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RESEARCH MEMORANDUM

for the

Department of the Navy

PERMEABILITY AND STRENGTH MEASUREMENTS ON SINTERED, POROUS, HOLLOW TURBINE BLADES MADE BY THE AMERICAN ELECTRO METAL CORPORATION

UNDER OFFICE OF NAVAL RESEARCH

CONTRACT N-ONR-295 (01)

By Hadley T. Richards and John N. B. Livingood

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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PERMEABILITY AND STRENGTH MEASUREMENTS ON SINTERED, POROUS, HOLLOW TURBINE BLADES MADE BY THE AMERICAN ELECTRO METAL CORPORATION UNDER OFFICE OF NAVAL RESEARCH CONTRACT N-ONR-295 (01)

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SUMMARY

An experimental investigation was made to determine the permeability and strength characteristics of a number of sintered, porous, hollow turbine rotor blades and to determine the effectiveness of the blade-fabrication method on permeability control. The test blades were fabricated by the American Electro Metal Corporation under a contract with the Office of Naval Research, Department of the Navy, and were submitted to the NACA for testing. Of the 22 test blades submitted, ten were sintered but not coined, five were sintered and coined, and seven were sintered and not coined but contained perforated reinforcements integral with the blade shells. Representative samples of each group of blades were tested.

Large variations in permeability in both chordwise and spanwise directions were found. Local deviations as large as 155 to -85 percent from prescribed values were found in chordwise permeability. Only one blade, an uncoined one, had a chordwise permeability variation which reasonably approached that specified. Even for this blade, local deviations exceeded 10 percent. Spanwise permeability, specified to be held constant, varied as much as 50 percent from root to tip for both an uncoined and a coined blade. Previous NACA analyses have shown that in order to maintain proper control of blade wall temperatures, permeability variations must not exceed ±10 percent. Satisfactory control of permeability in either the chordwise or the spanwise direction was not achieved in the blades tested.

Spin tests made at room temperature for six blades revealed the highest material rupture strength to be 8926 pounds per square inch. This value is about one third the strength required for rotor blades in

present-day turbojet engines. The lowest value of blade strength was 1436 pounds per square inch.

INTRODUCTION

A program for the development of sintered porous materials for transpiration-cooled turbine blades and for the fabrication of such blades has been carried on for a number of years by the Office of Naval Research and the Bureau of Aeronautics. The program was set up because of the superiority of transpiration cooling over other air-cooling methods (especially at high turbine-inlet temperatures). This superiority was demonstrated by analyses made some years ago at the NACA Lewis laboratory. Late in 1950 the Office of Naval Research, as part of this program, placed contract N-ONR-295 (01) with the American Electro Metal Corporation (AEMC) for the fabrication of sintered porous hollow turbine rotor blades. The ONR requested the NACA to supply drawings for blades that would be suitable for experimental engine testing at the Lewis laboratory. 3506

Two proposed blade designs, thought to be generally suitable at that time for installation in a modified jet engine used as a test vehicle, were submitted to the ONR by the NACA. The first design was for a twisted and tapered blade; the second, an untwisted and untapered blade. The first design was eliminated by the ONR because, as a first step, the fabrication problems appeared to be difficult. Furthermore, the time required for development of twisted and tapered blades might be excessive, and fundamental information connected with making sintered hollow blades would therefore be delayed. The second design, which was a modified form of that submitted to Stevens Institute of Technology under an NACA contract and reported in references 1 and 2, was accepted. Blades fabricated according to this second design, it was believed, would serve as an initial step toward development of hollow blades which might eventually be required. Moreover, knowledge gained in the development of the porous material, and in the fabrication of the blades themselves could probably be used for other blade shapes and types. In the engine tests of blades of this second design, strength and temperature data could be obtained. In addition, permeability or cooling-air-flow tests could be made to check the control and level of permeability compared to specifications; indication of the effectiveness of the fabrication process on control of permeability could thus be found.

At the time the blade designs were submitted, the accepted cooling-air-flow criterion was porosity. As a consequence, porosity specifications were submitted with the blade designs by the NACA. Later research indicated that the specifications should be made in terms of blade permeability. This was determined before the AEMC had reached the blade

fabrication stage (Jan. 1953). Consequently, the blades were actually fabricated according to a permeability specification submitted by the NACA at that time.

During the process of development and fabrication of the AEMC blades, improved types of transpiration-cooled turbine blades were developed. However, it was believed that information could still be obtained on the porous metal strength and the degree to which permeability in the shell could be controlled by testing the AEMC blades.

The AEMC transmitted 22 sintered hollow turbine rotor blades to the NACA in 1954 for experimental strength and permeability investigations. It is the purpose of this report to present the results of the permeability tests, to determine the effectiveness of the fabrication method on the control of permeability, and to compare the results with specifications. In addition, results of strength tests obtained by rotating the blades in a cold-spin test vehicle are presented.

SYMBOLS

The following symbols are used in this report:

K' permeability coefficient, sq ft; for $p_a^2 - p_g^2 = 3556^2 - 2116^2$, lb^2/ft^4

p static pressure, lb/sq ft abs

R universal gas constant

T temperature, $^{\circ}R$

v flow volume per unit surface area and time, ft/sec

μ absolute viscosity, lb-sec/sq ft

ρ density, lb/cu ft

τ thickness of blade wall, ft

Subscripts:

a cooling air

g gas side

0 for reference temperature of 518.7° R

APPARATUS AND INSTRUMENTATION

Blade Specifications

As noted previously, the second of two blade designs submitted by the NACA was accepted by the ONR. A sketch of this blade design and its pertinent dimensions are given in figure 1. Untwisted and untapered blades with a chord of 1.590 inches and a span of 4 inches were specified. Blades were fabricated from AISI type 316 stainless-steel powder. A porosity of 30 percent in the leading- and trailing-edge portions of the blade and a porosity of 15 percent for the other sections of the blade periphery were originally prescribed; these values were to be maintained throughout the blade span.

While the AEMC was developing its blade-fabrication methods, transpiration-cooling investigations continued. It became apparent that a method of prescribing blade cooling-air-flow characteristics more accurately than the use of porosity was necessary. A method for correlating the data for the flow of a gas through a porous plate had been developed at the California Institute of Technology (ref. 3) and adapted to transpiration-cooling work done at the Lewis laboratory. The term permeability coefficient, which specifies the permeability for one material thickness, was evolved. The permeability coefficient divided by the material thickness is generally used since, at given pressure levels on opposite sides of the porous wall, an actual indication of the quantity of flow through the material is given. For convenience, this quantity is herein evaluated at a pressure drop through the material of 10 pounds per square inch discharging at NACA standard sea-level conditions.

The permeability specifications given to AEMC as mentioned in the INTRODUCTION were considered to be the most reasonable available at the time. The values given were those for a stator blade. These values of permeability coefficient are given in a subsequent figure. When these specifications were supplied, no method was available for the determination of the spanwise pressure distribution in a rotating blind porous passage and, consequently, no reliable spanwise permeability could then be specified for a rotor blade. Moreover, it was believed that the strength of porous sintered material at elevated temperatures had not yet been developed to the point where application for hollow turbine rotor blades was feasible. Furthermore, specifications for a stator blade would be adequate to determine if a controlled permeability variation could be achieved by a certain fabrication process. It was for these reasons that the stator-blade permeability variation was selected for the specifications.

Blade Fabrication Method and Test Blades

The blade fabrication process as developed and followed by the AEMC in fulfilling the ONR contract for the fabrication of sintered, porous, hollow turbine rotor blades is described in detail in references 4 and 5. A brief description of this process and of the types of test blades submitted follows:

A hydraulic-press, cold-molding die was made. A predetermined amount of type 316 stainless-steel power with an incorporated amount of phenolic binder was poured into the die. The knife, or core rod, comprising the inner cooling air passage was inserted, and the remaining powder added. The die assembly was jogged to settle the powder, and baked at 450° F to cure the phenolic binder. The blade was then removed from the die in the molded-and-cured form ready for sintering. The blade was sintered at 2280° F for 80 minutes in a hydrogen atmosphere. Ten blades were fabricated by this method and submitted to the NACA for testing. One of these blades is shown in figure 2(a).

A second set of five blades was fabricated in this same way, but in addition, was placed in a separate die in which the shells were coined. The coining procedure was employed in order to reduce the blade permeability. In addition, coining increased the blade strength. A coined blade is shown in figure 2(b).

A third set of seven blades had perforated reinforcements inserted into the original mold. The powder and phenolic binder were then poured. These reinforcements consisted of sheets of stainless steel approximately 0.015 inch thick with holes of 0.035-inch diameter spaced 0.020 inch apart. Such reinforcements were located in both pressure and suction surfaces. These blades were not coined. The use of the perforated reinforcements integral with the blade shell was ostensibly to add strength to the shell. The geometry of the cooling-air passages of all the blades was essentially the same and a base view of a typical blade is shown in figure 2(c). The cooling-air passage in the base region and in the airfoil are shown.

Each of the 22 test blades described in the foregoing paragraphs had its base infiltrated with copper. The copper infiltration was allowed to extend approximately 1/8 inch into the blade shell above the blade base. By this method, an increase in the strength of the material in this section of maximum stress was achieved. The test blades as supplied by the AEMC had blank bases as shown in figure 2. Fir-tree-type base serrations were ground by the NACA in the bases of the blades used for spin tests.

Two blades, one coined and one not coined, were selected to be measured on a profile-measuring instrument at the Lewis laboratory.

When the measurements were compared with those originally specified to AEMC, it was found that a dimension through a cross section from outside suction surface to outside pressure surface at the midchord region exceeded the specified dimension by about 35 percent. The leading-edge radii were also oversize. The chord lengths were within specified limits.

Test Equipment

Permeability investigation. - A detailed description of the apparatus used for measuring local cooling-air-flow rates through the walls of hollow transpiration-cooled turbine blades is given in reference 1. (From these flow rates, local blade permeabilities can be obtained.) The blade to be tested was placed in a holder as shown in figure 3. The holder was connected to a controlled and metered air supply. The air was filtered and supplied at room temperature. Local flow rates at various locations on the blade periphery were measured by means of small probes, or sampling tubes, contoured to fit specific locations on the blade surface. These probes were connected through rotameters to a vacuum supply. A static-pressure tap located in the wall of the sampling tube permitted the adjustment of the pressure inside the tube to that of the ambient air around the blade exterior. Under these conditions, the presence of the sampling tube against the wall of the porous blade is believed to have a negligible effect on the air flow through the wall.

A static-pressure tap and a thermocouple located in the air-supply tube immediately upstream of the blade base were used to measure cooling-air pressure and temperature.

Strength evaluation. - In order to determine the strength of the porous blade material, single blades were installed in a turbojet-type rotor and spun to failure at room temperature in a spin rig. The rotor was suspended in an armored pit with the turbine shaft in a vertical position. The rotor shaft was connected to an air turbine which rotated the assembly. In order to reduce the torque required to spin the rotor, the portion of the rig surrounding the rotor was sealed and evacuated to about 7 inches mercury absolute pressure during the spin test. The rotational speed of the rotor was measured by an electronic tachometer. An automatic alarm system indicated blade rupture.

PROCEDURE

Experimental Procedure

Permeability investigation. - The local cooling-air-flow rate out of an area on the surface of a blade was obtained at room conditions by

placing a sampling tube against the blade wall at a particular location, equalizing the sampling-tube pressure with ambient pressure, and measuring the air-flow rates for a range of pressure losses through the blade wall (see ref. 1). Flow rates were obtained in four planes located about 3.25, 2.55, 1.75, and 0.75 inches from the blade root; at each of these spanwise locations, the sampling tube was positioned at seven chordwise locations on several blades. These chordwise locations, expressed in percent of chord from the blade leading edge, were at 0, 18, 45, and 68 percent chord on the suction surface and at 10, 34, and 62 percent chord on the pressure surface.

The flow rates through the walls of six blades were obtained in the manner described above. The blades investigated consisted of three uncoined blades (438, 459, and 464), two coined blades (603 and 610), and one uncoined blade with perforated reinforcements (710) integral with the blade shell. These blades were selected at random from those available. The numbers in the parentheses were assigned by the AEMC and will continue to be referred to in this report.

Strength tests. - The strength of the blade material was determined by spinning blades to rupture in the spin rig previously described. A total of six blades were spun to failure; the blades consisted of two uncoined blades, two coined blades and two uncoined blades with perforated reinforcements. The blades investigated in the spin rig are described in a subsequent table.

Each blade was individually spun to destruction in the spin rig. After the blade was installed in a suitably balanced rotor, the rotor assembly was installed in the armored spin pit chamber. The air pressure in the chamber was reduced to about 7 inches of mercury absolute and the rotor was accelerated slowly until blade failure occurred. The speed of the rotor at failure was recorded and the radial location of the failure was determined upon removal of the rotor from the spin chamber.

Calculation Procedure

Permeability evaluation. - The specified chordwise permeability distribution was calculated for a pressure drop through the porous blade wall of 10 pounds per square inch discharging to NACA sea-level conditions. In order to compare this specification with the experimental permeability data for the test blades, the following calculation procedure was employed. A modification of Darcy's law was used:

$$\frac{p_a^2 - p_g^2}{\tau} = \frac{1}{K'} \left[2RT_a\mu_a(\rho v)_a\right]$$

Darcy's law in this form employs a factor K called the permeability coefficient which is evaluated at $(\rho v)_a = 0$. Since it is necessary to extrapolate experimental data to zero flow and evaluate the slope of the line at this point to obtain K, a new definition of permeability factor K' will be used in this report. A pressure drop through the material of 10 pounds per square inch discharging to NACA standard sea-level conditions was arbitrarily chosen. If values of T_a and μ_a for air at standard sea-level conditions are substituted in the preceding equation as well as the corrected drop in pressure squared $(3556)^2 - (2116)^2$ for 10 pounds per square inch, the following expression results:

$$\frac{K'}{\tau} = \frac{2(53.3)(518.7)(3.77\times10^{-7})(\rho v)_a}{(3556)^2 - (2116)^2}$$

This reduces to

$$\frac{K'}{\tau} = 2.55(\rho v)_a \times 10^{-9} \text{ ft}$$

or

$$\frac{12K'}{\tau} = 30.6(\rho v)_a \times 10^{-9} \text{ in.}$$

The local permeability of different blades is compared on this basis.

Strength evaluation. - The rupture strength of the blades was determined from the blade density, the radius ratio (radius from center of rotation to an average line of the rupture over the radius from center of rotation to blade tip), and the speed of rotation at which rupture occurred. All measurements except density were obtained from the experimental strength tests. Density of the material was obtained experimentally by evaluating the density of the airfoil section of a coined and uncoined blade selected at random. It was assumed that the material density for all blades was the same as that determined for the two selected blades.

RESULTS AND DISCUSSION

Permeability Evaluation

Chordwise permeability. - Figure 4 compares the experimentally obtained chordwise permeability distribution at a plane 1.75 inches from the base for each of the six blades tested with the specified chordwise permeability variation shown as a dashed line. The results for the

three uncoined blades are shown in figure 4(a). Only one of these blades, number 464, has a permeability variation approaching that specified. For the other two blades, the trends of the curves are opposite to that for the prescribed distribution, particularly for the pressure surface.

Figure 4(b) shows the permeability distribution for two coined blades (603 and 610) and indicates that the coining process reduces the blade permeability locally. Coining should help to control the local permeability. The reduction in permeability of the coined blades as compared to the uncoined blades (fig. 4(a)) is based upon the assumption that the permeability of the coined blades prior to coining was similar to that for the uncoined blades. However, lack of uniformity in the permeability distributions for the uncoined blades makes direct comparison of the data for coined and uncoined blades uncertain.

Figure 4(c) shows the permeability distribution for blade 710, which was not coined but contained perforated reinforcements integral with the blade shell. It can be seen that an erratic distribution was obtained. Local measurements indicated variations from the specified permeability of as much as 39 to -13.5 percent. Comparison of the distributions for the six blades shown in figure 4 indicates very large variation in chordwise permeability and in deviation from the prescribed distribution. Since these blades were selected at random from those submitted under the contract, it is obvious that satisfactory control of permeability from blade to blade has not been achieved. Such chordwise variations in permeability would cause corresponding variations in shell temperature during engine operation. Previous NACA analyses have shown that in order to maintain proper control of blade wall temperatures, permeability variations must not exceed ±10 percent. Figure 4 shows deviations as large as 155 to -85 percent from those desired.

Spanwise permeability. - Recent analyses made at the NACA indicate the necessity of a design spanwise variation of permeability for rotor blades. Such variations will depend upon the blade profile and the particular application for which the blade is intended. However, for reasons given previously, at the time the specifications for the blades reported on were given, a uniform spanwise variation was prescribed. Since the chordwise permeability tests reported in the preceding paragraph showed inconsistent blade-to-blade results, only two blades were selected for spanwise checks of permeability variation. These blades were a coined blade (610) and an uncoined blade (438). The results shown in figure 5 are for several constant chordwise positions at four spanwise stations on each blade. Because of slight variations in blade profiles and the use of a single set of sampling tubes, no data at the leading edge of the coined blade and at several positions on the uncoined blade were obtainable. The coined blade (fig. 5(a)) and the uncoined blade (fig. 5(b)) generally showed a trend of increasing permeability from root

to tip. One position on each blade (position 1 on the coined blade and the leading edge on the uncoined blade) showed the opposite trend. The increase in permeability from root to tip was about 50 percent for the coined blade and about 45 percent for the uncoined blade. These results together with the fact that a uniform spanwise variation was specified show that control of the permeability in the spanwise direction has not been achieved.

Spin Tests

In order to determine the total stress imposed upon a rotating turbine blade, it is necessary to consider centrifugal force, bending forces (imposed either by blade warpage, misalinement, or gas bending) and vibration. Since the blades considered in this investigation were spin tested in an evacuated chamber, gas bending forces and vibration did not affect the results. Furthermore, calculations indicated that the amount of warpage or misalinement of these blades made an insignificant contribution to the total stress imposed. Therefore, the results of the spin tests presented in the following table represent the effect of centrifugal force alone:

Blade	Type of blade	Rotational speed at failure, rpm	Length of blade stub after failure, in. (a)	Calculated centrifugal stress, psi
438	Uncoined	2740	0.23	1436
464	Uncoined	3620	.22	2545
603	Coined	7064	1.52	6771
611	Coined	5274	.52	4983
712	Uncoined with reinforcements	6800	.25	8926
713	Uncoined with reinforcements	5480	.25	5795

[a]Distance is measured from blade base to platform to plane of failure.

The results indicated that all the blades failed considerably below design speed (11,500 rpm). A typical failed blade is shown in figure 6. The maximum stress at which a blade failed was 8926 pounds per square inch. The root stress in blades of this type at design speed in a current turbojet engine would be on the order of 27,000 pounds per square inch, about three times the maximum stress achieved in the spin tests. As would be expected, the results also indicated that the coined blades were stronger than the uncoined blades. The uncoined blades with reinforcements exhibited strengths that averaged about 5370 pounds per square inch greater than simple uncoined blades. It would appear from the results of the spin tests that the addition of reinforcing strips of the type used is beneficial. It should be noted that this trend cannot continue under design conditions, since calculations indicate that the type of reinforcing strip employed is virtually incapable of self-support at design speed. At low speeds the reinforcing strip is stressed far below its yield point, whereas the porous material is stressed nearly to its ultimate strength. Assuming adequate bond between the reinforcing strip and the porous material, the total strength of the porous blades is therefore increased at lower speeds by the addition of these reinforcing strips.

Particular attention should be given to the fact that the spin tests were conducted at room temperature. If such tests had been conducted at a temperature comparable to that encountered in engine operation, it should be expected that blade failures would occur at rotative speeds lower than those obtained for the room-temperature tests.

The strength of the material in the test blades appears to be considerably below that of test bars made of the same material and fabricated in a manner similar to the test blades. Reference 4 indicates that strengths of the order of 30,000 pounds per square inch or greater should be expected. The densities of the porous materials reported in reference 5 were on the order of 5.9 to 6.26 grams per cubic centimeter, whereas the density of the blade shell material in the test blades was about 4.42 grams per cubic centimeter. The latter value was determined from density measurements made on a coined and an uncoined blade selected at random from the group of blades submitted to the NACA for investigation. Reference 6 shows that the strength of porous sintered materials decreases rapidly with decreasing density. Although the porous material of reference 6 is not the same as that investigated herein, similar trends in material strength would be expected. It is believed therefore that the relatively low density of the blade shell material is a major factor contributing to the low strength of the test blades.

GENERAL DISCUSSION

The present investigation involved shell-supported transpiration-cooled turbine blades that were untwisted and had relatively thick, untapered walls. The reasons for fabrication of such blades were given in

the INTRODUCTION. These blades permitted, for the first time, actual spin testing of several shell-supported porous blades for strength evaluation. The blades also permitted permeability evaluation of material fabricated by the AEMC process and incorporated into an actual blade configuration.

As inferred from the previous paragraph, features that will be required in the final design of shell-supported sintered-type transpiration cooled blades are:

(1) Thin walls (on the order of 0.020 to 0.035 in.) so that adequate cooling of the leading- and trailing-edge regions of the blades can be obtained. This is particularly necessary for blade shapes contemplated for transonic turbines in which relatively long and thin trailing edges appear necessary from an aerodynamics standpoint.

(2) Twisted airfoil sections from root to tip so that satisfactory aerodynamic performance of the blade can be obtained.

(3) Taper from root to tip in the wall of the porous shell so that a reduction in unit centrifugal stress in the blade shell is obtained as compared to that for a blade with a nontapered wall. Provision for taper in the blade wall will further complicate the problem of providing adequate permeability control because permeability is a function of wall thickness.

In addition to the features that the blade should possess, the following characteristics must be exhibited by the porous material in the blade shell:

(1) A rupture strength on the order of 30,000 to 35,000 pounds per square inch at temperatures of about 1000° F

(2) Control of permeability within the limits specified, as discussed previously

(3) Reproducibility of shell permeability from blade to blade

The previously itemized features and characteristics admittedly contribute to the difficulty of fabricating a shell-supported blade such as those made for the reported investigation. In fact, it seems possible that to include all the necessary features in a shell-supported porous blade may prove to be so difficult that attainment of satisfactory blades may be impractical. If thought, however, that it is practical to fabricate such blades, considerable research and development is still required.

Because the cost of fabricating and investigating porous shell-supported turbine blades is high and time consuming as compared with

fabricating and investigating sample sheets and bars of porous material, it is believed that thought should be given to working with porous samples if future development of porous sintered materials for such blades is contemplated. When porous samples can be produced that have suitable strength, thickness, permeability range, and permeability control it would then seem in order to attempt fabrication of blades with the required features for test purposes. Caution must be exercised, however, to assure that the use of porous samples will produce results that are indicative of those that might be expected with actual turbine blades. As was pointed out previously in this report, the strength and density results obtained by the AEMC in reference 4 for material samples was considerably different from that attained for the material from which the blades were fabricated, thus indicating that satisfactory agreement between samples and blades was not attained in this instance.

SUMMARY OF RESULTS

The results of the flow and strength tests made for a number of the sintered, porous, hollow turbine rotor blades submitted by the AEMC under contract N-ONR-295 (01) are summarized as follows:

1. Local chordwise permeability deviations as large as 155 to -85 percent from the prescribed values were found. Of the six blades tested, only one (an uncoined blade) had a chordwise permeability variation which reasonably approached that specified; local deviations from specified values exceeding 10 percent were observed for this blade. Previous NACA analyses have shown that ±10 percent is the maximum allowable to maintain proper control of the blade wall temperatures. Satisfactory control of chordwise permeability and duplication of chordwise permeability among blades by the fabrication process used has not been achieved.

2. A spanwise permeability difference of the order of 50 percent from root to tip was observed for both a coined and an uncoined blade. Since constant spanwise permeability was prescribed, it is apparent that satisfactory permeability control in this direction has not been achieved. The same permeability criterion as stated in the preceding result must be met in order to hold blade-shell temperature variations to an acceptable range.

3. Six blades were spun to destruction at room temperature in a spin rig. The material rupture strength obtained ranged from 1436 to 8926 pounds per square inch. This latter value is about one third the strength required for rotor blades in present-day turbojet engines. Similar tests, if conducted at elevated temperatures, would result in blade failures at lower rotational speeds.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, September 17, 1954

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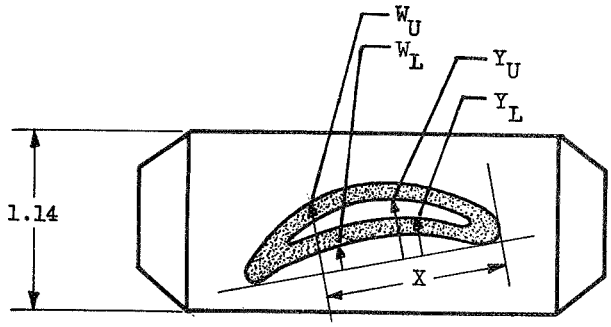
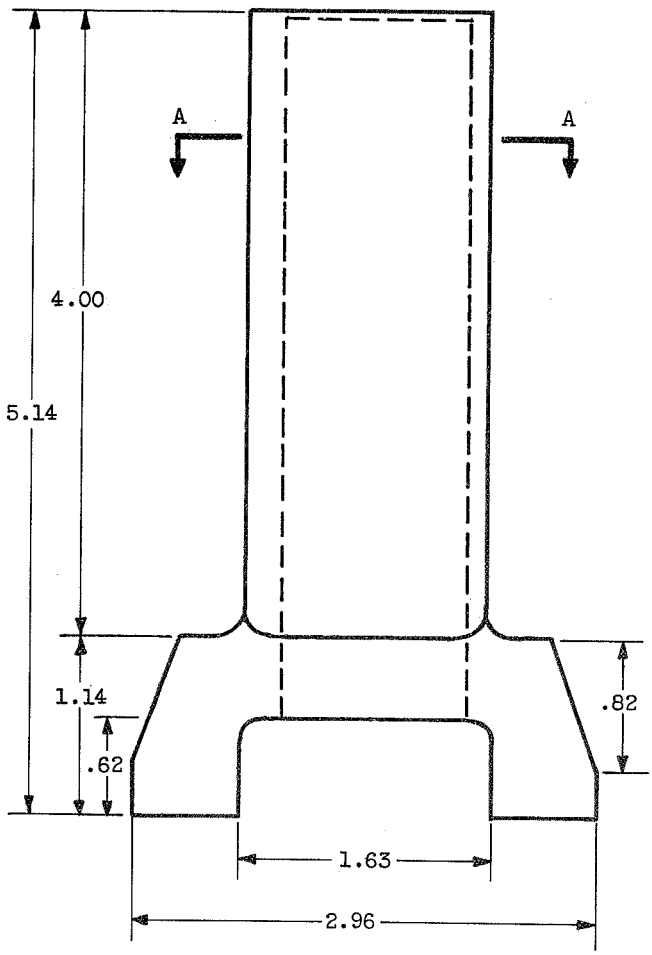


Section A-A

External blade coordinates

X	W_L	W_U
0	0.118	0.118
.050	.024	.219
.100	.004	.268
.150	.002	.306
.330	.045	.404
.530	.092	.470
.830	.110	.486
1.030	.100	.452
1.230	.066	.368
1.430	.026	.222
1.560	.000	.078
1.590	.030	.030
.131	.124	R_1 = .130
1.557	.033	R_2 = .032



Internal blade coordinates

X	Y_L	Y_U
.150	.102	.174
.330	.174	.282
.530	.214	.349
.830	.232	.365
1.030	.220	.335
1.230	.184	.252
.131	.124	R_3 = .020
1.280	.193	R_4 = .030

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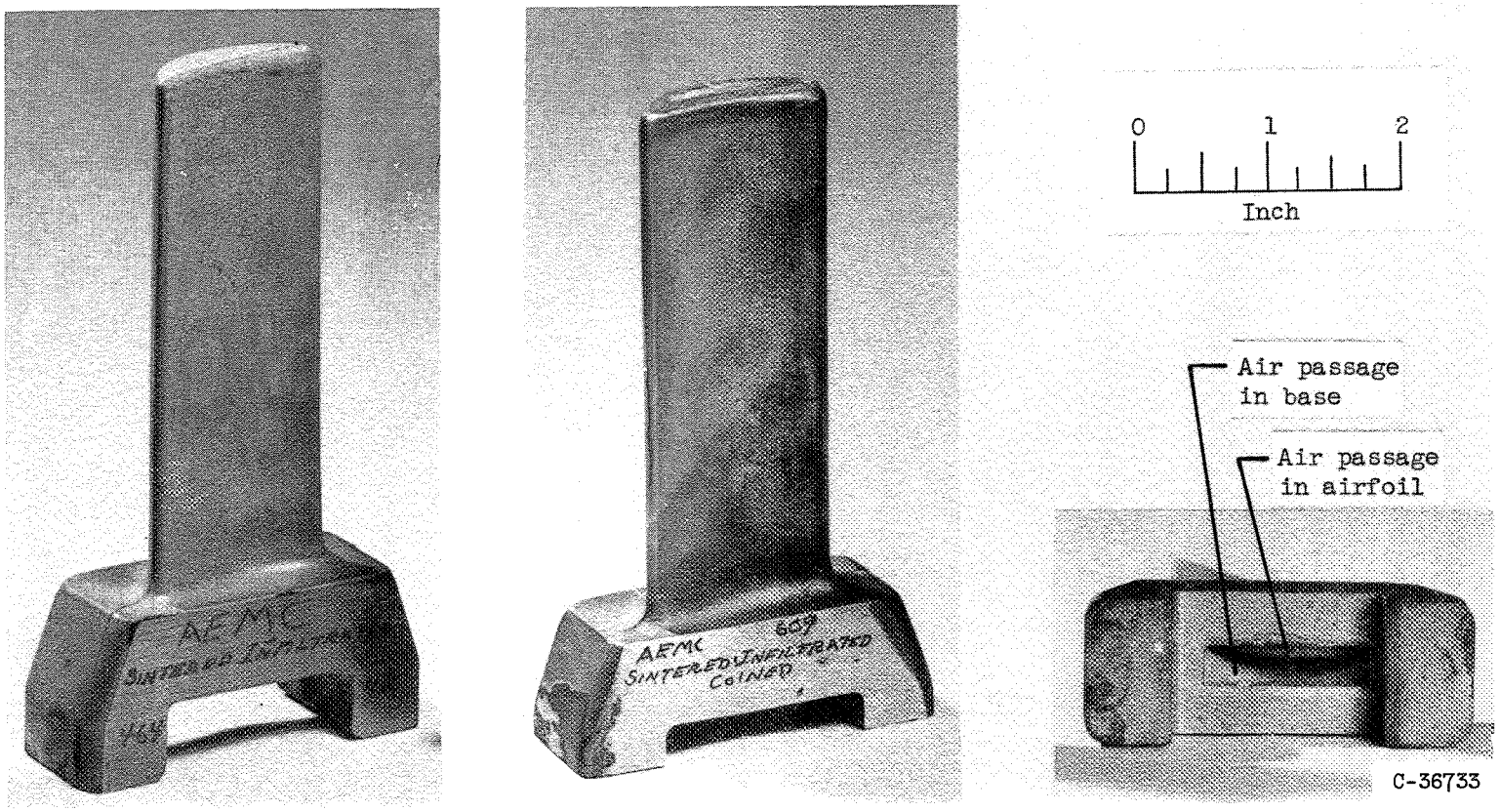
Figure 1. - Porous turbine blade as specified by NACA.



(a) Uncoined blade. (b) Coined blade. (c) Typical bottom view of blade.

Figure 2. - Sintered porous blades fabricated by American Electro Metal Corporation.

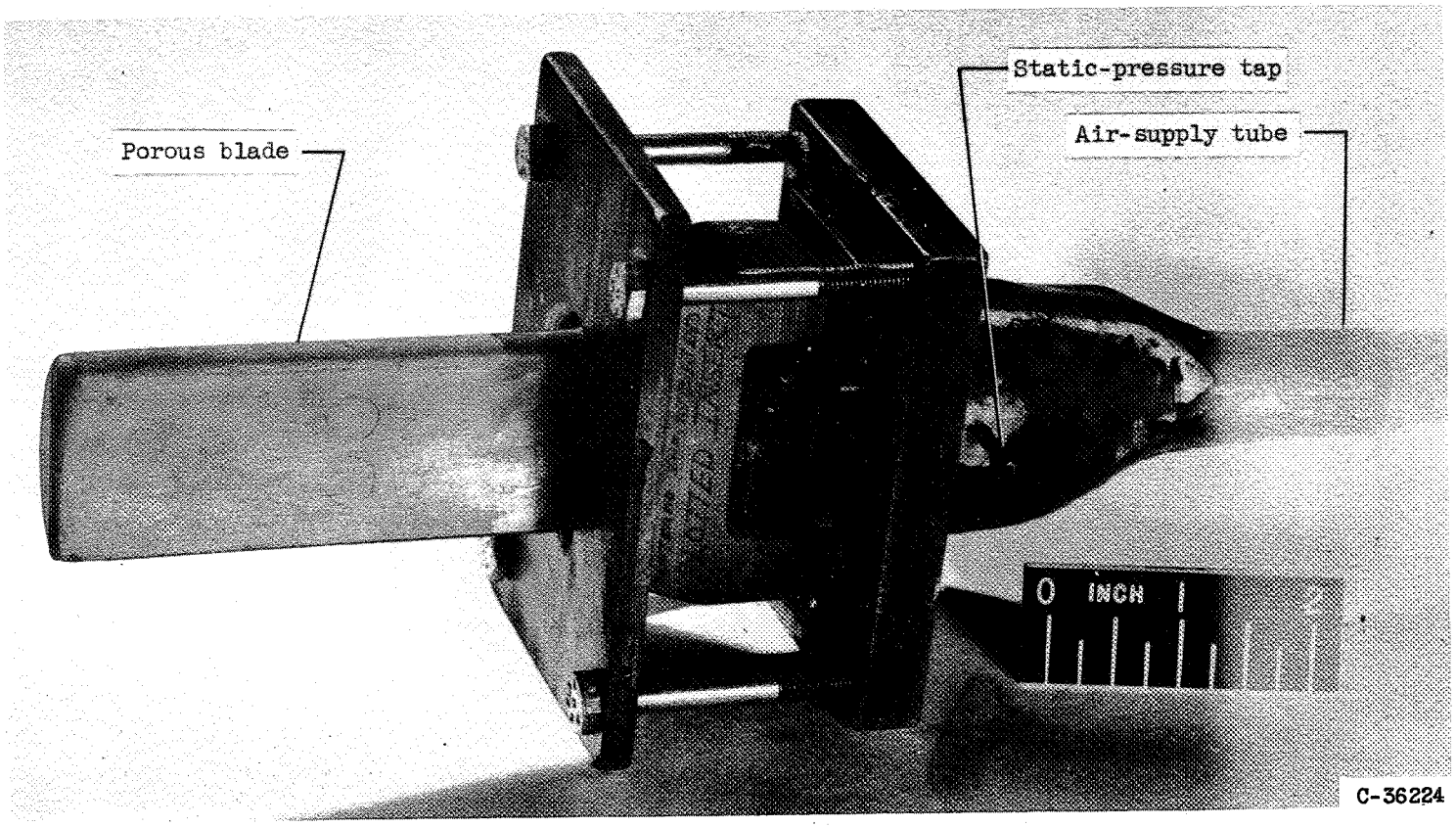
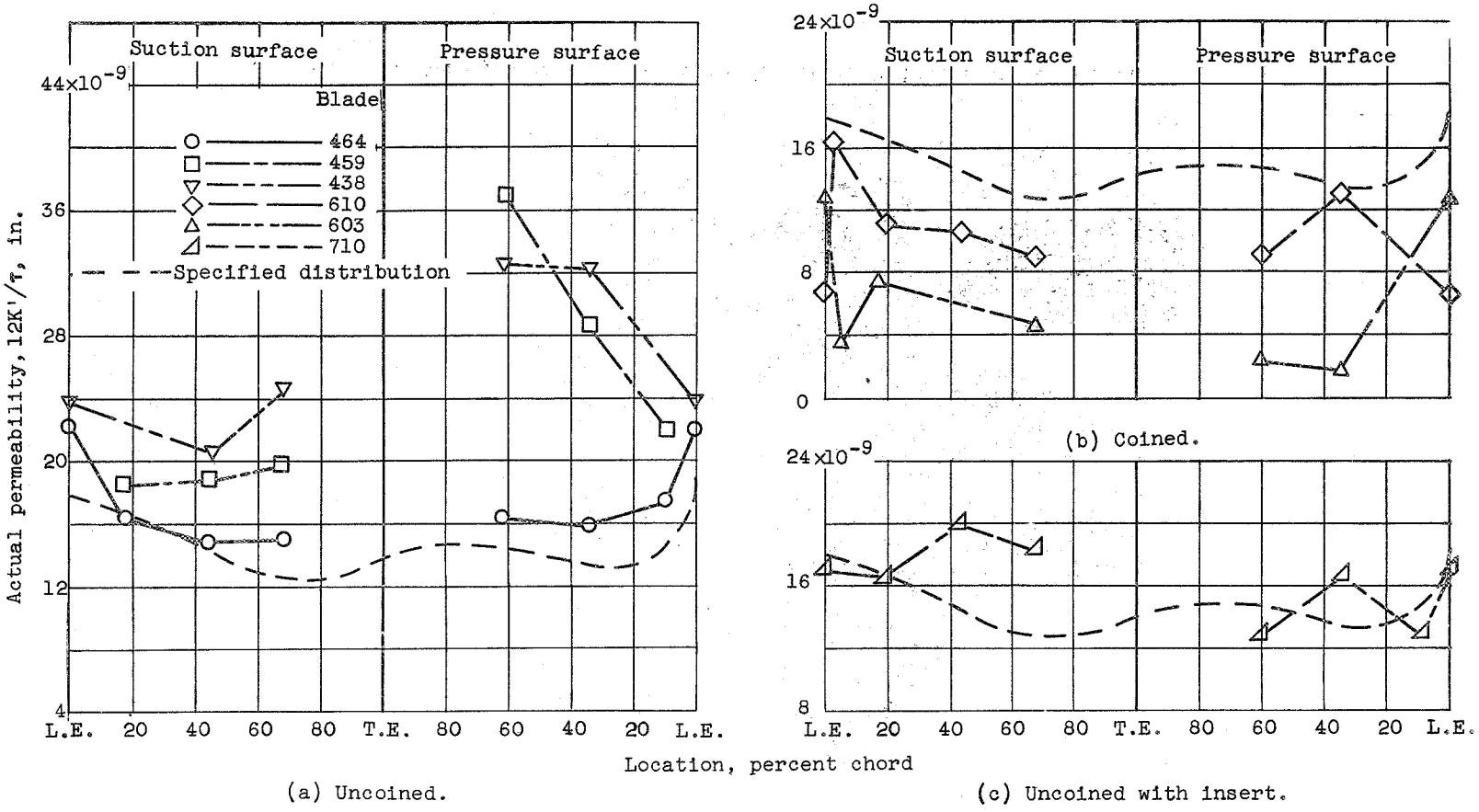


Figure 3. - Sintered, porous, hollow blade installed in holder of permeability test rig.

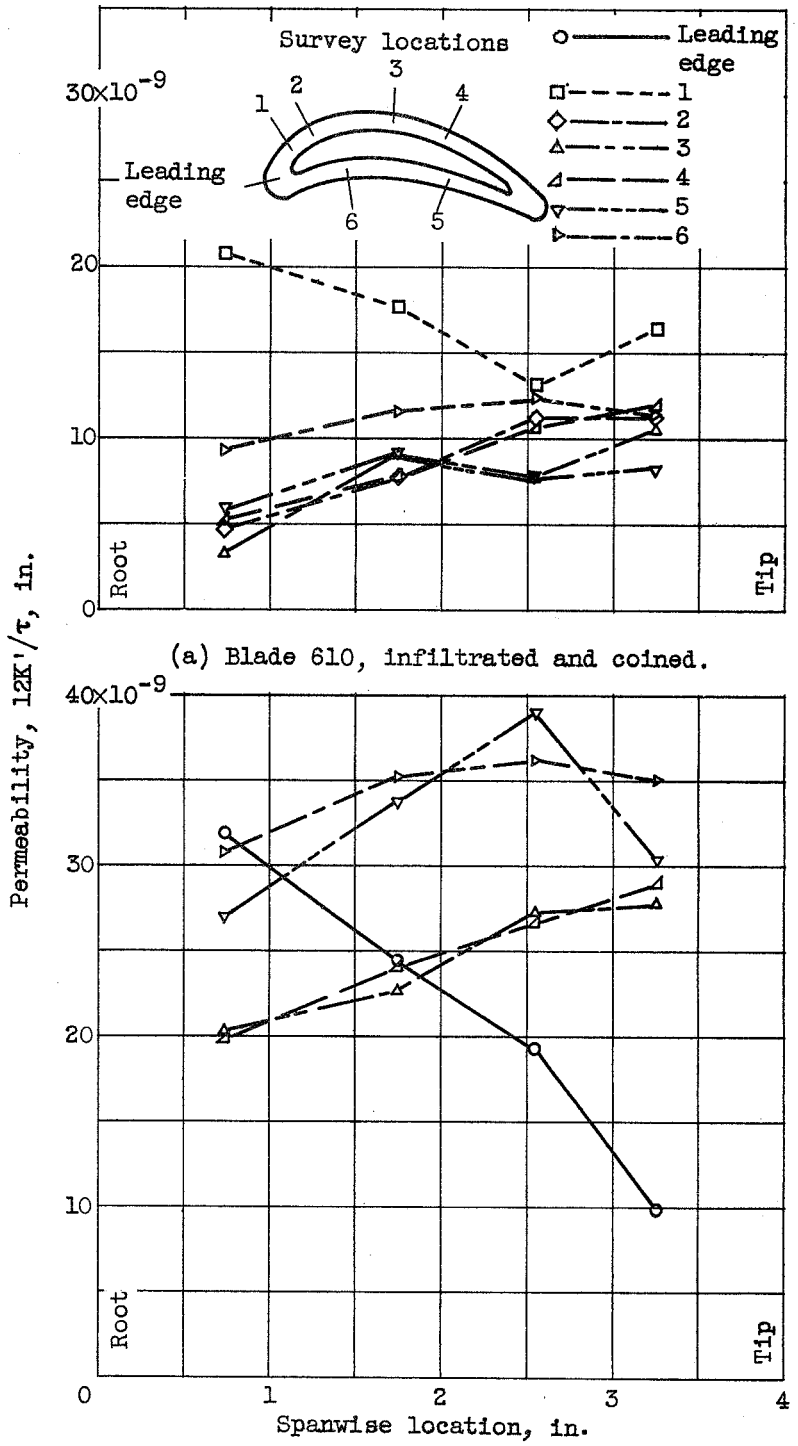


(a) Uncoined.

(b) Coined.

(c) Uncoined with insert.

Figure 4. - Experimentally measured permeabilities around periphery of six blades at plane 1.75 inches above blade base compared with values specified.



(a) Blade 610, infiltrated and coined.

(b) Blade 438, infiltrated but uncoined.

Figure 5. - Spanwise permeability distribution for various chordwise locations.

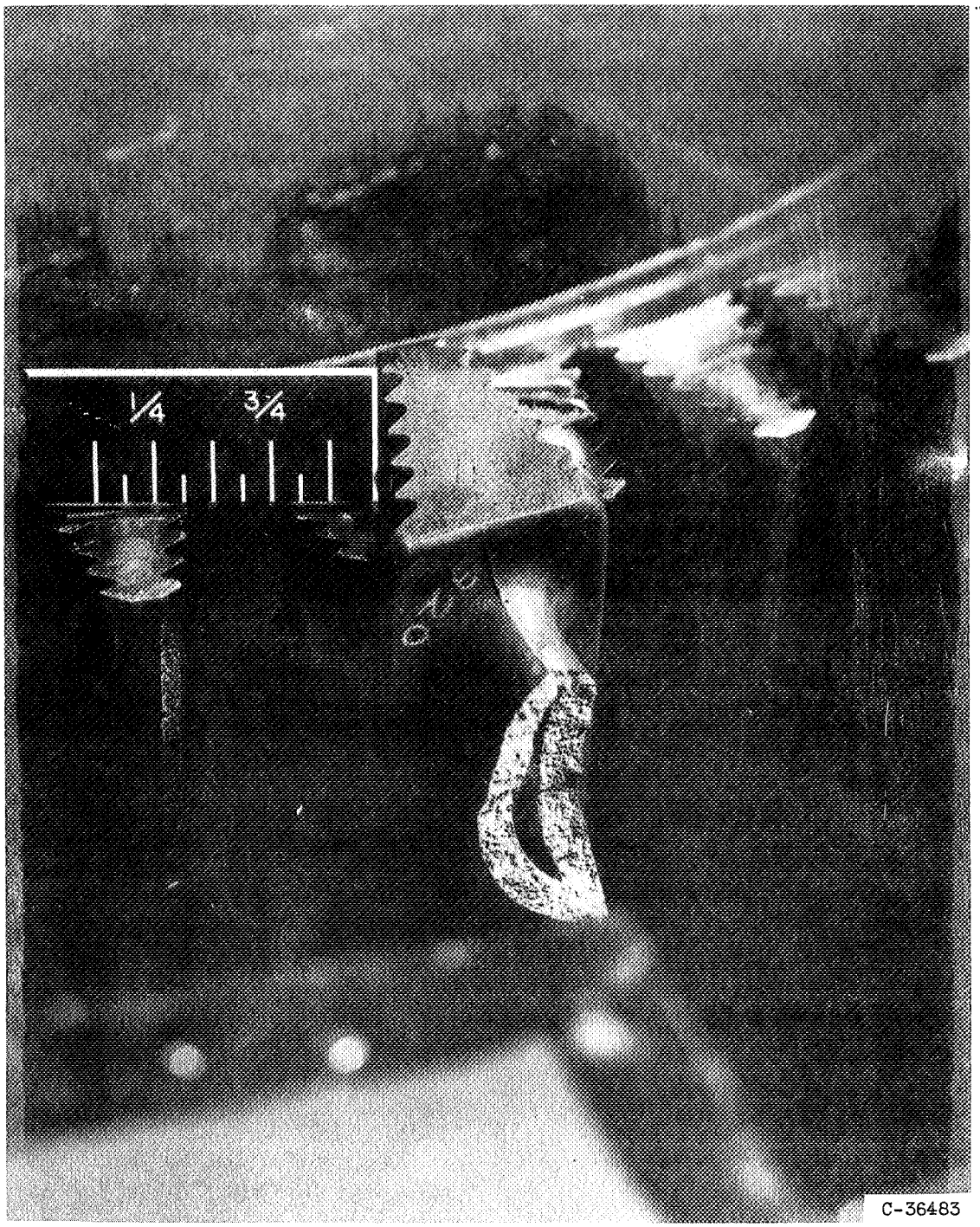


Figure 6. - View of broken porous blade mounted in spin test rotor.

PERMEABILITY AND STRENGTH MEASUREMENTS ON SINTERED POROUS HOLLOW TURBINE BLADES MADE BY THE AMERICAN ELECTRO METAL CORPORATION UNDER OFFICE OF NAVAL RESEARCH CONTRACT N-ONR-295 (01)

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Abstract

Large variations in permeability in both chordwise and spanwise directions were found, indicating that satisfactory control of permeability was not achieved. Spin tests of six blades at room temperature revealed maximum rupture strengths about one third the strength required for rotor blades in present day engines.