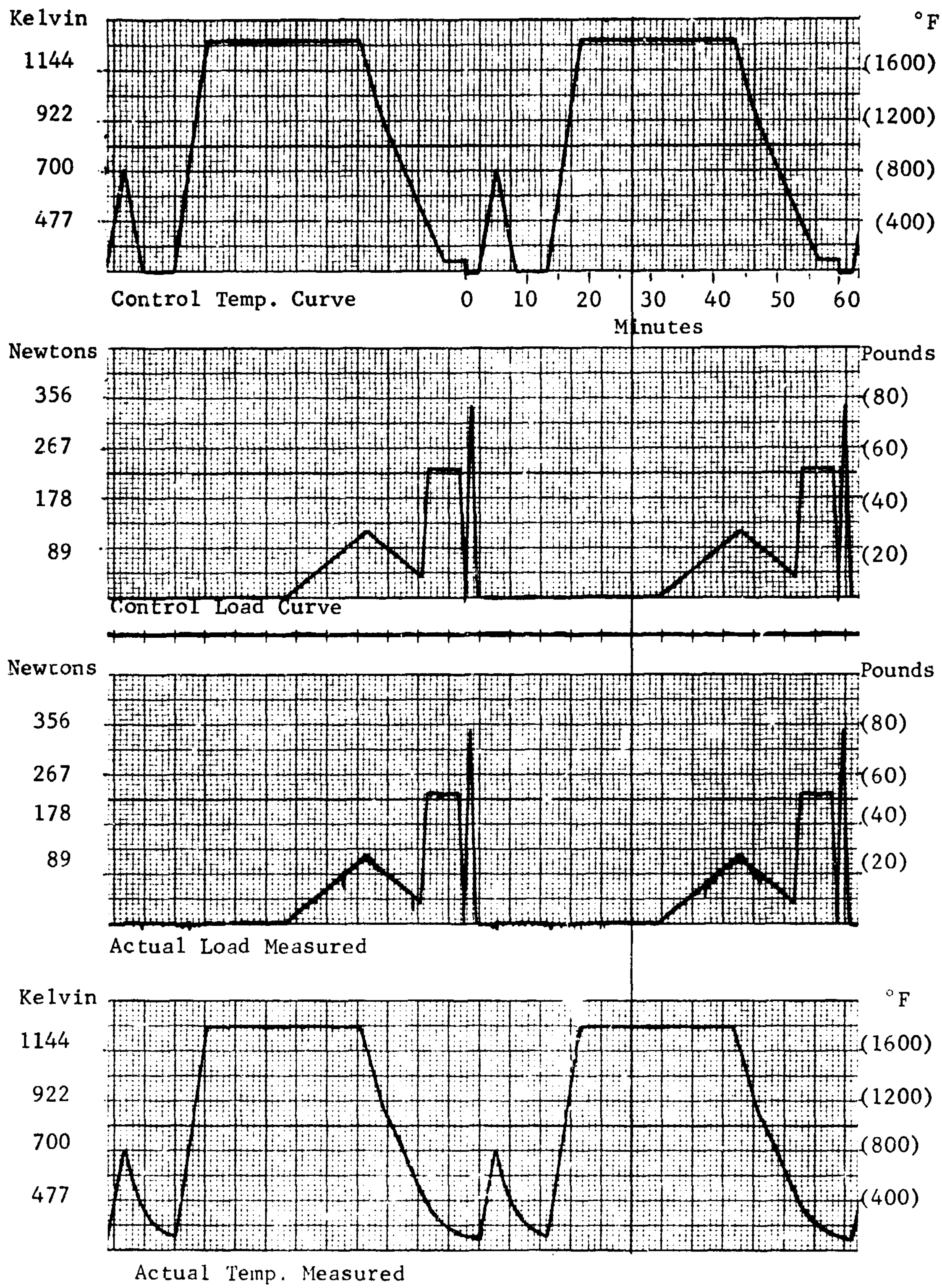


Figure 35. System Tracking Record of Control vs. Actual Test Parameters

TABLE 3

Actual vs. Programmed Load and Temperature Results

Cycle Check Point	Load Program	Actual	Temp. Program	Actual
1 Min.	334 N (75 lbf.)	339 N (76.2 lbf.)	Ambient	316 K (110°F)
44 Min.	111 N (25 lbf.)	108.5 N (24.4 lbf.)	1200 K (1700°F)	1204 K (1707°F)
53 Min.	35.5 N (8 lbf.)	37.8 N (8.5 lbf.)	505 K (450°F)	519 K (475°F)

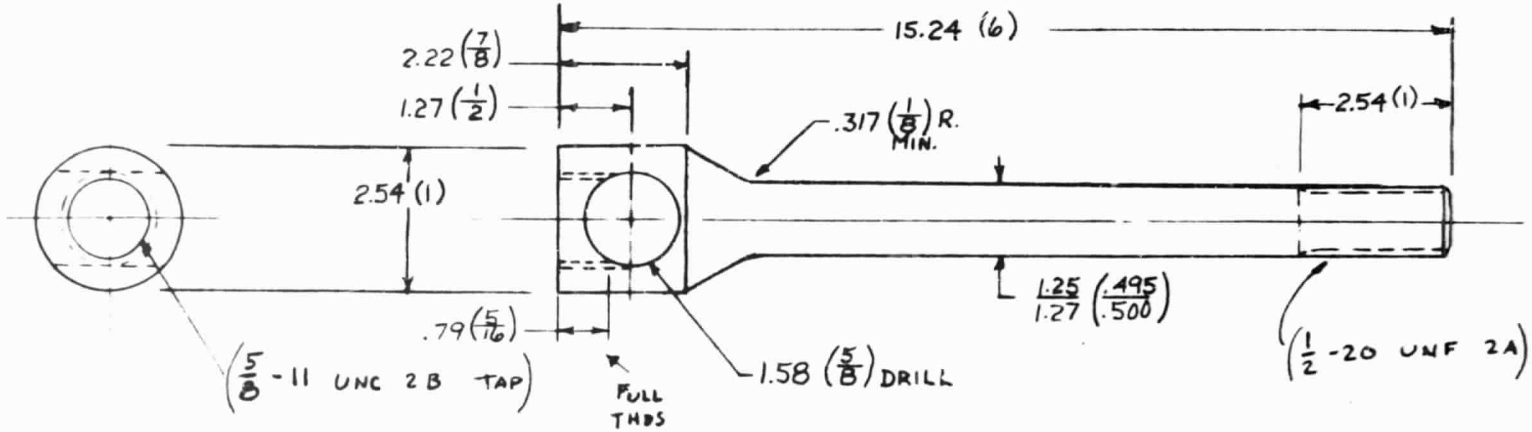
Mission simulation consisted of running each test specimen through ten one-hour cycles with the profile described. At the end of each ten cycles, the joint was disassembled and examined for any effects from the test. The test joint was then reassembled with a new retainer and the cycling continued. After the ninth disassembly, the joint was examined, reassembled, and run for 10 cycles for a total of 100. The joint was then subjected to the residual ultimate strength tests at ambient and elevated temperature.

Fastener Strength Tests - Testing fixtures for the fastener strength tests were fabricated from Haynes 188 material. The fixtures were designed to assure fastener failure.

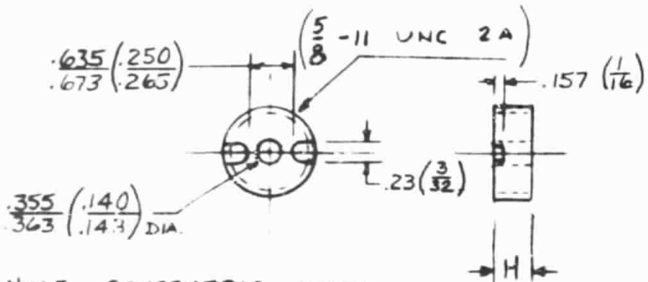
The tensile test fixture design is shown in Figure 36. A photograph of the test assembly, Figure 37 shows how the fixture parts were utilized to run the tests. The fastener was initially assembled into a pair of threaded bushings and then the bushing assembly threaded into the bell shaped fixtures. Item 1 threaded bushings (Figure 36) were used for the crimp type collar retainer and Item 2 bushings were used for the split ring type retainer. The two bushing lengths were necessary in order to place the stud retaining groove in the proper position in the test joint for each type of retainer.

The shear test fixture design is shown in Figure 38. The fastener and retainer were initially assembled in the plain bushings before assembly of the bushings into the shear fixtures. Items 1 and 3 were used for the split ring type retainer. The long clinch type fastener, Figure 15, Item 2, was used for tensile and shear strength evaluations.

The fastener ultimate strength tests at both room and elevated temperature were conducted in a 133440 N (30,000 lbf.) capacity Tinius Olsen Testing machine. This machine was equipped with recording instrumentation to record head travel and load simultaneously. From the curves generated, approximate proportional limit and failure loads were determined.



TEST MANDREL 2 REQ.



HOLE CONCENTRIC WITH THD WITHIN .003 TIR

ITEM	H	
	CM	INCHES
1	.475/.480	(.187/.189)
2	.536/.541	(.211/.213)

TEST BUSHING

2 EACH ITEM REQUIRED

Figure 36. Fastener Tensile Strength Test Fixtures Dimensions in cm (inches).

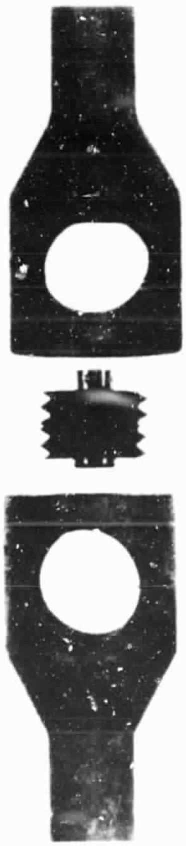
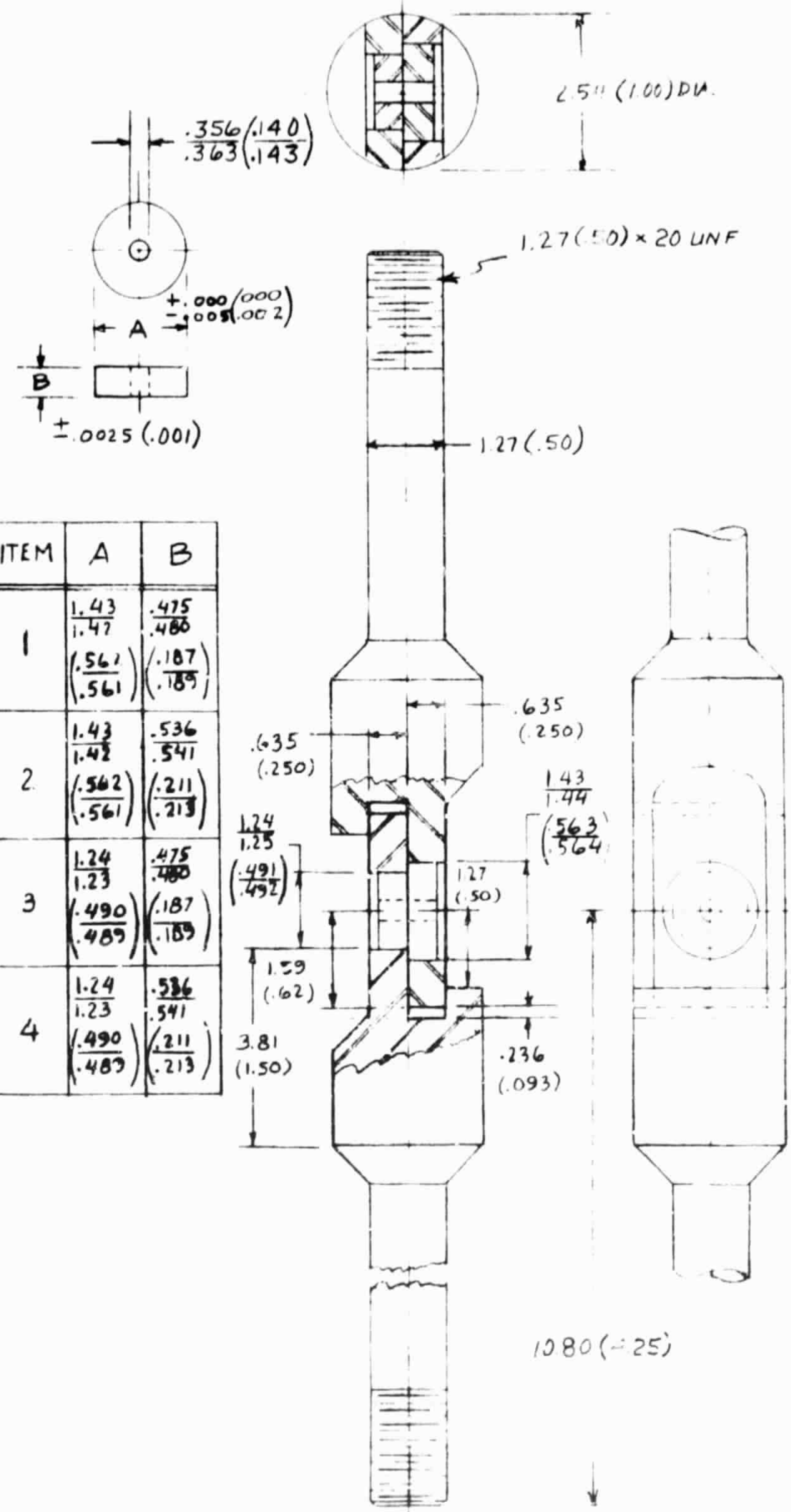


Figure 37. Fastener Tensile Strength Test Assembly (Exploded View)



ITEM	A	B
1	1.43/1.42 (.562/.561)	.475/.480 (.187/.189)
2	1.43/1.42 (.562/.561)	.536/.541 (.211/.213)
3	1.24/1.23 (.490/.489)	.475/.480 (.187/.189)
4	1.24/1.23 (.490/.489)	.536/.541 (.211/.213)

Figure 38. Fastener Shear Strength Test Fixture
Dimensions in cm (inches).

7. RESULTS AND DISCUSSION

There were two types of fastener evaluation results. One was joint strength tests with a simulated vehicle structure and the other was fastener strength tests in joints to characterize the tensile and shear strength of the fastener itself. The results of the joint strength and of the fastener strength tests are summarized in tables that indicate the test parameters.

<u>Joint Strength Test Results</u> - Table 4 shows the joint strength test results for each fastener type evaluated. The results indicate the effect of shuttle cycle simulation on the ultimate shear strength of the simulated vehicle joint. Note that in all cases the ultimate shear strength of the joint was at least 4.8 times the design requirement at room temperature and at least 5.6 times the design requirement at 1200 K (1700°F) after mission simulation. This indicates potential for further lightening of these fastener systems through more detailed design and evaluation.

Tables 5, 6, and 7 show the results of joint and fastener deformation observations made during the 100 cycle shuttle simulation. Examination consisted of checking for cracks of the test joint material or of the fastener, and for any deformation of the joint or fastener at each disassembly. The crack check was made by visual examination with a 10X binocular microscope. Deformation of the .355 - .363 cm (.140 - .143 in.) hole in the .048 cm (.019 in.) sheet was noted and the results record change in hole size from the initial diameter. The tabulated data are the average of the four specimens tested. Table 6 additionally shows results of a pushout test performed on the clinch type fastener to evaluate the clinched joint used to permanently attach the stud to sub-structure. The pushout force of 111 Newtons (25 pounds) was applied to the grooved end of the stud after each test joint disassembly with the joint supported on a flat surface with a hole to clear the head of the stud. The clinched joint passed the pushout test with no evidence of joint loosening.

In all ultimate joint strength tests, except for the three noted in Table 4, failure occurred by tear-through of the .048 cm (.019 in.) sheet. Figure 39 shows a typical failure mode for the three types of fasteners evaluated. This type of failure occurred at both room and elevated temperature.

<u>Fastener Strength Test Results</u> - Tables 8 and 9 show fastener tensile strength and shear strength results respectively. The results indicate the effect of fastener strength of exposure to a load/temperature cyclic exposure. The cyclic exposure schedule for the residual tensile strength tests is shown on Table 10. The schedule included a total of 42 hours at 1200 K (1700°F) with 100 cycles of 84.5 N (19 lbf.) loading. Assembly and disassembly of the fasteners was also included during the exposure. Again in all cases the ultimate strength was several times the design requirement showing that these fastener systems are more than

adequate for metallic heat shield applications and have potential for further weight reduction.

Ultimate shear tests were conducted on fasteners as-assembled and on fasteners after exposure to a load/temperature cycle. The exposure was at 1200 K (1700°F) temperature for 42 hours during which 100 cycles at 111 N (25 lbf.) load was applied. The fasteners were not disassembled since the tests determined only the shear strength of the fastener.

TABLE 4

Joint Strength Test Results

Fastener	Type of Test	Exposure	Test Temperature	Approximate Proportional Limit N	(lbf.)	Ultimate Shear Strength, P_s N	(lbf.)
Cage Type with Collar Retainer	Ultimate Shear	As Assembled	Room	1468	(330)	2971	(668)
				1468	(330)	3269	(735)
				1512	(340)	3118	(701)
			1200 K (1700°F)	1023	(230)	1379	(310)
				734	(165)	1379	(310)
				689	(155)	1068	(240)
	Ultimate Shear Residual	100 Mission Cycles	Room	1468	(330)	2446	(550)
				1557	(350)	2633	(592)
			1200 K (1700°F)	534	(120)	934	(210)
				578	(130)	956	(215)
Clinch Type with Collar Retainer	Ultimate Shear	As Assembled	Room	1157	(260)	2833	(637)
				1334	(300)	2869	(645)
				1112	(250)	2767	(622)
			1200 K (1700°F)	778	(175)	1076	(242)
				552	(124)	1076	(242)
				712	(160)	1014	(228)
	Ultimate Shear Residual	100 Mission Cycles	Room	1245	(280)	2527	(568)
				1779	(400)	2669	(600)
			1200 K (1700°F)	778	(175)	1379	(310)
				712	(160)	1245	(280)
Weld Type with Split Ring Retainer	Ultimate Shear	As Assembled	Room	1779	(400)	3194	(718)
				1645	(370)	3292	(740)
				1601	(360)	4092	(920)
			1200 K (1700°F)	867	(195)	1681	(378)
				912	(205)	1757	(395)*
				734	(165)	1690	(380)*
	Ultimate Shear Residual	100 Mission Cycles	Room	1379	(310)	2624	(590)
				2135	(480)	3158	(710)
			1200 K (1700°F)	756	(170)	1455	(327)
				778	(175)	1290	(290)*

Notes: 1. *Shear Failure at Root of the Stud Retaining Groove
2. Ultimate Shear Load Design Requirements — Room Temp. P_s = 500 N (112.5 lbf.); 1200 K (1700 F) P_s = 167 N (37.5 lbf.)

TABLE 5

Simulated Mission Cycle Test Results

Caged Type Fastening System

Averaged Results of Four Test Joints

Cumulative Cycles	Cumulative Hole Size Change: Normal to Test Load	Cumulative Hole Size Change: Parallel to Test Load	Remarks: Check for Cracks	Remarks: Other Deformation
10	+.00025 cm .0001 in.)	+.0033 cm (.0013 in.)	None	None
20	+.00102 cm (.0004 in.)	+.00762 cm (.0030 in.)	None	Pin Deformation Due to Collar Removal
30	+.00127 cm (.0005 in.)	+.0119 cm (.0047 in.)	None	
40	+.00178 cm (.0007 in.)	+.0145 cm (.0057 in.)	None	
50	+.00203 cm (.0008 in.)	+.0183 cm (.0072 in.)	None	
60	+.00229 cm (.0009 in.)	+.0213 cm (.0084 in.)	None	
70	+.00229 cm (.0009 in.)	+.0236 cm (.0093 in.)	None	
80	+.00254 cm (.0010 in.)	+.0277 cm (.0109 in.)	None	
90	+.00254 cm (.0010 in.)	+.0320 cm (.0126 in.)	None	
100	---	---	--	

TABLE 6

Simulated Mission Cycle Test Results

Clinch Type Fastening System
Averaged Results of Four Test Joints

Cumulative Cycles	Cumulative Hole Size Change: Normal to Test Load	Cumulative Hole Size Change: Parallel to Test Load	Pushout 111 N (25 lbs.)	Remarks: Check for Cracks	Remarks: Other Deformation
10	+.00051 cm (.0002 in.)	+.00406 cm (.0016 in.)	Passed	None	None
20	+.00076 cm (.0003 in.)	+.00685 cm (.0027 in.)	[illegible]ed	None	Pin Deformation Due to Collar Removal
30	+.00152 cm (.0006 in.)	+.00965 cm (.0038 in.)	Passed	None	
40	+.00203 cm (.0008 in.)	+.0124 cm (.0049 in.)	Passed	None	
50	+.00203 cm (.0008 in.)	+.0142 cm (.0056 in.)	Passed	None	
60	+.00229 cm (.0009 in.)	+.01[illegible]9 cm (.00[illegible]6 in.)	Passed	None	
70	+.00356 cm (.0014 in.)	+.0218 cm (.0086 in.)	Passed	None	
80	+.00381 cm (.0015 in.)	+.0244 cm (.0096 in.)	Passed	None	
90	+.00406 cm +(.0016 in.)	+.0277 cm (.0109 in.)	Passed	None	
100	---	---	---	---	

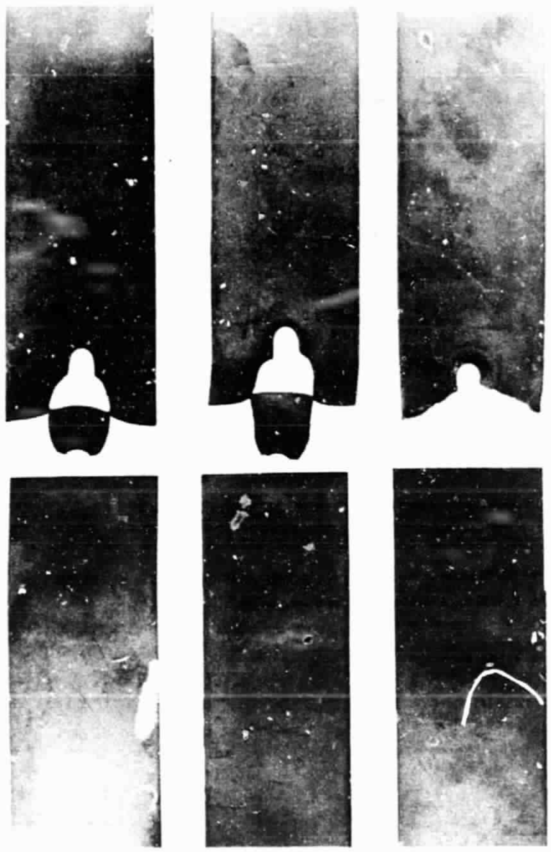
TABLE 7

Simulated Mission Cycle Test Results

Weld Type Fastening System

Averaged Results of Four Test Joints

Cumulative Cycles	Cumulative Hole Size Change: Normal to Test Load	Cumulative Hole Size Change: Parallel to Test Load	Remarks: Check for Cracks	Remarks: Other Deformation
10	+.0000 cm (.0000 in.)	+.00227 cm (.0009 in.)	None	None
20	+.00051 cm (.0002 in.)	+.00457 cm (.0018 in.)	None	None
30	+.00051 cm (.0002 in.)	+.00483 cm (.0019 in.)	None	None
40	+.00051 cm (.0002 in.)	+.00533 cm (.0021 in.)	None	None
50	+.00051 cm (.0002 in.)	+.00635 cm (.0025 in.)	None	[illegible]
60	+.00076 cm (.0003 in.)	+.00660 cm (.0026 in.)	None	Deformation of Stud Groove Due to Ring Installation
70	+.00076 cm (.0003 in.)	+.00813 cm (.0032 in.)	None	
80	+.00076 cm (.0003 in.)	+.00940 cm (.0037 in.)	None	
90	+.00120 cm (.0004 in.)	+.00991 cm (.0039 in.)	None	
100	---	---	---	



1 2 3

Figure 39. Typical Failure Modes for Ultimate Shear Joint Specimens Exposed to 100 Test Cycles

1. Cage Type Fastening System
2. Clinch Type Fastening System
3. Weld Type Fastening System

TABLE 8

Fastener Tensile Strength Results

Fastener	Type of Test	Exposure	Test Temperature	Proportional Limits N	(lbf.)	Ultimate Tensile Strength, P_t N	(lbf.)
Clinch Type with Collar Retainer	Ultimate Tensile	As Assembled	Room	1557	(350)	2380	(535)
				1957	(440)	2913	(655)
				1779	(400)	2793	(628)
			1200 K (1700°F)	934	(210)	1232	(277)
				956	(215)	1277	(287)
				890	(200)	1090	(245)
	Ultimate Tensile Residual	Load/ Temperature	Room	2936	(660)	4270	(960)
				2936	(660)	4208	(946)
			1200 K (1700°F)	979	(220)	1268	(285)
				890	(200)	1156	(260)
Clinch Type with Split Ring Retainer	Ultimate Tensile	As Assembled	Room	2290	(515)	3002	(675)
				2180	(490)	2904	(653)
				1779	(400)	2357	(530)
			1200 K (1700°F)	890	(200)	1125	(253)
				979	(220)	1446	(325)
				1357	(305)	1735	(390)
	Ultimate Tensile Residual	Load/ Temperature	Room	3203	(720)	4590	(1032)
				3158	(710)	3777	(849)
			1200 K (1700°F)	1201	(270)	1446	(325)
				1245	(280)	1423	(320)

Note: Ultimate Tensile Load Design Requirements — Room Temp. P_t = 374 N (84 lbf.); 1200 K (1700°F) P_t = 124 N (28 lbf.)

TABLE 9

Fastener Shear Strength Results

Fastener	Type of Test	Exposure	Test Temperature	Ultimate Shear Strength, P_s N	lbf.
Clinch Type with Collar Retainer	Ultimate Shear	As Assembled	Room	8496 8941	(1910) (2010)
			1200 K (1700°F)	1659 1423	(373) (320)
		Load/ Temperature	Room	9897 9452	(2225) (2125)
			1200 K (1700°F)	2001 1801	(450) (405)
Clinch Type with Split Ring Retainer	Ultimate Shear	As Assembled	Room	5627 4893	(1265) (1100)
			1200 K (1700°F)	2535 1517	(570) (341)
		Load/ Temperature	Room	5649 7672	(1270) (1725)
			1200 K (1700°F)	1917 1624	(431) (365)

Notes:
1. All Shear Failures Occurred at the Fastener Shank
2. Ultimate Shear Load Design Requirements: Room Temp. P_s = 500 N (112.5 lbf.); 1200 K (1700°F) P_s = 167 N (37.5 lbf.)

TABLE 10

Fastener Cyclic Exposure Schedule and Observations

(With Collar and Split Ring Retainers)

Sequence	Temperature 1200 K (1700°F)	Load Cycles*	Number of Disassemblies	Remarks: Cracks	Remarks: Other Deformation
1	4 hours	50	3	None	Pin Deformation
2	17 hours	0	3	None	Due to Collar
3	4 hours	50	3	None	Removal or Ring
4	17 hours	0	0	None	Installation
	42 hours	100	9		

* Each Load Cycle = 84.5 N (19 lbf.)

Discussion of Results - In the joint strength tests, results were similar for each fastener type. This was tensile failure of the .048 cm (.109 in.) sheet. In the three cases where the weld type fastener failure mode was by shear at the root of the stud retaining groove, Table 4, shear values were similar to the sheet tear-out values It should also be observed that ultimate shear values were similar before and after simulated mission cycling for all three fastener types, indicating no change in the strength of the .048 cm (.019 in.) sheet. Figures 40 and 41 show stud end deformation due to repeated assembly and disassembly of the retainers after 90 cycles of mission simulation. Penetration of the collar and ring into the retaining groove ramp is noted.

In the fastener tensile strength tests, the collar and the split ring retainer separated from the stud with similar ultimate strength results. Since the loads obtained were well above the design requirements, adequate tensile strength of the fasteners was demonstrated. Higher tensile strength, if required for other applications than those discussed herein, could possibly be obtained by changes in the stud retaining groove and retainer design. This would be determined by the needs of a specific application.

The tensile strength tests showed no reduction of tensile strength due to either the repeated disassembly or to the cyclic tensile loads applied. Figure 42 shows the mode of failure for the collar retainer system. Note the deformed stud end which has assumed a square configuration conforming to the positions of the four crimp indentations on the collar. A similar effect is seen in Figure 43 showing the failure mode of the split ring retainer. Note the reduction of the diameter of the stud end. In this case the deformation was circular, conforming to the ring configuration. The room and elevated temperature failure modes are similar.

Ultimate shear strength results vary substantially, Table 9. This is to be expected in a shear test with clamped members, since the joint friction will affect results. Attempts to determine the proportional limit for the shear joint tests were abandoned for the same reason.

Figure 40. Stud deformation after 90 cycles of mission simulation including 9 assemblies and disassemblies of the collar retainer.

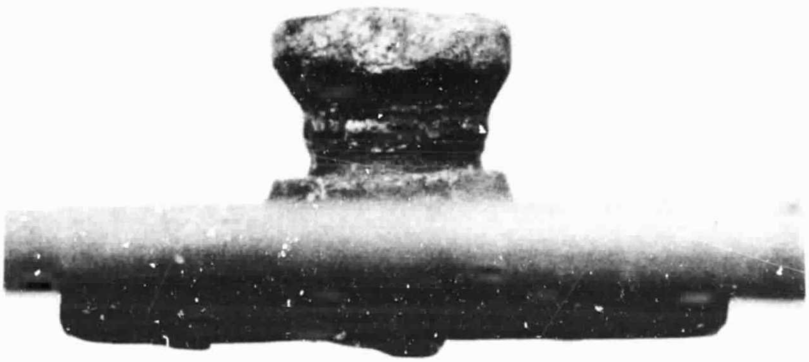


Figure 41. Stud deformation after 90 cycles of mission simulation including 9 assemblies and disassemblies of the split ring retainer.

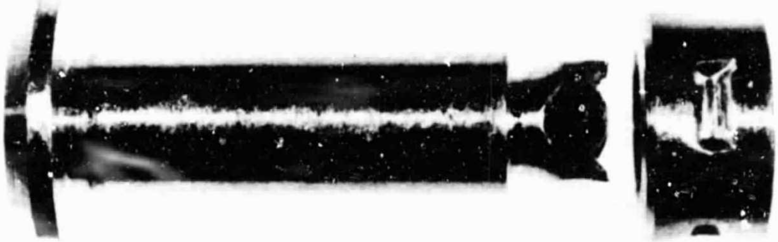


Figure 42. Tensile failure mode of collar retainer, no exposure.

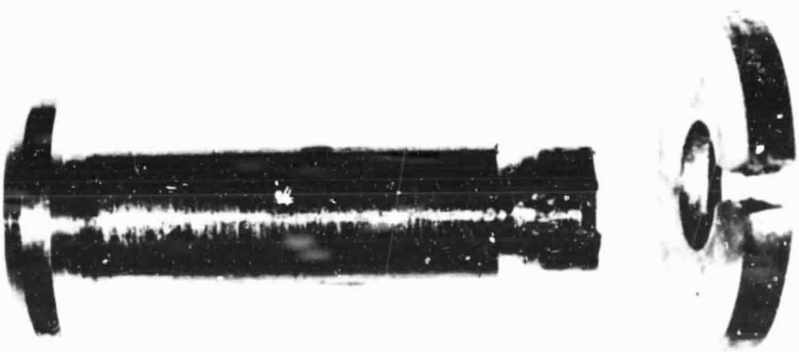


Figure 43. Tensile failure mode of split ring retainer, no exposure.

8. FASTENER WEIGHT AND COST

One of the primary objectives in this program was to develop a lightweight fastener. To verify that this objective was accomplished, comparison with a type of fastener used in structure comparable to the shuttle was necessary. An anchor nut and protruding head bolt was used for comparison since this fastener combination is applied where the substructure necessitates a threaded member to which a bolt is assembled from the exterior of the structure.

Weight comparison - Table 11 lists the actual weights of the three types of fasteners along with the conventional type. Two of the three types of fasteners evaluated in this program, the clinch stud/collar retainer and the weld stud/ring retainer are substantially lighter than the conventional fastener. The clinch stud with collar retainer was 46 percent, and the weld stud with split ring retainer was 55 percent of the weight of the conventional protruding head bolt with anchor nut. The cage type fastener evaluated was heavier than the conventional type because an existing nut cage design was used. However, a proposed redesign for a caged stud is shown in Figure 44. This design allows a smaller stud head and cage since the non-rotating feature of the nut cage is unnecessary. The calculated weight of the proposed cage stud is also listed in Table 11. The design changes for the proposed caged stud will not result in any difference of performance from that obtained on the heavier caged stud. The proposed stud and collar retainer was 98 percent of the weight of the conventional protruding head bolt and anchor nut.

Cost of Fastening Systems - An estimate of the cost of the fastening systems indicates that they are comparable to conventional threaded fasteners. Manufacturing methods to produce the fastener in quantity are available with a number of fastener producers. Selling price of a No. 6-32 anchor nut and protruding head bolt is approximately sixty cents in quantities of 5,000. The price of the cage type stud with the collar retainer would be about equal to the conventional fastener. The clinch and weld type studs with their retainers would cost somewhat less than the cage type stud.

Additional costs would be in the category of development of the fastening systems. Tools for assembly and disassembly would be required as well as tools for the cage type fastener. After development of the total system, the installed cost per fastener would approach conventional fastener cost.

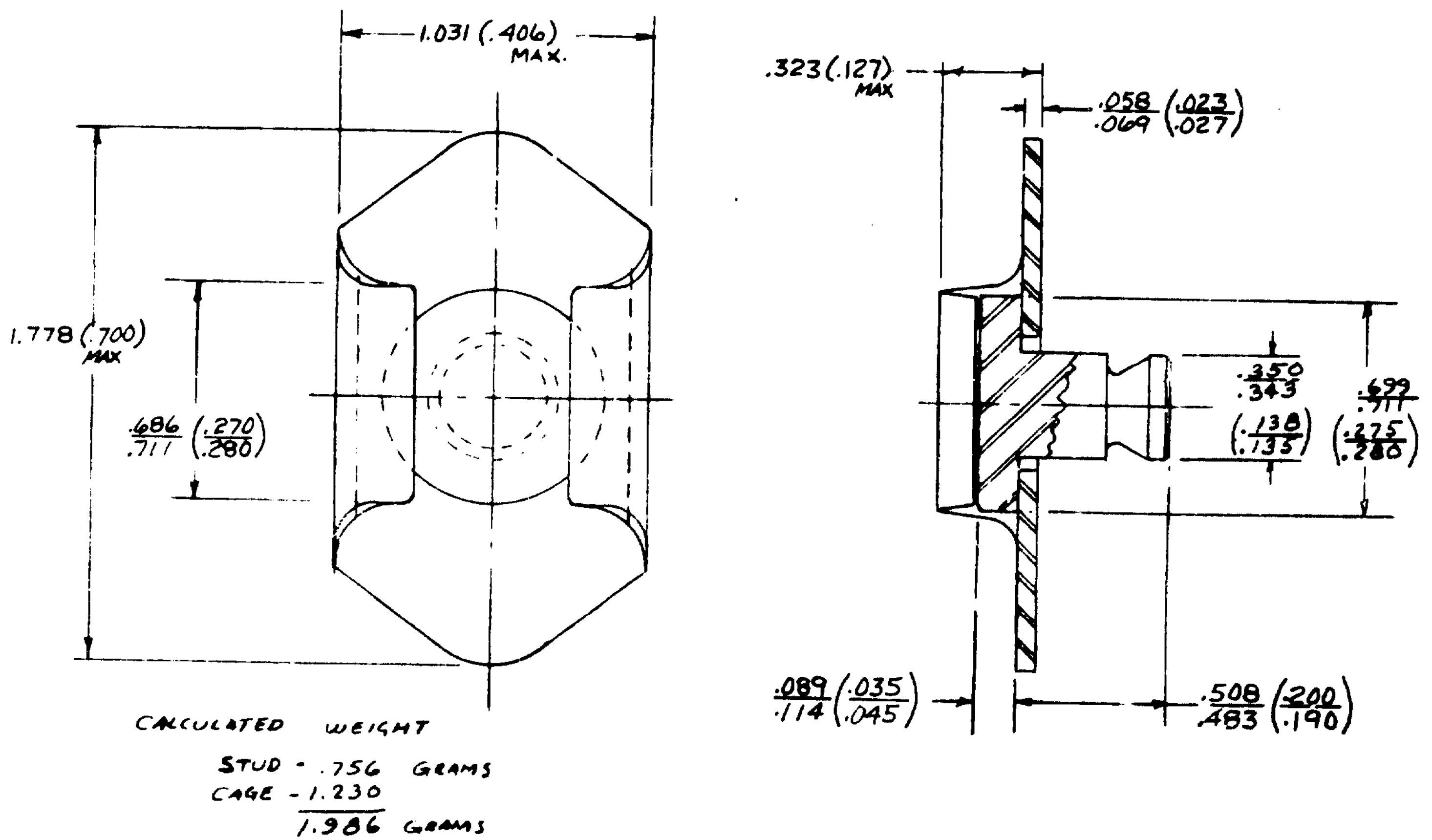


Figure 44. Proposed Cage Type Fastener Dimensions in cm (inches).

TABLE 11

Weight Comparison For
Three New Fastening Systems vs. Conventional Fastener System

Fastener Type	Individual Part, Weight, g	Combined Weight, g
New Fastener Systems:		
Caged Stud	2.827	
Collar Retainer	0.422	3.248
Proposed Caged Stud	1.986	
Collar Retainer	0.422	2.408
Clinch Stud	0.692	
Collar Retainer	0.422	1.114
Weld Stud	0.871	
Ring Retainer	0.482	1.353
Conventional Fastener System:		
#6-32 Anchor Nut SPS No 13605	1.542	
#6032 Protruding Head Bolt NAS No. 1121	0.907	2.449*

* Combined weight of bolt and anchor nut

9. CONCLUDING REMARKS

The principal objective in this program was to design, fabricate and test reusable, lightweight fastening systems for advanced aerospace vehicle thermal protection systems. Three new systems were designed and fabricated from Haynes 188 Alloy and feasibility was demonstrated by means of environmental exposures and residual mechanical property tests.

The three designs that were evaluated included a clinch stud with a collar retainer, a weld stud with a split ring retainer and a caged stud with a collar retainer having shank diameters similar to a No. 6 size threaded fastener. The design criteria required that part of the fastener would be fixed to the inner structure and be reused. The heat shield retaining portion of the fastener would be removed, discarded, and replaced with a new retainer. All three designs depart from conventional threaded fasteners and permanent type riveting.

Environmental testing of joints simulating thermal protection system attachments to aerospace vehicle structure demonstrated that each of the fastening systems would perform through 100 simulated mission cycles to 1800°F. Assembly and disassembly of the fastener 10 times during the 100 cycle tests indicated adequate fastener performance with no significant reduction of fastener strength.

Special tooling was required to install and remove the retaining devices. The tooling was not complicated, and power tools can be developed from the concepts demonstrated. This would allow fast assembly and disassembly methods in a production application. Installation of the fastener in representative structure utilized conventional spotwelding and clinching methods.

The clinch stud/collar retainer and weld stud/ring retainer fastener systems were approximately half the weight of a conventional threaded fastener that would be used in similar type structures; the caged stud with the collar retainer can be designed to weights similar to the conventional fastener system. Projected costs of the new systems are comparable to conventional fastener systems.

Advantages and disadvantages of each type of fastener would have to be further evaluated with respect to metallic heat shield structural designs to develop the fastener best suited for each application. The evaluation could reveal that the cage type fastener with a split ring retainer in place of the collar retainer would be the best combination. While not tested in this particular combination in this program, the new combination would be feasible. Additional fastener evaluation is also necessary for application to specific heat shield configurations. Factors such as grip accomodation, vibration resistance, fatigue strength, available clamp load and relaxation are some of the properties that must be determined.

It is concluded that a viable metallic heat shield fastening system can be developed, using the concepts evaluated. Additional studies are recommended beyond this feasibility phase to optimize the concepts developed in this program.

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10. REFERENCES

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