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HUGHES TOOL COMPANY · AIRCRAFT DIVISION
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Report 285-18 (62-18)

CONTRACT NO. AF 33(600)-30271

HOT CYCLE ROTOR SYSTEM
MATERIALS & PROCESSES

March 1962

HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
Culver City, California

This report has been prepared by Hughes Tool Company -- Aircraft Division under USAF Contract AF 33(600)-30271 "Hot Cycle Pressure Jet Rotor System," D/A Project Number 9-38-01-000, Subtask 616. It is submitted in partial fulfillment of Item 10 "Materials Research and Development" of the contract, and completes the work required under that item.

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SUMMARY

Discussed herein are the more important aspects of the materials and processes developed and used in the fabrication of the Hot Cycle Rotor System.

The 1200°F temperature and 25 psig pressure of the gases ducted from the fuselage area to the blade tips requires considerable attention to selection of materials and development of processes for use on those components exposed to or directly affected by the gases. Every effort was made to confine the high temperature to the duct system in such a way as to permit use of conventional structure and existing fabrication techniques. In some cases, however, pioneering work was done in the adaption of relatively new materials and in extension of the state-of-the-art of some existing fabrication methods.

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The Hot Cycle pressure Jet Rotor System is based on the principle wherein exhaust gases from high pressure turbine engines are ducted through the rotor blades and exhausted at the tips to produce forces which turn the rotor. These gases produce temperatures of 1050° to 1200°F and pressures up to 25 psig. Materials directly affected by these gases were selected on the basis of their ability to maintain the necessary functional and/or strength properties at their particular operating conditions.

Some of the materials thus selected required an advanced development of the techniques for fabrication. In a like manner, some development work was required to obtain satisfactory seals, lubricant, finishes, etc., to withstand the operating conditions. Some of the most interesting of these activities are reported herein.

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SECTION 2MATERIALS APPLICATIONS2.1 TITANIUM (ROTOR SPARS)

A decision to use 6Al-4V titanium was based on its strength-weight ratio, its adaptability to the desired chordwise natural frequency and the greater fund of fatigue data as compared with other available titanium alloys. During the initial study when a complex cross section indicated machining would be very difficult, some thought was given to the possibility of extruding the spars. However, extruding a section of this area and length (320 inches) would present a number of problems, since equipment and techniques were just being developed. As the study proceeded an essentially rectangular spar cross section was adapted and the techniques for machining titanium developed rapidly during this same period. Consequently, a decision was made to mill the spars from rolled rectangular bar. As far as is known, these are the longest bars of titanium rolled for a specific purpose¹.

The material was annealed and warm rolled, and was used in that condition. Grain size was from 7 to 8 with normal alpha structure. A photomicrograph is given in Figure 2.1-1. Other static and fatigue properties are reported in Reference 1.

The spars were bent and twisted as required after machining while at a temperature of between 900 and 1000°F. The maximum time at this temperature was held to one hour. Following the forming operation, the spars were stress relieved at 1000° + 30°F for 4 to 4-1/2 hours with a furnace atmosphere slightly oxidizing. After stress relieving the rear spars were shot peened with an intensity of 0.004 to 0.006 using an Almen "A" strip measured with a No. 2 gage. Finished spars are shown in Figure 2.1-2.

2.2 CARBON (SEALS)

The unique seals, in view of their operating temperature range and size, required by the Hot Cycle rotor, resulted in expenditure of considerable design effort (Refer to Report 285-12, 65-12.). The seal requirements were discussed with material suppliers, seal manufacturers and seal users. The final designs represented a wealth of experience obtained from these sources.

1 Furnished by Reactive Metals, Inc., Niles, Ohio

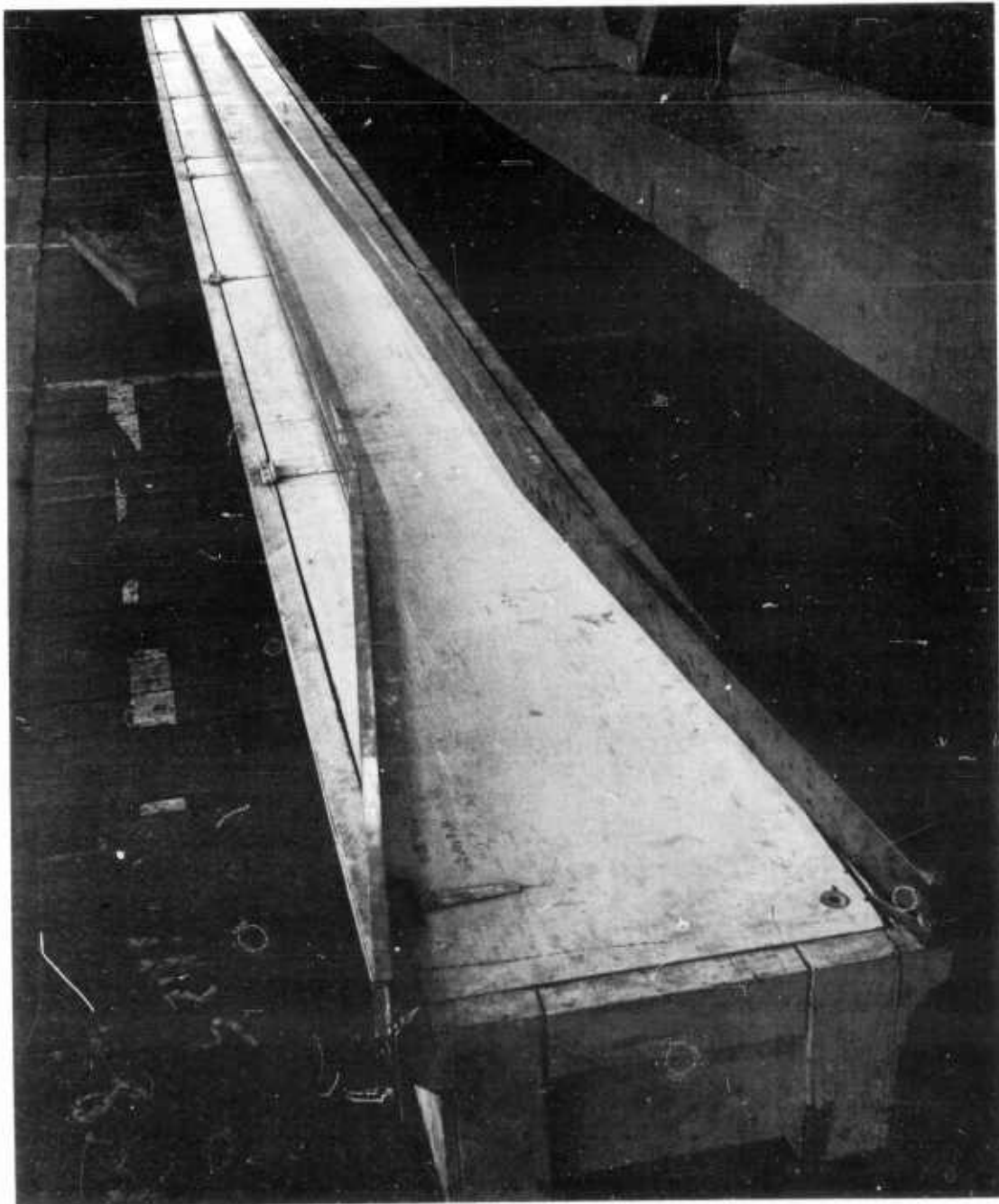


Figure 2.1-2. Blade Spars - Titanium

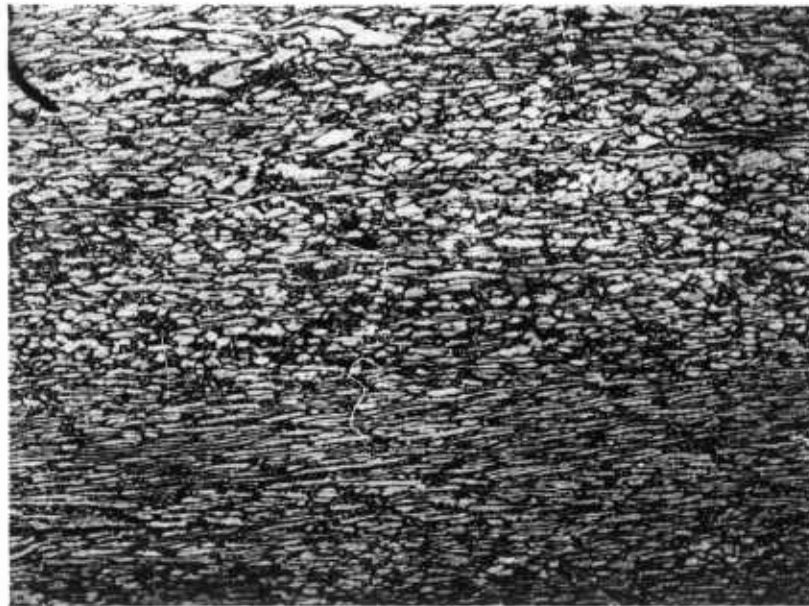


Figure 2.1-1. Photomicrograph of Spar Material

Titanium 6Al-4V
Magnification 100x
Normal Alpha Structure
Grain Direction Longitudinal To Spar

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Segmented rings of impregnated carbon-graphite riding on type 347 corrosion resistant steel or aluminum oxide are used as the sealing system in the hub outer seal, hub inner seal non-rotating joint, and articulate duct inboard seal. On the other hand, a single ring riding on aluminum oxide comprised the rotating face seal used at the hub duct inner surfaces. The carbon is used with no supplemental lubrication in all cases.

Available data indicated that three carbon materials, from three different manufacturers, were equally satisfactory for use at the 1000 to 1200°F anticipated. All three carbon materials; Purebon #56HT¹, Graphitar #2490², and National #CDJ-83³ were used; the first on the hub outer seal, the second on the hub inner seal, and the third on the articulate duct inner seal.

After 18 hours of whirl tests, inspection of the carbon seal materials disclosed some local soft spots in the U. S. Graphite No. 2490 and in the National Carbon Company's No. CDJ-83, which resulted in a tendency toward erosion. The softening and edge erosion can be seen in Figure 2.2-1. In contrast to the above, the Pure Carbon Company's No. 56 HT showed no evidence of softening in any portion of the material.

The 56 HT segments, because of damage in service or handling, were replaced. The #2490 face seal ring, because of leakage through the soft eroded area, was reground flat and smooth and reinstalled. However, since the CDJ-83 seals showed no signs of appreciable leakage, these particular segments were again utilized for an additional 17 hours of whirl tests. At the end of that time, inspection revealed the following:

- a. The 56 HT segments were in excellent condition and were re-installed.
- b. The #2490 ring was again eroded to form a leak path, and because of diminished thickness, was replaced.
- c. The CDJ-83 segments appeared essentially as before and since leakage rate was actually lower, two sets of these were re-installed. The third was damaged in handling and, therefore, was replaced.

1 Pure Carbon Company, St. Marys, Pennsylvania

2 The United States Graphite Company, Saginaw, Michigan

3 National Carbon Company, Cleveland, Ohio

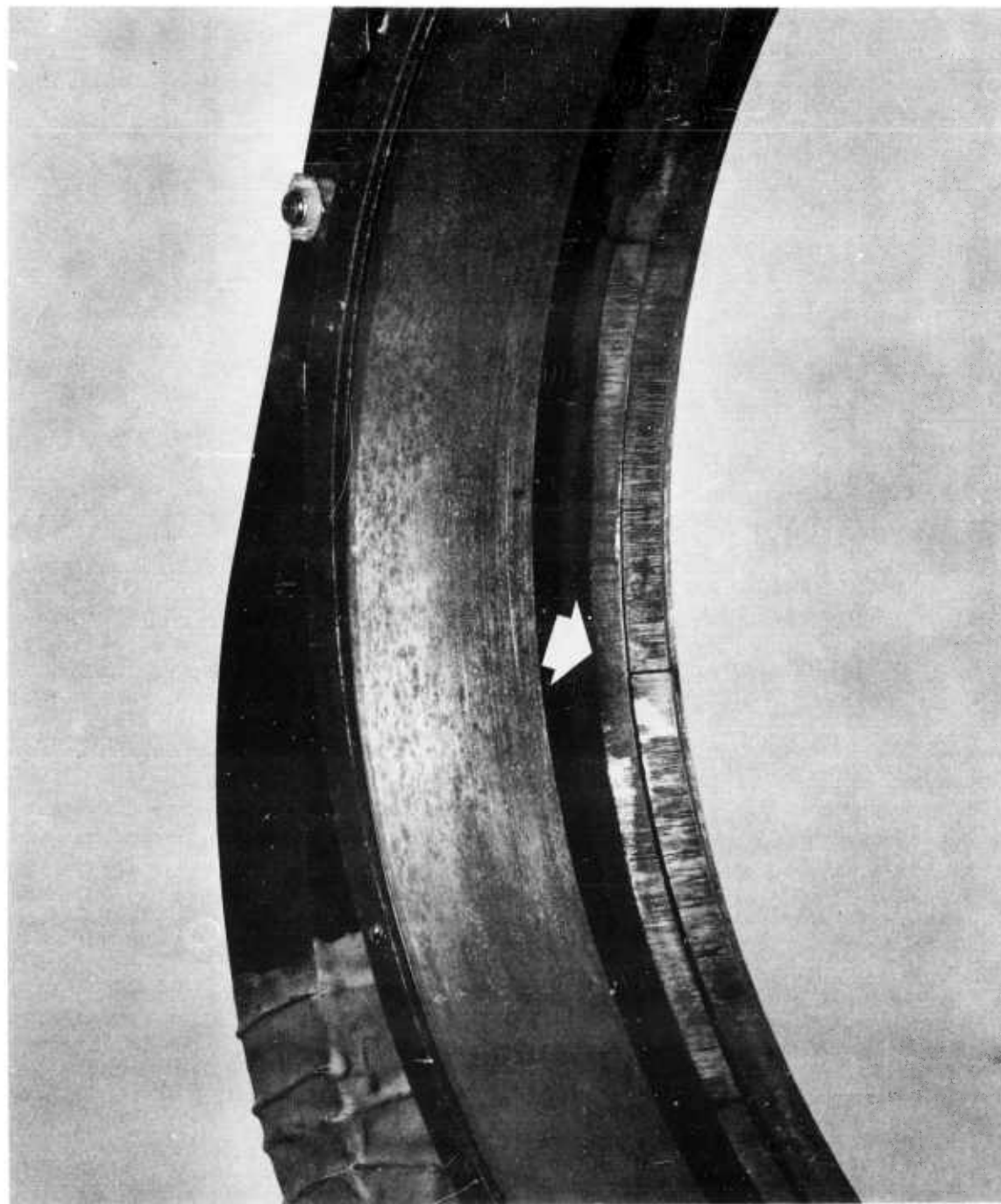


Figure 2.2-1 Close-up of Articulate Duct Inboard Seal Segmented Carbon Rings.
Note local softening of carbon and resulting erosion of edge.

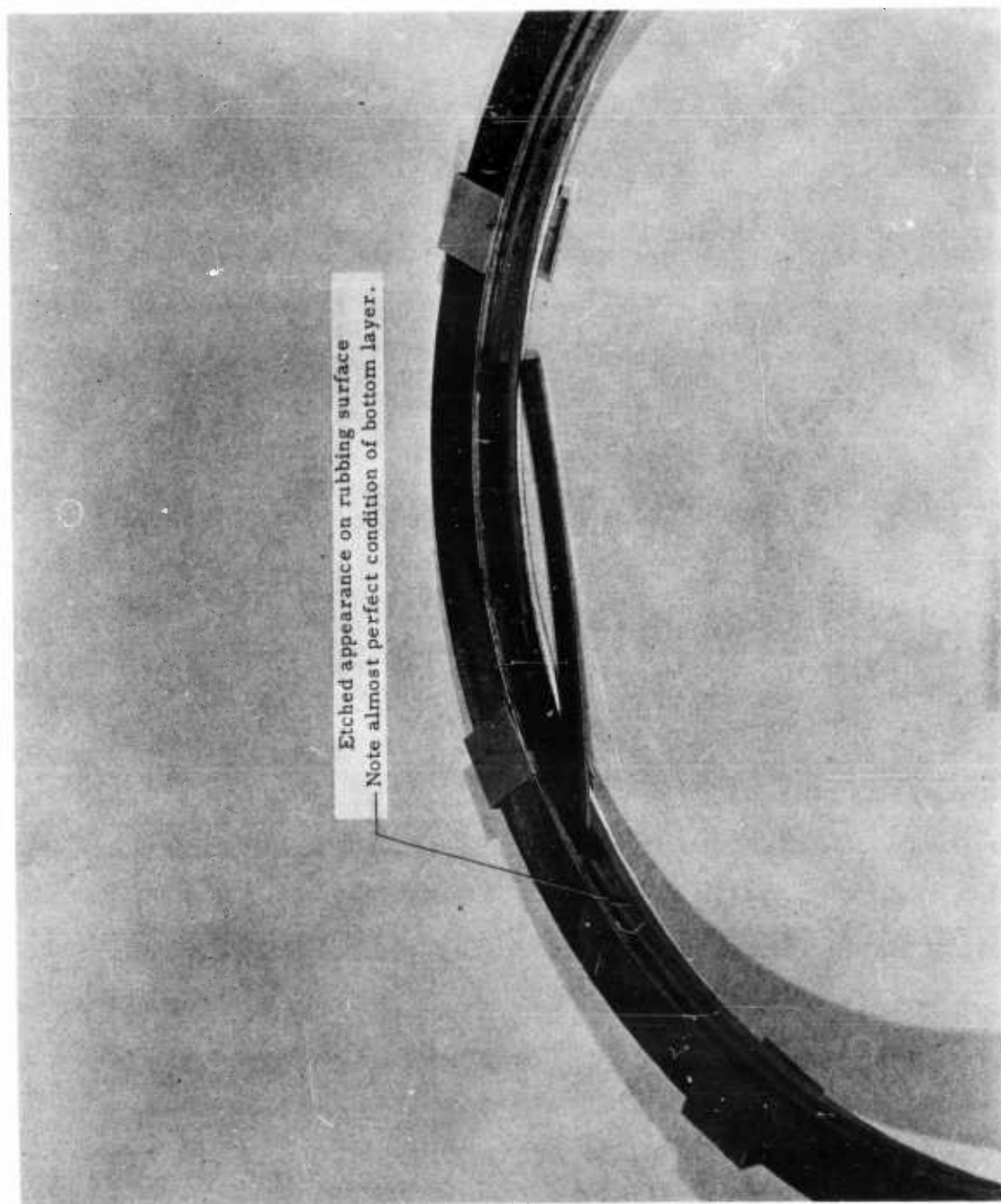


Figure 2.2-2. Etching of Carbon Seals.

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At the end of an additional 25 hours of whirl tests, the conditions were as follows:

- a. The 56 HT, on the upper ring of segments almost exclusively, showed an etched appearance, possibly from the effects of rain water prevalent at that time. The condition is shown in Figure 2.2-2.
- b. The #2490 ring was in excellent condition.
- c. The CDJ-83 segments appeared essentially as before, and leakage rate was essentially identical to the previous values.

2.3 TEFLON FABRICS (ANTI-FRETTING MATERIALS)

The blade segments are flexibly jointed. This condition introduces some small relative movement between the spars and the segments. In order to eliminate fretting or galling between these members, it was necessary to provide a lubricant. During the early work and in the Screening Fatigue Test (Reference 2), a teflon suspensoid (DuPont teflon enamel¹) was used. This material, however, rubbed off. As a result of a survey and test to find a suitable material approximately 0.010 inch thickness, tetrafluoroethylene fluorocarbon resin coated glass fabric (Armalon²) was selected. More complete discussions of the design and tests are contained in References 2, 3 and 4. Inspection at the end of 60 hours of whirl test has disclosed that the material operated satisfactorily. There was no evidence of contact of the metal surfaces, and therefore no wear or fretting of the metal surfaces occurred.

1 and 2 E. I. duPont de Nemours and Company, Inc.,
Wilmington 98, Delaware

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SECTION 3DEVELOPMENT OF FABRICATION TECHNIQUES3.1 SPOTWELDING (BLADE SEGMENTS)

Figure 3.1-1 shows a typical blade cross section and flexible coupling. After finalization of the blade segment design, a primary decision was necessary as to the method of attaching the components; either spot and rollwelding or brazing. Samples of both brazed and spotwelded segments were tested. Both specimens proved equally good in the Screening Fatigue Test (Reference 2). The decision to use the spotwelded design was based on greater availability of dependable fabricators in the Los Angeles area and the resulting opportunity to more closely control the work as it was in process.

Spotwelding of the blade segments proceeded smoothly after all of the certifications and preliminary testing in the weld fixtures was done. However, some difficulty was initially encountered in welding of the Rene' 41 material. Spotwelding the thin materials used in the segments requires equipment having the ability to closely regulate the various weld parameters, since satisfactory welding can only be obtained within very narrow margins of weld time, heat and electrode pressures. Limited data was available on the welding of Rene' 41 materials; however, it was not applicable to the thin materials (0.012 inch) used in this application. Preliminary weld testing was done in order to determine the conditions required for obtaining quality welds. Line power factor conditions were found to have an important influence on the welding results. Following the initial development period, during which machine settings and type of welding equipment were established, consistent and excellent welds were obtained. The final welding schedule is given in Table 3.1-1. The segment shown in Figure 3.1-1 is a production spotwelded assembly, while Figure 3.1-2 shows a typical Rene' 41 rib.

In addition to the spotwelding proper, it was necessary to establish cleanliness of the material and determine etchants which would satisfactorily show the weld macro sections for inspection of the internal structure. Before spotwelding, the material must be free of oxides and other foreign matter. Liquid honing was tried for cleaning the material used in preliminary welding, but because of the thinness of the material, warpage and distortion were obtained, even though fixtures and reduced honing pressures were used to minimize the condition. Cleaning of the production parts was done in a sodium hydride bath, eliminating the problem of warpage and subsequent straightening operations.

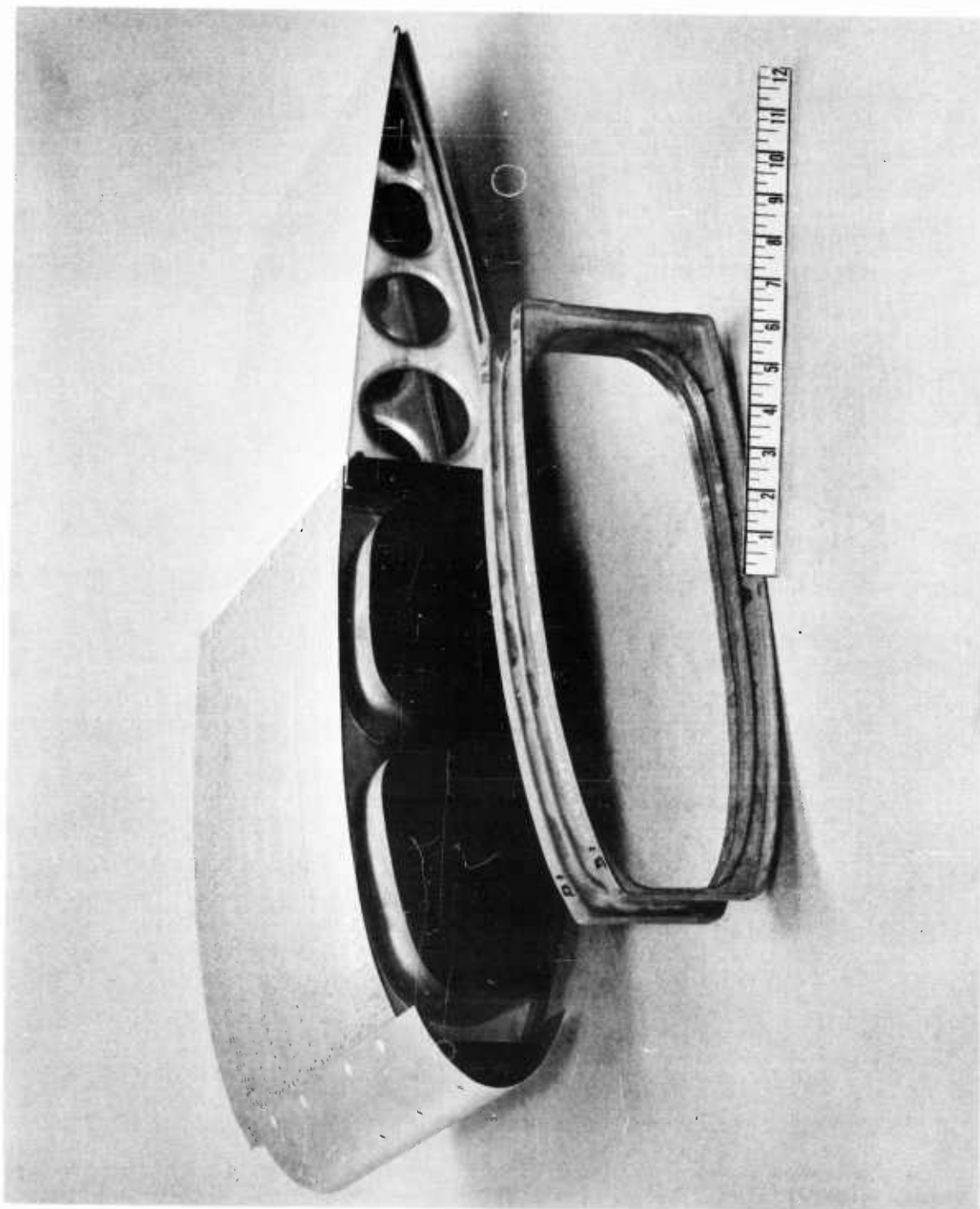


Figure 3.1-1. Typical Blade Cross Section and Electroformed Flexible Coupling

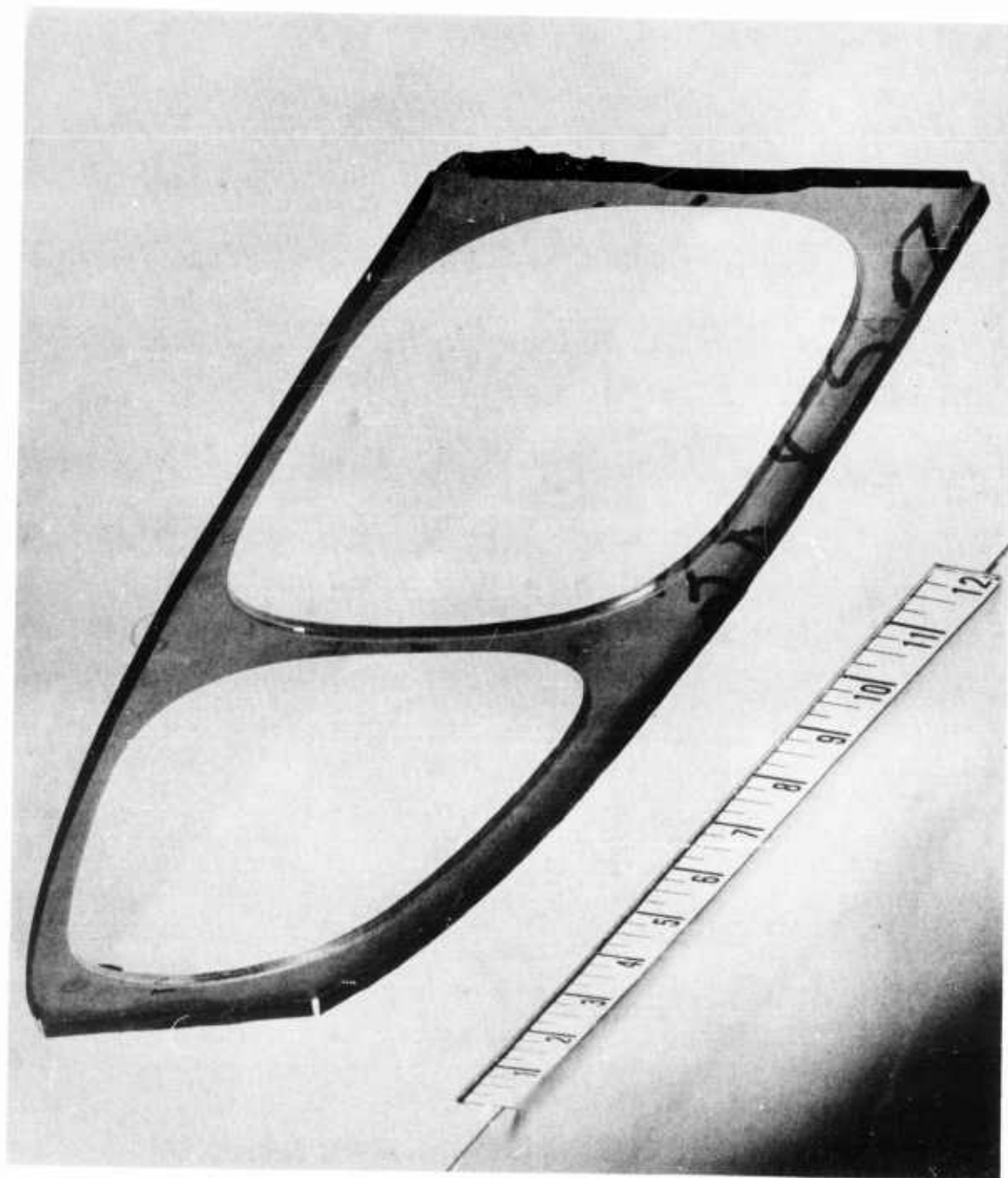


Figure 3.1-2. Blade Rib, Rene' 41 Material

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TABLE 3.1-1WELDING SCHEDULE

For welding 0.010 Rene' 41 to 0.010 Rene' 41
50KVA Sciaky Spot and Seam Welder Serial PMMOTLCK
Intermittent Spot and Seam Welding

Phase Shift	64%
High Pressure	550
Back Pressure	200
Weld Pressure	350 lbs
Heat (Cycles)	1
Weld Impulses	1
Cool Time (Cycles)	8.5
Squeeze Time (Cycles)	50
Hold Time (Cycles)	50
Electrode-Upper	6 inch diameter Class III
"	0.060 inch width at face
"	4 inch face radius
Electrode-Lower	6 inch diameter Class III
"	1/2 inch width at face
"	Flat (No radius)
Weld Penetration (Top)	50%
Weld Penetration (Bottom)	40%
Seam Welds (24/inch)	25% overlap

3.2 ELECTROFORMING (FLEXIBLE COUPLING)

The blade segments between spars are joined by flexible couplings, as shown earlier in Figure 3.1-1. Those flexible couplings used on the Screening Fatigue Test blade (Reference 2) were made by the electroforming method using commercially pure nickel. (See Reference 5 for material tests.) Since these couplings had performed satisfactorily, it was decided that this system would be used for the fabrication of parts for the whirl and full scale fatigue test blades.

The electroform process consists of making a plaster mold and spraying certain surfaces of the mold with an electrical conducting material. The mold is then placed in a nickel bearing solution. The nickel electro-deposits on the mold, which is later broken away leaving a shell of essentially pure nickel conforming to the outline of the mold. This nickel shell is then put back into the bath and plated with the nickel until the desired thicknesses are obtained. It was decided that a split metal female pattern would be provided for use in making the frangible plaster shell molds. It was believed that this method would reduce distortion and damage that might otherwise occur in the use of an intermediate plaster master.

The techniques worked out on the screening fatigue test parts appeared to be adaptable to large whirl test parts. The larger sizes and varying thicknesses, however, required additional development. Although the quality of the parts obtained was acceptable, the inherent nature of the process resulted in an unacceptably low rate of production.

3.3 DROP HAMMER FORMING (FLEXIBLE COUPLING)

Because of the production difficulty noted above, another material was then developed which proved considerably superior both in production time and quality of the part.

Fatigue loading is major consideration in the design of this component, and this favors a method of fabrication utilizing wrought material. Therefore, a considerable study of the problem relative to different types of production methods and techniques was undertaken. Information drawn from this study favored drop hammer forming of heated sheet material by forming in several stages in heated dies. Accordingly experimental drop hammer work was undertaken to produce an initial part. After some initial trials, a part of excellent quality was produced from 0.020 Inconel X material. It might be mentioned that other materials also appear promising, but were dropped in view of the fact that acceptable parts were being obtained from Inconel X.

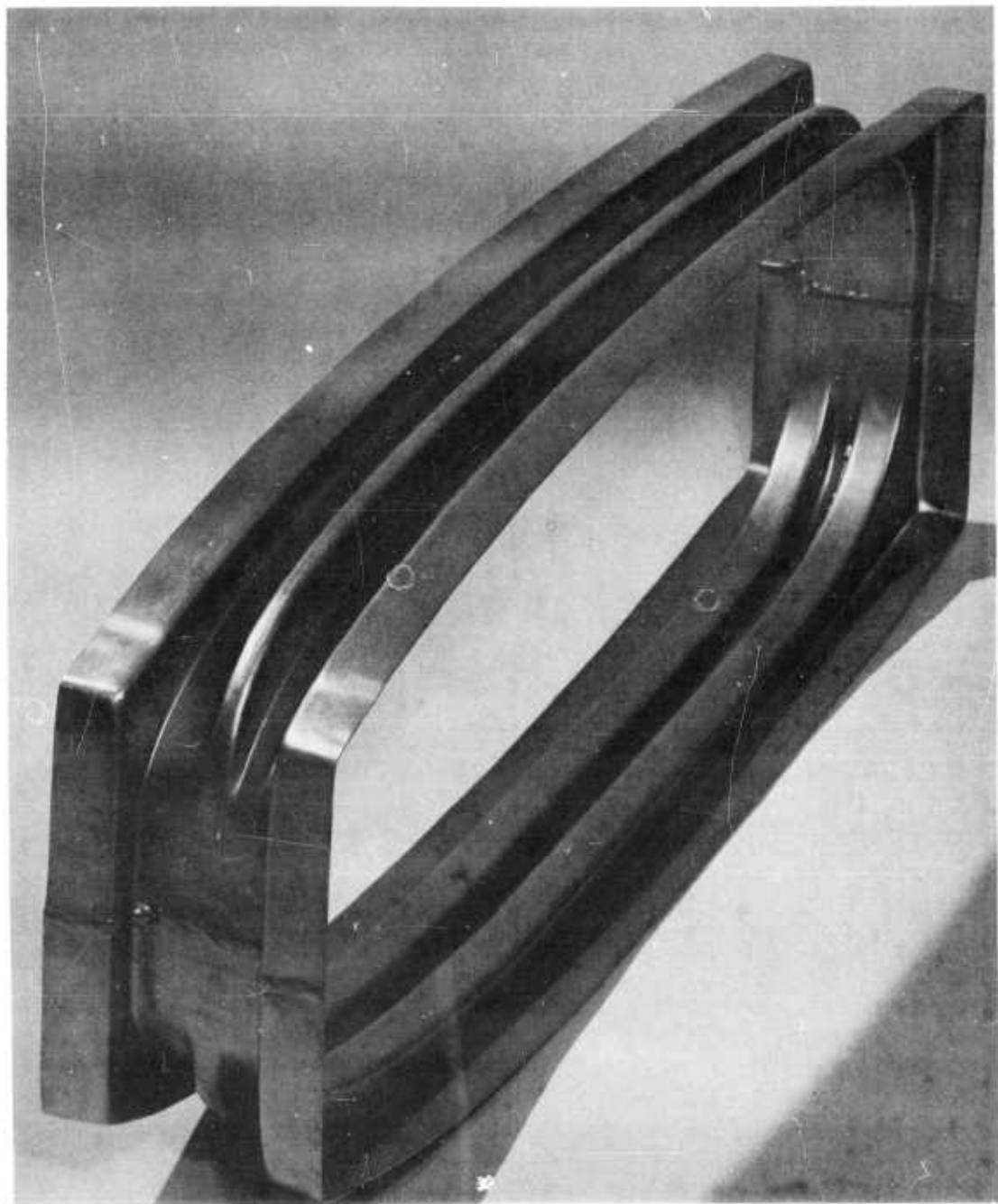


Figure 3.3-1. Preliminary Sample of Drop Hammered Inconel "X" Flexure

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The flexible coupling is a complex cross section where flexibility is required in one direction and stiffness in the other. The part was made in two halves and joined at the chord plane, as shown in Figure 3.3-1, by fusion welding with the tungsten inert arc method using Inconel X filler. Parts were then placed in a fixture and tie straps resistance welded to the upper and lower sides of the sections. Before spotwelding the parts were liquid honed in the area where the welding was to be performed. In order that the surfaces to be welded would not be contaminated, marked pieces of platers tape were attached adjacent to the weld area and these were used to index the welds.

Upon completion of the welding, the flexures were aged at 1350°F for a period of 20 hours to produce the physical strengths required. Finally, these flexures were shot peened using a glass bead to an intensity of 0.006 to 0.009 as determined by an Alman A gage on a 2024 T aluminum alloy test strip 0.024 thick. This produces a compressive layer on the surface of the material which improves fatigue properties.

3.4 CHROME PLATE ON ALUMINUM (FEATHERING-FLAPPING BEARING)

On each blade there is a feathering-flapping bearing consisting of all aluminum alloy ball (Figure 3.4-1) in contact with a teflon-faced outer race. Because of the complex internal configuration, the ball was cast. For wear resistance, the aluminum ball was chromium plated with a dense, moderately hard coating. On the ball of the initial test bearing, the chromium plate was applied directly to the aluminum surfaces without a base coat. After approximately one month exposure to outdoor atmospheric conditions, blisters were found on the upper surface. Examination revealed a typical aluminum corrosion beneath the chromium plating.

In order to prevent this condition on parts for the whirl-test blades, an extensive investigation was conducted regarding the experience of platers and chrome-on-aluminum users. No experience could be found with chromium plating on cast materials, but considerable exposure has been accumulated for chromium plated directly on aluminum alloy forged bar stock, without a base coat, and used extensively on landing gears for fighter and bomber planes. Findings of the investigation led to the conclusion that casting porosity, and thoroughness of cleansing of the plating preparatory solutions were major factors in producing the corrosion and blisters. It was therefore decided to produce finer grained castings and to chrome plate directly on the aluminum as before, but with much more careful control of the process.

After the feathering balls were put into service on the Hot Cycle whirl test (18 hours of whirl, six months elapsed time within one mile of the Pacific Ocean), some blistering of the chromium plated surface was observed on two

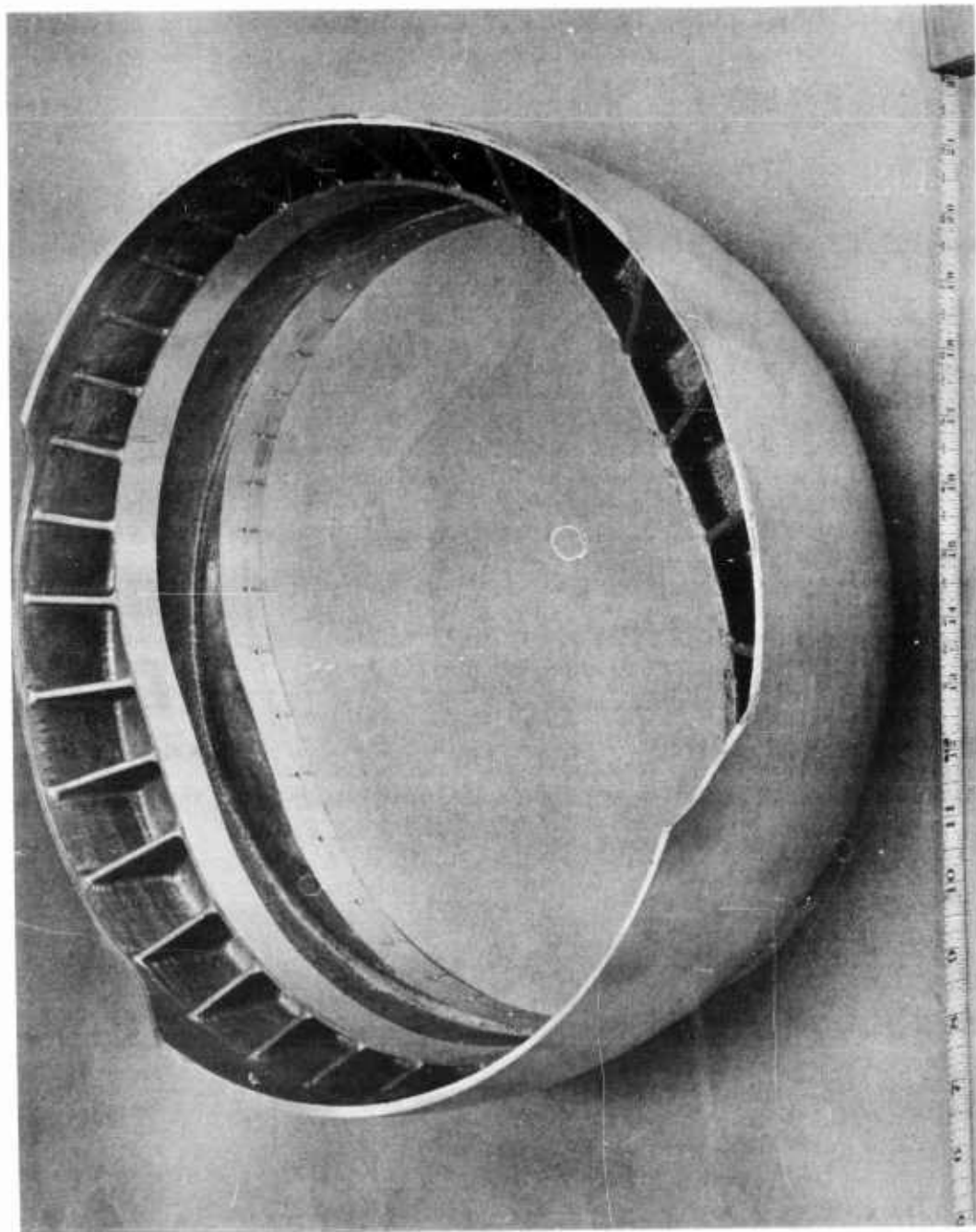


Figure 3.4-1. Blade Feathering - Flapping Bearing Ball, prior to honing and chrome plating

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bearings. No corrective action, however, was considered necessary at that time. At the end of a total of thirty-five hours testing (7-1/2 months total elapsed time), it was found that one ball showed no blistering, one had a very small amount in a non-critical region, while the third showed a considerable amount of blistering which approached a critical wear area. The blistering is shown on Figure 3.4-2. It was decided to replace the third ball.

During the time that the above noted balls had been in service, additional investigation was carried on. As a result, it was concluded that a part of the problem was the tendency of some metals, upon exposure to air, to form passive films **which prevent** adhesion of subsequent plating unless completely removed. Aluminum is among the metals requiring special attention in this respect. The passive film was cleaned from the replacement ball by a quick acidic dip and rinsed immediately preceding plating, and an undercoat of 0.002" electroless nickel was applied to exclude moisture at the bimetallic interface. However, gassing occurred during this plating operation which resulted in a blistered nickel deposit. The barrier coat was then stripped and the casting flashed with approximately 0.0001" of copper and again plated with 0.002" of electroless nickel. Some superficial blistering was encountered, but was removed by buffing prior to plating with the final coat of 0.0015" of dense chromium.

During an additional 25 hours of whirl test and 1-1/2 months elapsed time, the two original balls have indicated no change in surface appearance, and the replacement ball has not blistered.

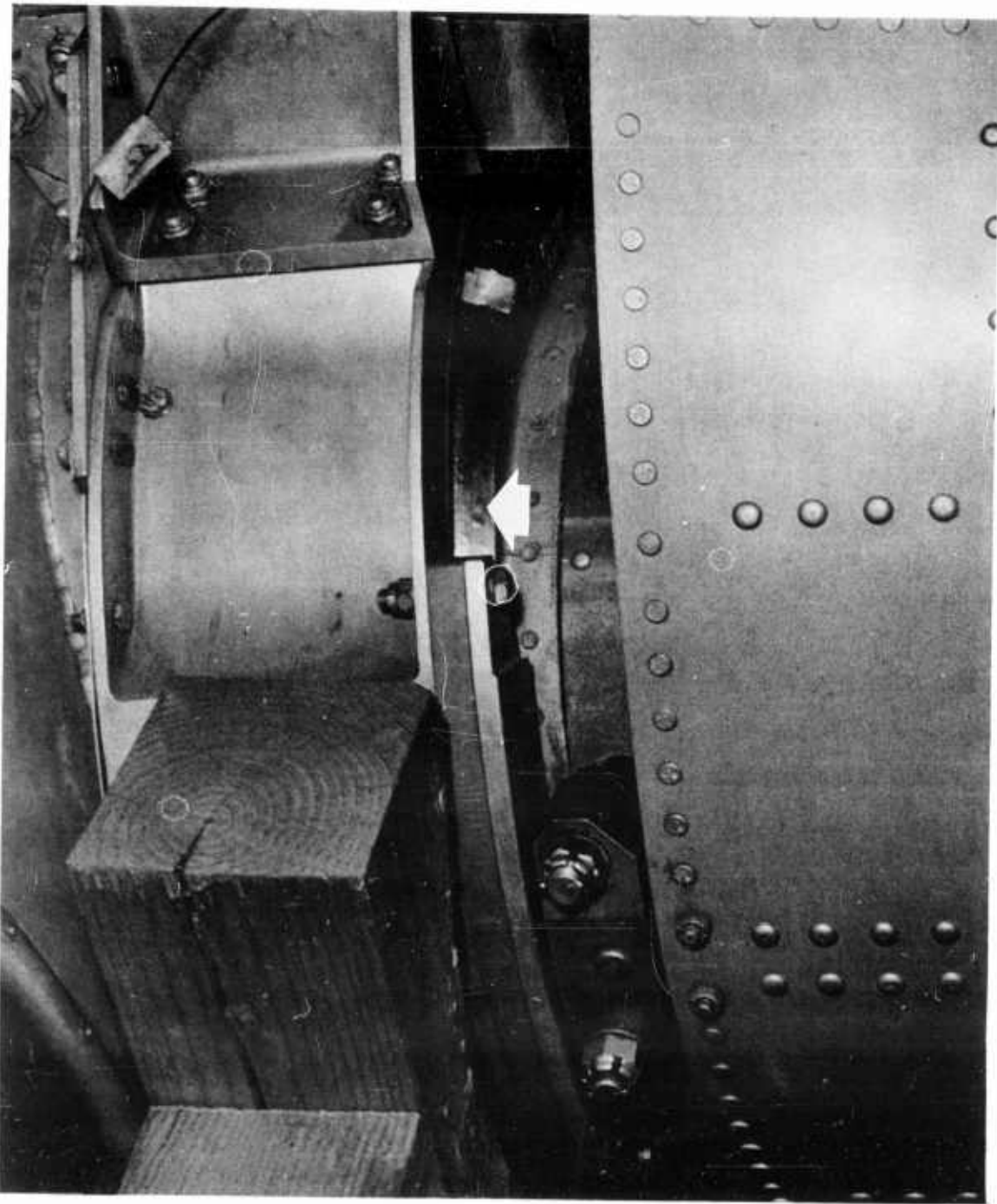


Figure 3.4-2. Close-up of Feathering Bearing Ball. Note blistering of chrome plate apparently as result of sub-surface corrosion.

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SECTION 4PROCESSES AND FINISHES4.1 SEALANT (RTV601)

The Hot Cycle Rotor Blade consists of a series of one-foot long segments with two ducts suspended within the ribs. It was necessary to seal the segments at the flexure rib and skin joint (refer to Section 3 and to Figure 4.1-1) because sealing was not possible at the duct joints. It was originally expected that, with engine output limited to 900°F, the blade skin temperatures would not exceed 200°F. Many sealant materials were investigated including ceramic cements and various elastomeric materials. Silicones elastomers demonstrated superior flexibility, adhesion, and strength up to 500°F.

The blade Screening Fatigue Test (Reference 2) used Dow Corning silicone elastomer RTV501¹ as the sealant. This test was operated for 300 hours and six million cycles with the duct temperature between 800°F and 900°F and a skin temperature of 180 to 195°F.

Based on the success of the Screening Fatigue Test, no change was contemplated in sealing the whirl test blades. With the subsequent contractual change which resulted in an increase in duct temperature to 1100 - 1150°F, thermodynamic analysis indicated possible skin temperatures in excess of 500°F. Continued search for new sealing materials revealed that Dow Corning had perfected and were laboratory testing a silicone material, S 5350, which was usable up to the 600°F range. Laboratory tests were performed at HTC-AD which showed S 5360 silicone to be superior to the RTV501 silicone in the 600°F range and this material was selected for the whirl blades.

Production use of S 5350 (which was subsequently identified as RTV601) was closely controlled. Each batch was tested after mixing to assure that it cured properly and that the adhesion was satisfactory prior to using it in the blades. However, after all blades had been assembled and subjected to a pressure test of 23 psig, many leaks were apparent. The Silastic material extruded from between the flexures and from under the rivet heads. A study showed that the RTV601 had not completely cured in many areas.

An intensive investigation and test revealed that a defective batch of primer had been furnished by Dow Corning which prevented adhesion of the compound. It was also found that because of the difficulty in drilling and

1 Dow Corning Corporation, Midland, Michigan

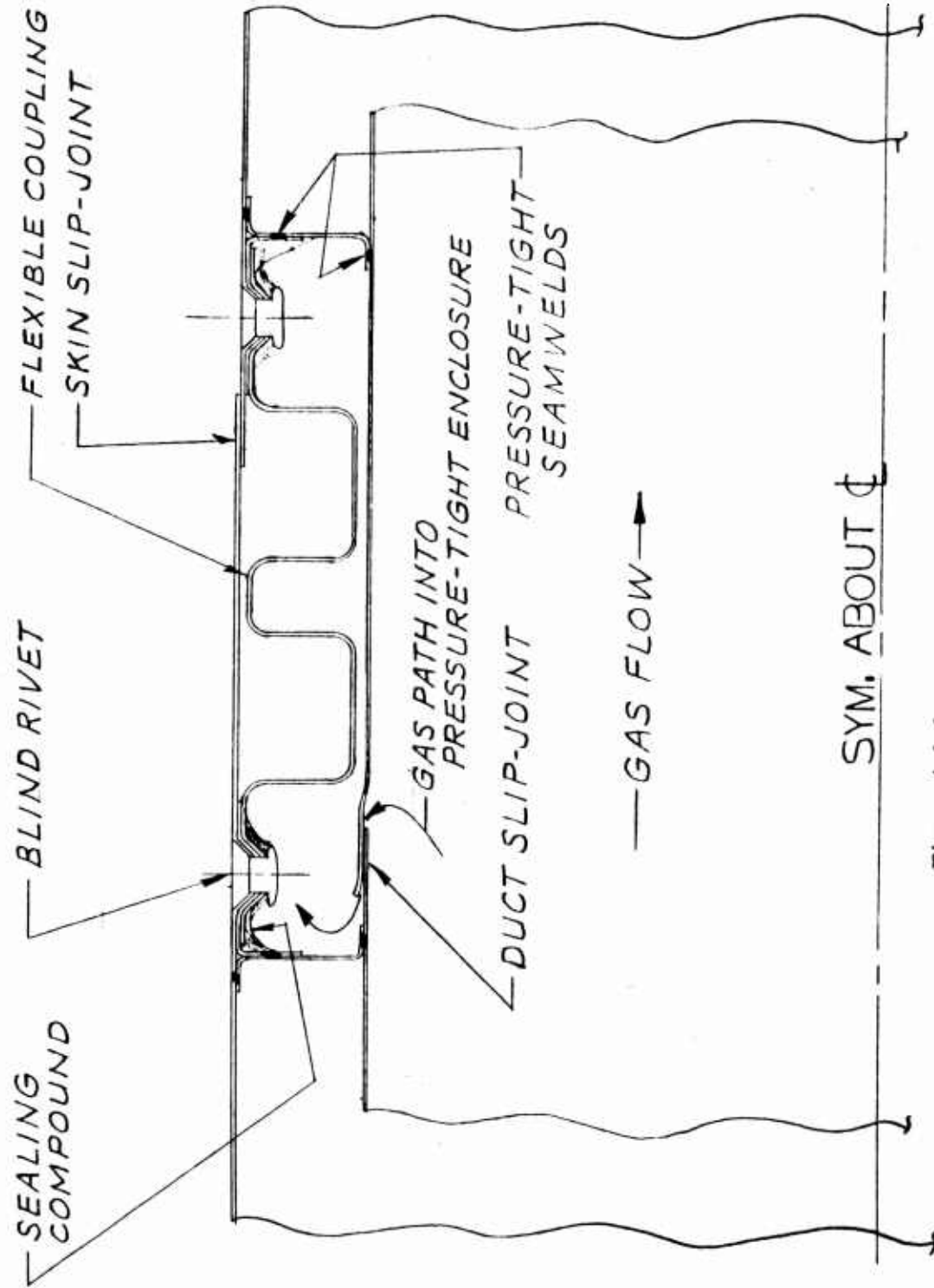


Figure 4.1-1
Typical Blade Segment Joint

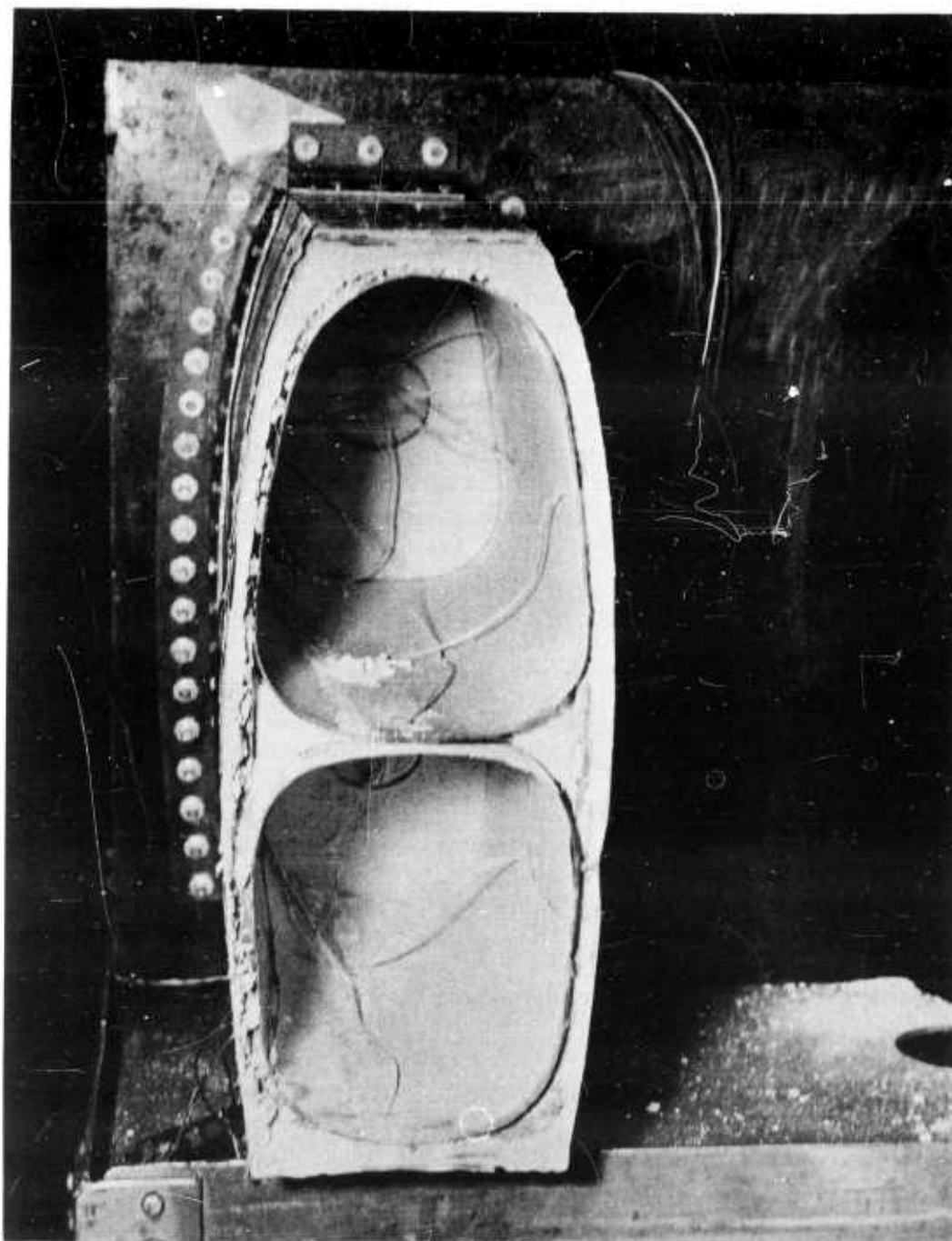


Figure 4.1-2. Results of the Sealant Decomposition Test.
Note material decomposed around ducts -
pliable around outer surfaces

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dimpling the blade materials, a sulphur bearing cutting oil had been used. The surfaces were then flushed with M50 solvent prior to assembly. Brushes were also used, where possible, to agitate the solvent. However, removal of the remnants of this type of oil is very difficult even under more ideal conditions. A report from Dow Corning shows that it requires only a very minute amount of sulphur to poison the catalyst system and prevent cure.

Because of the extensive rework involved in disassembling the blades, a repair was attempted by placing a bead of RTV601 Silicone over the existing material. Laboratory tests had indicated that by coating the existing silicone material with Dow Corning A 4094 Primer a satisfactorily cured seal could be produced. A pressure gun with a 1/8" O. D. tube attached was used through a rivet hole to lay the bead. This was by nature a blind operation and in several areas RTV601 Silicone was forced into the duct area, similar to that shown on the test specimen of Figure 4.1-2. This in turn created a question of the stability of RTV601 at 1100 to 1150°F.

Preliminary laboratory tests gave evidence of burning of the RTV601 at 850 to 900°F. Tests were run at Truesdale Laboratories of Los Angeles which established the autoignition temperature of RTV601 Silicone gases to be in the range of 850° to 900°F, confirming HTC-AD tests indicating ignition at 900°F. In addition, actual blade specimen tests with operational temperatures were conducted by HTC-AD to determine effects under simulated operating conditions. These are reported in Reference 1.

The completely sealed blades, which had a pressure loss of less than 4 CFM per blade at 23 psig, were installed on the whirl tower. Based on recommendations of Dow Corning and the results of the tests at Truesdale, the initial whirling was done at 800°F maximum duct temperature for 7 hours. When no difficulty was experienced, the duct temperature was raised gradually to an eventual 1188°F without difficulty being experienced with the RTV601 sealant. The blades were pressure tested several times during the whirl tests and, without reworking the RTV601 sealant areas, produced leakage comparable to that obtained when the blades were originally installed. The blade subsequently completed 60 hours of whirl testing without further problems involving the RTV601 Sealant.

4.2 GOLD PAINT

Since the mast and upper hub support were operating in close proximity to the duct system it was desired to prevent as much heat transfer as possible to these members. Because of its high reflectivity at temperatures in the 100 to 1000°F range, gold paint was applied to the external surfaces over the electroless nickel plate. This material was a 23 carat liquid bright gold. It was applied three to five microinches in thickness after the surfaces had been thoroughly cleaned. The parts were then placed in an oven and brought to a

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temperature of 625°F. After temperature in the oven was stabilized, it was gradually increased until a maximum temperature of 825° was reached, after which heating was continued for 20 to 30 minutes.

Testing of specimens in salt spray atmosphere showed that the gold paint reduced the corrosion resistance of the nickel surface. However, since the tests showed the reduction in corrosion resistance was relatively small, and because of the desire for a surface of maximum reflectivity to the heat radiated from the ducts, the gold paint was applied to the mast and spoke piece.

The corrosive action of the atmosphere in the area of the shaft, however, was apparently more severe than was expected, because extensive corrosion and deep pitting occurred, as shown in Figure 4.2-1. In contrast it is noteworthy that the spoke piece was free of corrosion. Temperatures recorded for the various portions of the shaft, on the other hand, were considerably lower than those anticipated. For these reasons the gold paint was removed after 18 hours of whirl test (6 months elapsed time) and the surfaces covered with an aluminum filled silicone base paint. This paint has a lower reflectivity but a substantially improved corrosion resistance. It performed quite satisfactorily in both corrosion protection and heat reflection functions during 42 hours (4 months elapsed time) of whirl testing.

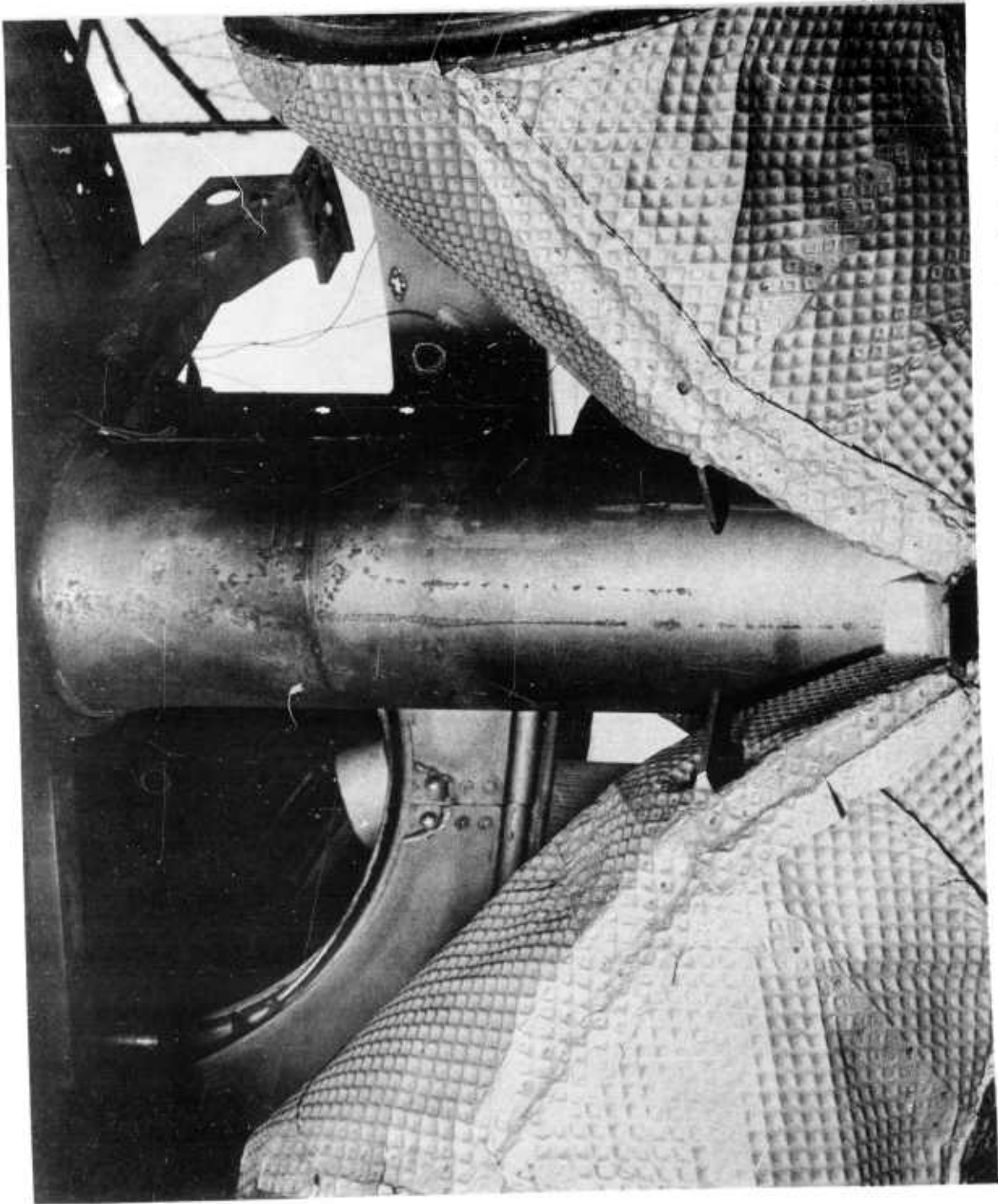


Figure 4.2-1. Close-up of Hub Shaft and Support Spoke, Gold-Painted for Heat Reflectivity. Note corrosion on shaft, and absence of same on spoke.

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2. H. C. Stanley; Results of Component Test Program, Test No. 5 - Blade Screening Fatigue Test, 285-9-5, 1 May 1959.
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4. H. C. Stanley; Results of Component Test Program, Test No. 6 - Fabroid Vs. Armalon Anti-Fretting Test, 285-9-6, 20 May 1959.
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