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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF SEVERAL ROOT DESIGNS FOR CERMET TURBINE BLADES IN TURBOJET ENGINE

III - CURVED-ROOT DESIGN

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

Cermet turbine blades were made with the root centerline curved to approximate the camber of the airfoil; the design eliminates any overhang between the root and the airfoil. This change eliminated the need for the blade platform and thus reduced the effective tensile stress in the blade root 20 to 30 percent and the nominal tensile stress in the root component of the rotor about 22 percent.

The blades were tested in a full-scale jet engine at an estimated blade temperature of 1500° F. In five engine tests, minimum life at rated speed was 77 hours; this blade failed in the airfoil. The shortest life terminated by root failure was 143 hours, which indicates increased strength and reliability of the root. In the longest run, operation was arbitrarily discontinued after 150 hours with no failure of the cermet blades.

INTRODUCTION

An extensive program is being conducted at the NACA Lewis laboratory to evaluate fastening designs for cermet turbine blades. Prior investigations are reported in references 1 to 4. The work reported herein is a continuation of that reported in reference 4. This reference outlined a method of reducing the effective bending stresses in blade roots by properly skewing the root centerline with respect to the turbine axis. Deviating from the linear or rectangular roots of either the axial- or skewed-style root and forming curved or circular arc roots makes possible still further reductions in stresses. The curved root also eliminates the need for a blade platform, and thus further reduces the centrifugal load carried by the root.

Five engine runs with curved root blades were made. Four cermet test blades were used in each run.

In previous work (ref. 4), the best position for the centerline of a rectangular root was approximated by dividing the blade into leading and trailing halves (cut by a plane through the midchords and parallel to the plane of the turbine rotor) and determining the center of gravity of each half. The root centerline then was placed parallel to a line passed through these centers of gravity. The offset between the root centerline and the line through the centers of gravity was adjusted to compensate for the bending caused by the gas forces acting on the airfoil.

To determine the optimum root centerline for the curved root blade, the airfoil was divided into ten radial columns instead of in halves. The computed center of gravity of each column was plotted on the base cross section of the airfoil (fig. 1).

The optimum centerline of the root would conform to the curve through the centers of gravity, but displaced from it to compensate for gas bending loads. A root developed in this manner, however, could not be assembled in the rotor, because the curve through the centers of gravity has different radii of curvature at the several points. A root with a circular-arc centerline provides a good compromise that can be assembled readily. The radius of the proper arc depends on the camber of the airfoil; a 1.953-inch radius was selected for the airfoil investigated. Figure 1 shows the curved centerline selected, along with the standard and the skewed centerlines from reference 4.

COMPARISON OF TENSILE STRESSES

With the curved-root design, no platform is needed for the airfoil. With rectangular roots, the platform is essential to avoid either producing an irregular flow surface at the periphery of the turbine rotor or undercutting the airfoil at the base section near the leading edge, the center, or the trailing edge. Elimination of the platform from the blade reduces tensile stresses in the root neck areas of both the blade and the rotor, as can be noted by comparing the computed centrifugal tensile stresses given in table I. Although root thickness and notch radius of the root are the same for the skewed and the curved blades, the stress concentration factors differ because elimination of the platform resulted in a fillet instead of a radiused groove or notch. Calculations of the stress concentration factors were made in accordance with references 5 and 6.

DESCRIPTION OF CERMET BLADES

Cermet blades with a curved root (fig. 2) were fabricated by Kennametal Inc. The airfoil was the same shape and size as those of the standard metal blades, as were the cermet blades discussed in reference

4. The cross section of the curved root, which was the same as that of the skewed-root blade reported in reference 4, was of optimum proportions as established in reference 1.

Composition, by weight, of the material used to make the curved-root blade was 62 percent titanium carbide, 30 percent nickel, and 8 percent of a solid solution of columbium, tantalum, and titanium carbides. The solid-solution carbides were added to improve resistance to oxidation. This composition was used in most of the runs reported in references 3 and 4. Prior to operation in the engine, all blades were inspected visually and by density measurements and radiographic methods. The nominal density of the cermet material is 0.217 pound per cubic inch. The blades for runs 1 and 2 were inspected by standard penetrant-oil methods; those for runs 3, 4, and 5 were inspected by more sensitive penetrant-oil methods that utilize separate dye and emulsifying agents. The blades used in run 5 had fine grinding cracks at the edges of the end face of the root. These cracks were eliminated by hand-lapping the corners to a radius of about 1/16 inch with diamond dust. After inspection, the bearing surfaces of the roots of all blades were diamond honed.

ENGINE EVALUATION PROCEDURES

The cermet blades were run in five sets of four blades each. In each set, two blades were placed adjacent to each other and the other two diametrically opposite. Each pair of test blades was mounted in the space normally occupied by three metal blades; however, the spacing between the two cermet blades was normal, with wider than normal spacing between adjacent metal and cermet blades. The remaining positions in the turbine wheel were occupied by conventional alloy blades. As in the majority of previous engine runs, 0.0075-inch 40-mesh electroformed nickel-plated copper screen was inserted between the cermet roots and the rotor recesses to distribute bearing stresses. The screening was preformed to the root curvature before assembly, and as before the blades were retained in the wheel by a cotter pin. Engine instrumentation was that used in the previous studies (refs. 3 and 4). The estimated blade temperature was 1500° F.

After installation of a new set of blades, the engine was slowly brought up to rated speed (11,750 rpm), a procedure requiring about 10 minutes. Rated speed was then maintained for about 13 hours per day. After each day's operation the blades were visually inspected through the tail cone after shutdown. Subsequent engine starts with the same set of blades were made with accelerations considered normal for metal blades.

Previous engine evaluations of cermet turbine blades (refs. 1 to 4) indicate that the blade lives were not reproducible. In this study, reliability for reasonable service life rather than the determination of the maximum life was emphasized. For this reason, a set of blades that survived 150 hours of rated-speed operation was removed and replaced with a new set. A summary of the five engine runs is given in table II.

Run 1. - The curved-root blades of run 1 successfully completed 150 hours. One of them is shown in figure 3. Except for a discoloration of the surface, no change in the blade during operation was detected. During the course of this run the engine was shut down 19 times.

Run 2. - The second set of curved-root blades had accumulated 77 hours and 4 minutes at rated speed when an airfoil failed, as shown in figure 4(a), and damaged the other cermet blades (fig. 4(b)). While no definite cause for the failure was established, the blades were severly corroded along the leading edge. The enlarged view of the leading edge of the failed blade (fig. 5) is typical of the appearance of the leading edges of all the cermet blades in this run. X-ray diffraction of flakes chipped from the edges of the blades did not indicate the presence of foreign material; only the constituents or their oxides were detected. Since this corrosion was not evident in the many previous engine runs with this composition, it is not considered characteristic of either the nominal composition or the normal operating environment.

Run 3. - In run 3, a curved-root blade failed at the base of the airfoil after 132 hours and 15 minutes at rated speed. A black powdery substance spotted the suction surfaces of all blades, particularly near the leading edges (fig. 6). X-ray diffraction patterns of scrapings of this powder indicated only carbon. Since the formation of carbon is unusual in this engine, the deposit indicates that the engine was malfunctioning. The deposit itself was tightly adherent; it was not removed when the blade was held against a linen buffing wheel. The tight adherence of the deposit as well as the presence of carbon near the origin of the fracture (fig. 7(a)) suggests that a chemical reaction may have occurred between the carbon and the blade material. Malfunction of the engine may have propagated the stress raiser formed by such a reaction. To investigate this possibility, carbon was collected from deposits in the combustion chambers of several engines and compacted into pellets. These were heated to 1500° F in a furnace, in contact with the surface of an unfailed curved-root blade. The carbon soon burned away, but the blade was left in the furnace to react with whatever ash or residue may have resulted. No reaction was detected after 200 hours at 1500° F. Although the fracture is located in an area of low vibratory stress, appearance of the fracture (fig. 7(b)) suggests a fatigue mechanism.

Run 4. - A curved-root blade (fig. 8(a)) failed in the root after 142 hours and 58 minutes at rated speed, damaging the adjacent cermet blade but inflicting only minor damage to the opposing pair of blades (fig. 8(b)). The failure has the spalled appearance that has previously been attributed (ref. 4) to the presence of high compressive stresses, particularly those resulting from the progressive pinching action of the turbine wheel during engine operation that involves many engine stoppages. During run 4, the engine was stopped and started 25 times. Reference 4 states also that the root radius used in this study is superior to the larger radii used previously from consideration of the buildup of these compressive stresses.

Run 5. - After 102 hours at rated-speed during run 5, the wheel failed in the serration area between two cermet turbine blades (fig. 9), damaging the cermet turbine blades and terminating the run. The wheel had been used for all the runs discussed in this report, accumulating more than 600 hours of rated-speed operation, and had been subjected to 98 starts and stops. As indicated in table I, wheel stress is considerably less with the curved root than with the root forms previously investigated (refs. 3 and 4). The expected stress-rupture life of the rotor alloy had not been attained at the time of failure, and the appearance of the fractured face is not characteristic of a stress-rupture mechanism. Cause of the failure was not determined.

SUMMARY OF RESULTS

The study reported herein is part of a program to improve the operating life of cermet turbine blades in the J33 turbojet engine. This report presents the results of a study which included:

1. Redesign of the blade root, so that the blade no longer required a platform. This change reduced tensile stresses in the root.

2. Five engine runs, in each of which two pair of curved-root cermet turbine blades were run in diametrically opposed positions in the turbine wheel. Blades with the redesigned root exhibited greater reliability than was previously observed; the longest run was discontinued after 150 hours without blade failure; the shortest run lasted 77 hours before failure of the first blade. Only one blade failed in the root, the most troublesome area with previously evaluated root forms.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 5, 1955

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2. Meyer, André J., Jr., Kaufman, Albert, and Calvert, Howard F.: Comparative Tensile Strengths at 1200° F of Various Root Designs for Cermet Turbine Blades. NACA RM E53C25, 1953.

3. Deutsch, George C., Meyer, André J., Jr., and Morgan, William C.: Preliminary Investigation in J33 Turbojet Engine of Several Root Designs for Ceramal Turbine Blades. NACA RM E52K13, 1953.

4. Meyer, A. J., Jr., Deutsch, G. C., and Morgan, W. C.: Preliminary Investigation of Several Root Designs for Cermet Turbine Blades in Turbojet Engine. II - Root Design Alterations. NACA RM E53G02, 1953.

5. Neuber, H.: Theory of Notch Stresses: Principles for Exact Stress Calculation. Trans. No. 74, Navy Dept., David Taylor Model Basin, Nov. 1945.

6. Peterson, R. E.: Stress Concentration Design Factors. John Wiley & Sons, Inc., 1953.

TABLE I. - CENTRIFUGAL TENSILE STRESSES OF CERMET BLADES OF THREE ROOT DESIGNS

	Root Style			Improvement of curved root over	
	Axial (a)	Skewed (a)	Curved	Axial, percent	Skewed, percent
Nominal stress in blade, psi	17,515	18,390	14,680	16.2	20.2
Stress concentration factor	1.68	1.41	1.37	18.5	2.8
Effective stress in blade, psi	29,430	25,930	20,110	31.7	22.4
Nominal stress in rotor, psi	34,780	35,530	27,430	21.1	22.8

[a] From ref. 4.

TABLE II. - SUMMARY OF ENGINE EVALUATION OF CURVED-ROOT CERMET BLADES

Run	Code	Operating time				Remarks
		Total		Rated-speed		
		hr	min	hr	min	
1	23	157	41	150	1	Run discontinued; blades did not fail
2	24	82	2	77	4	All blades failed in airfoil
3	38	137	35	132	15	One blade failed at base of airfoil
4	40	152	50	142	58	One blade failed in root
5	41	112	8	101	55	Wheel failed

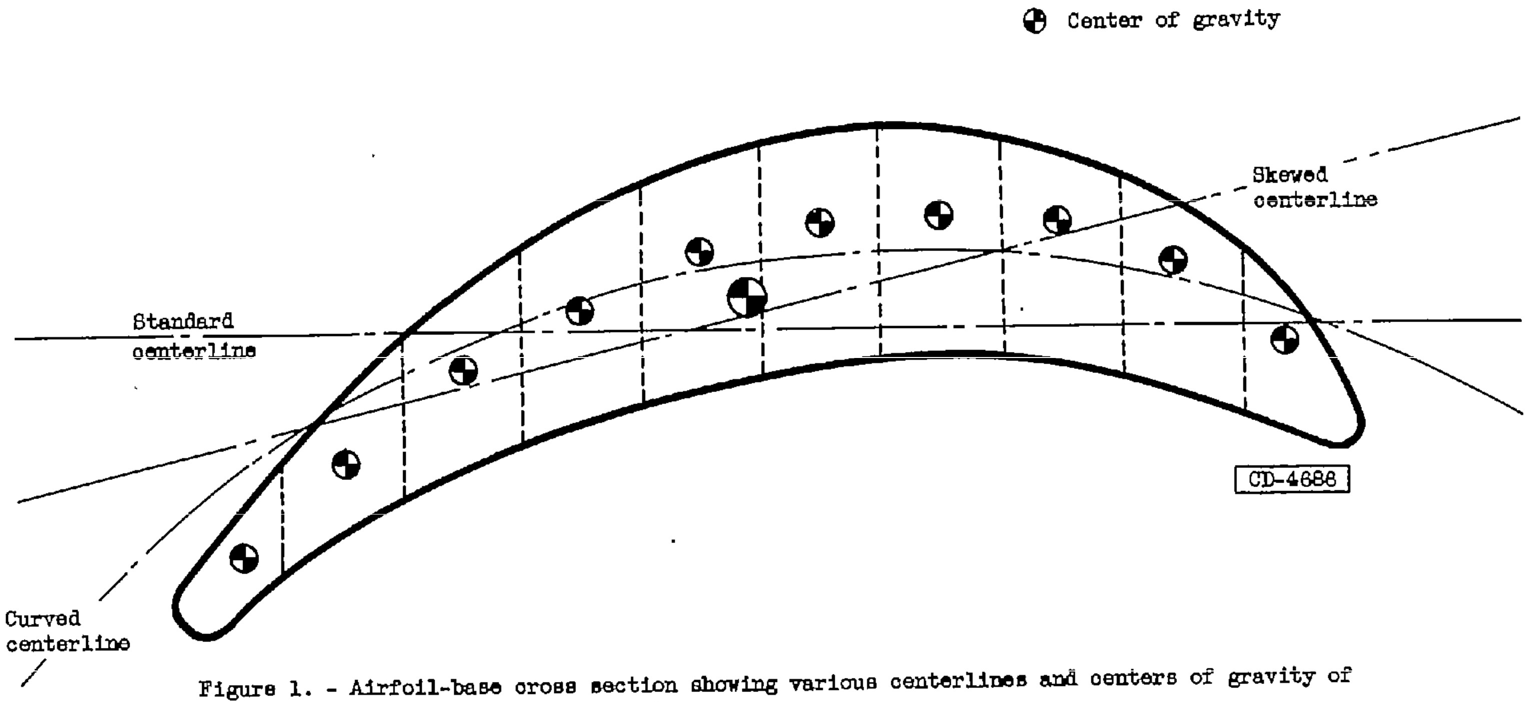


Figure 1. - Airfoil-base cross section showing various centerlines and centers of gravity of whole airfoil and of ten radial columns.

C-35436

Figure 2. - Curved-root cermet turbine blade.

C-37387

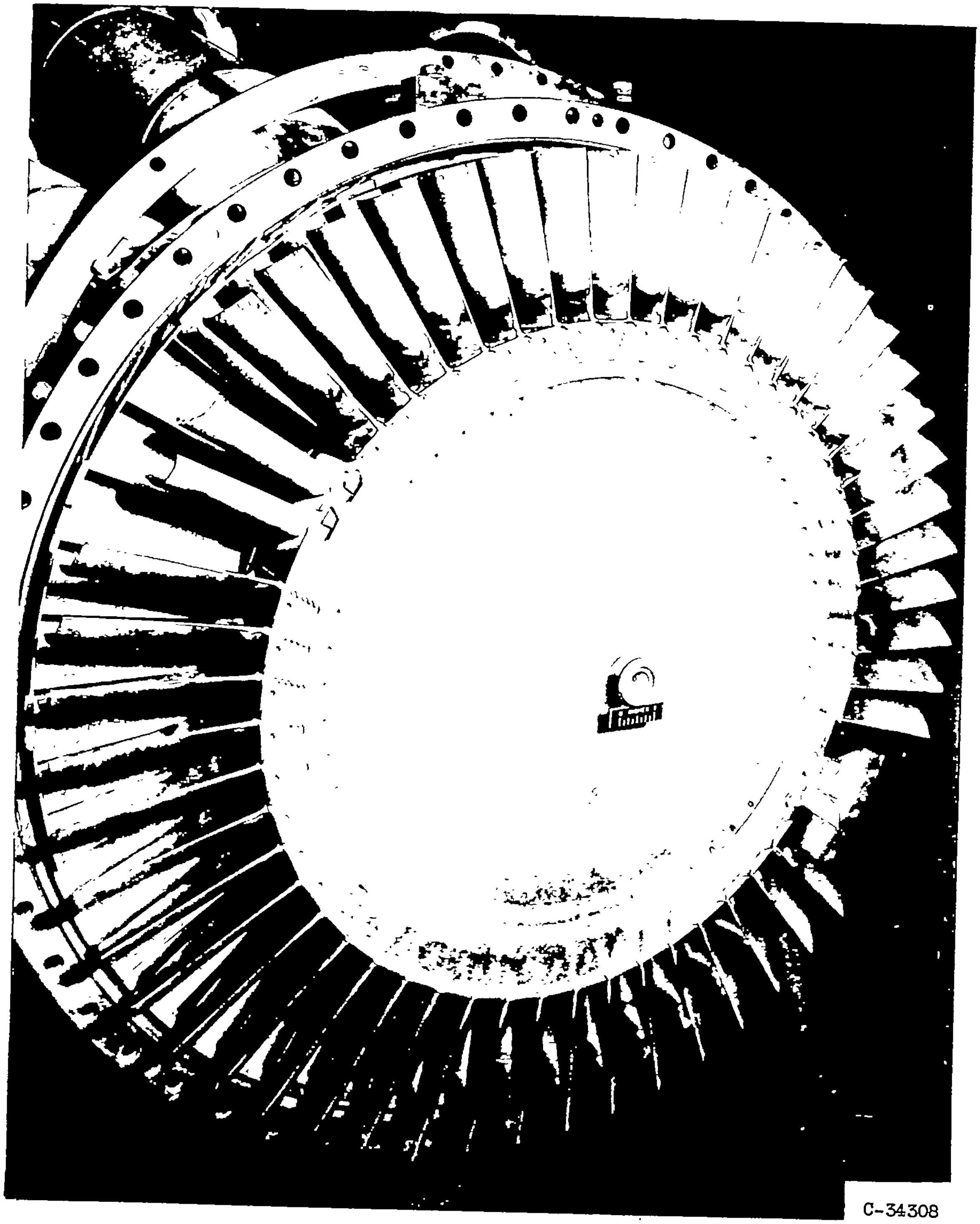
Figure 3. - Cermet turbine blade after 150 hours of operation. Run 1.

C-34310

(a) Originally failed blades.

Figure 4. - Failure of curved-root cermet turbine blades after 77 hours and 44 minutes at rated speed. Run 2.

CP-2 back 3385



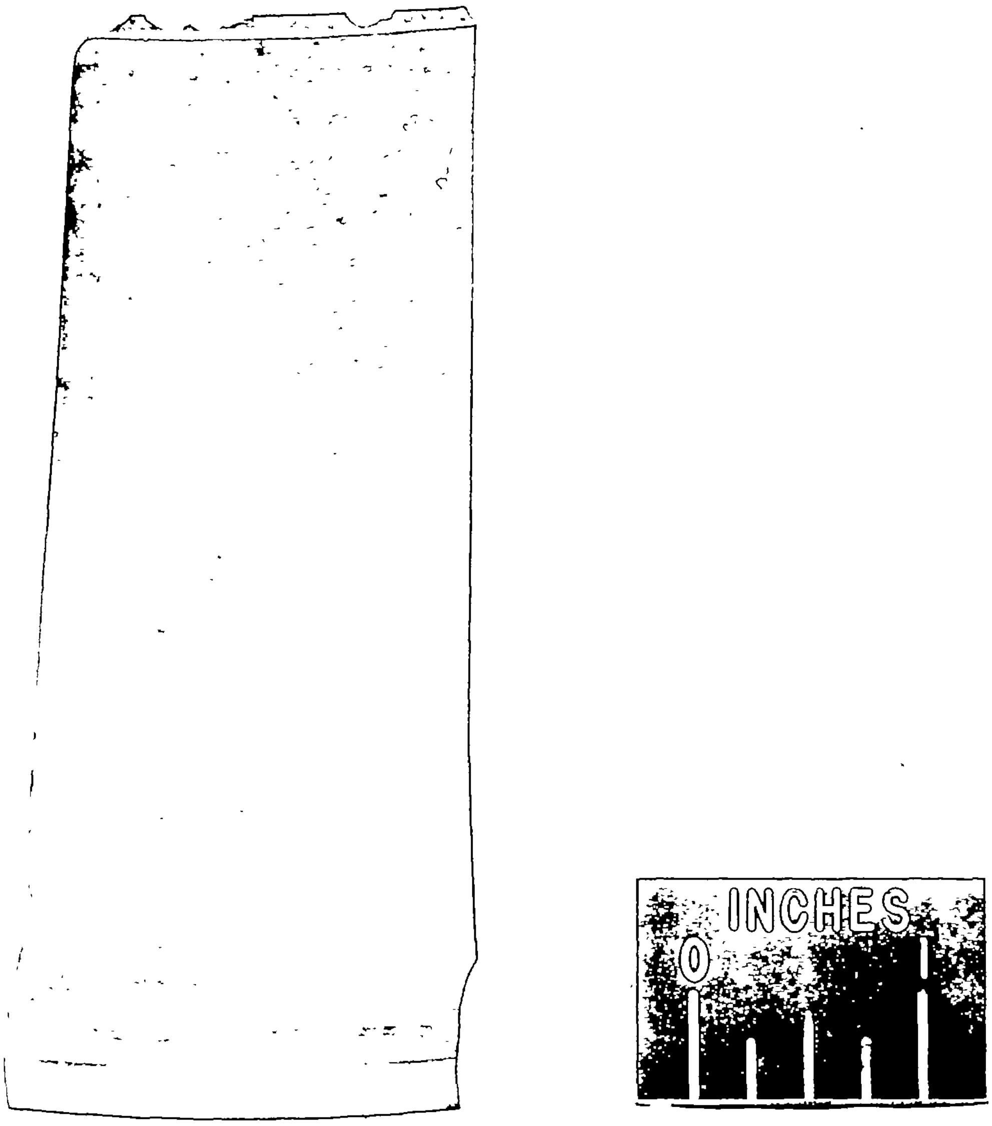
C-34308

(b) Damage to entire wheel.

Figure 4. - Concluded. Failure of curved-root cermet turbine blades after 77 hours and 44 minutes at rated speed. Run 2.

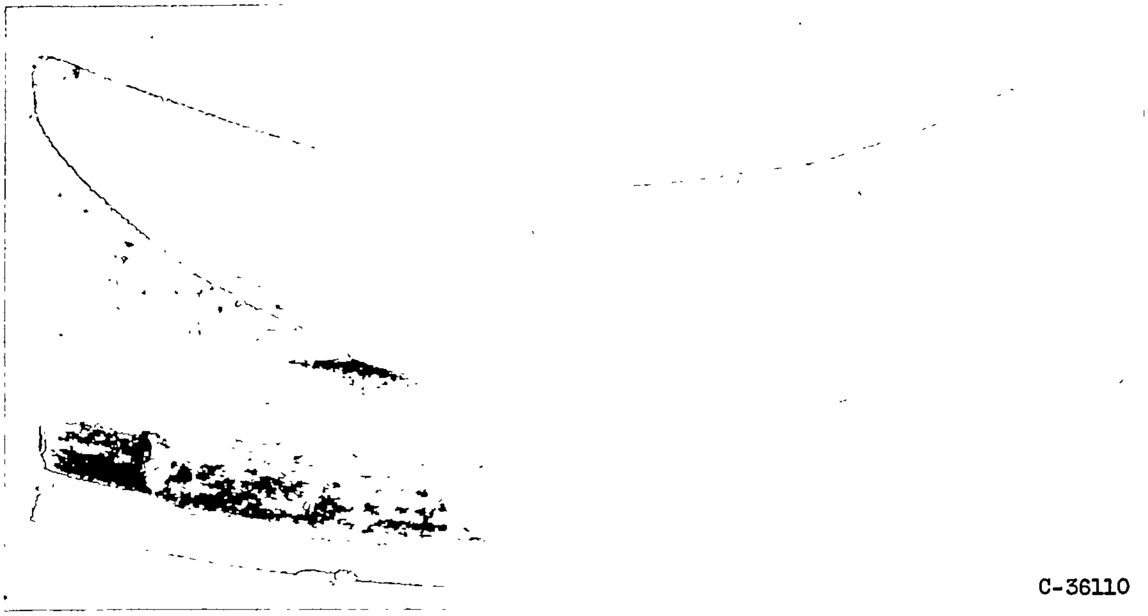
C-40090

Figure 5. - Enlarged view (X15) of failed curved-root cermet turbine blade showing corrosion along leading edge. Run 2.

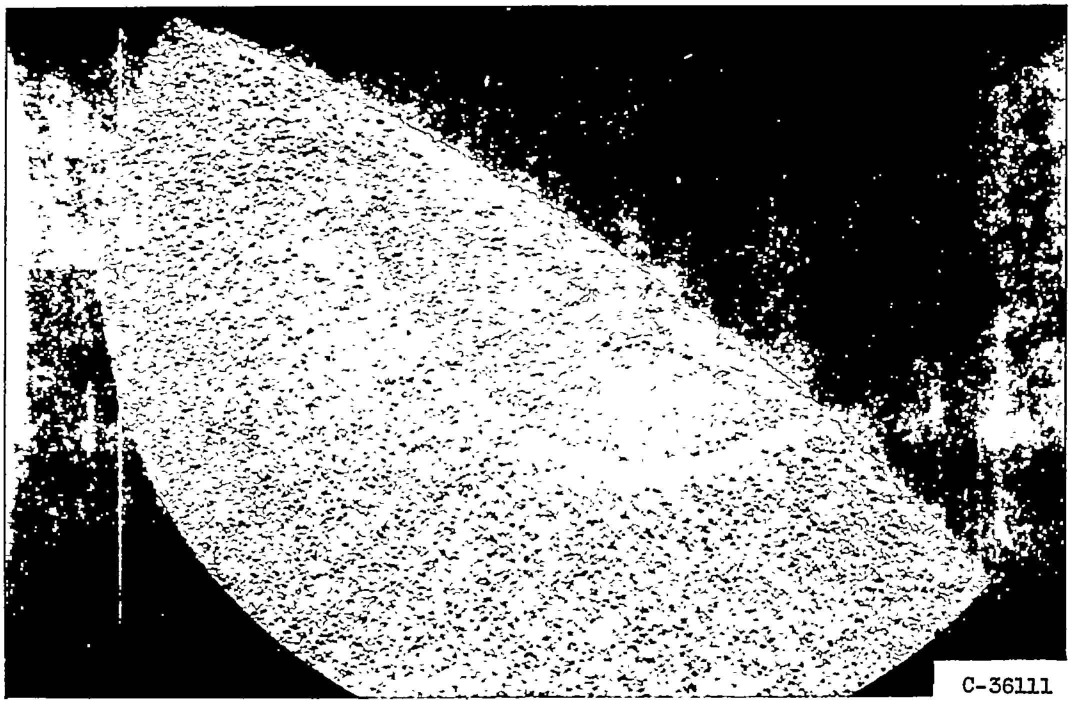


C-35790

Figure 6. - Carbon deposits on curved-root cermet turbine blade after 132 hours and 15 minutes at rated speed. Run 3.

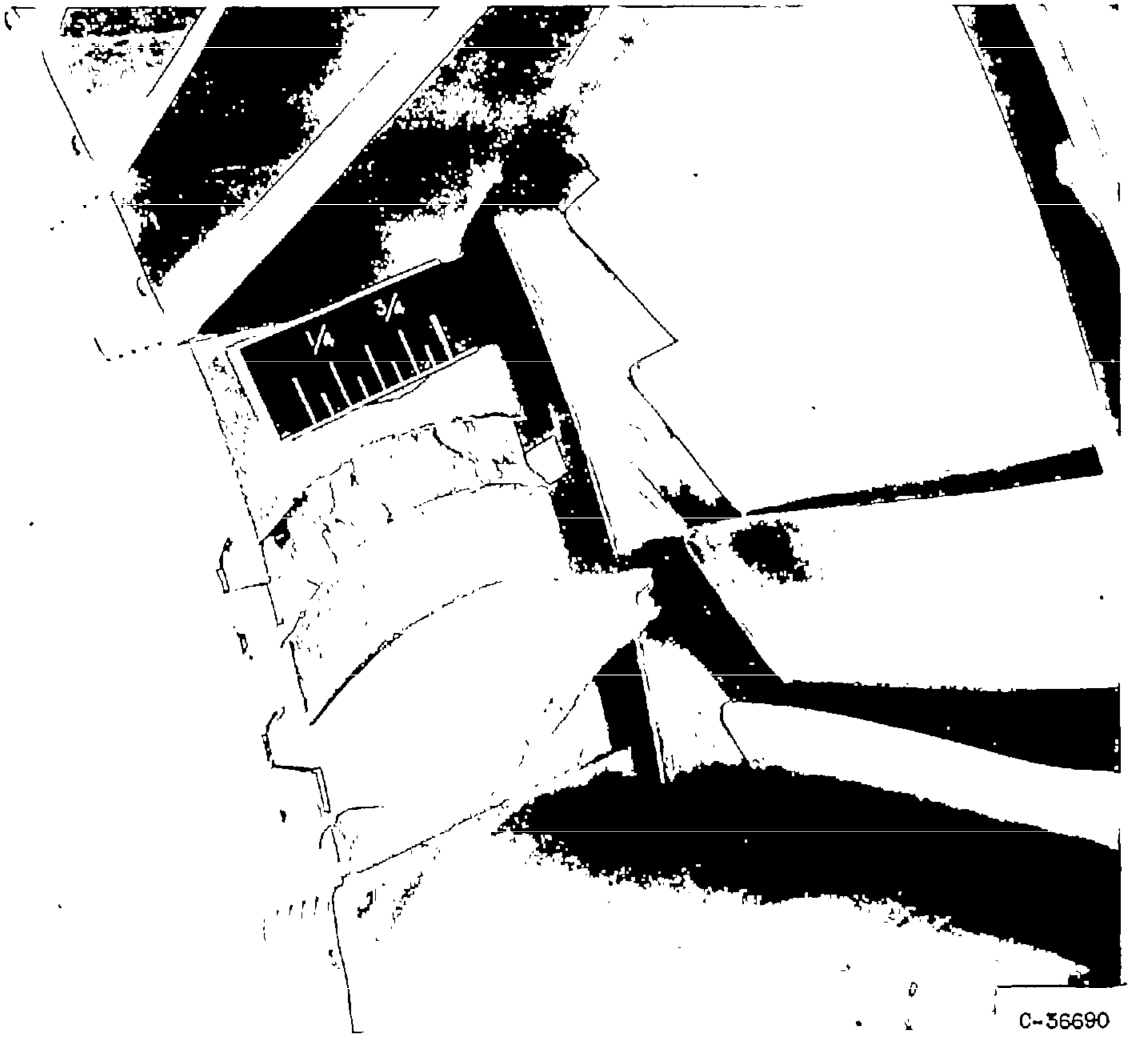


(a) Failure location; base of airfoil.



(b) Origin of failure. X15.

Figure 7. - Failure of curved-root cermet turbine blade after 132 hours and 15 minutes at rated speed. Run 3.



(a) Root failure showing spalled appearance characteristic of compressive stressing.

Figure 8. - Failure of curved-root cermet blades after 142 hours and 58 minutes at rated speed. Run 4.

(b) Blades damaged by diametrically opposite blade with root failure.

Figure 8. - Concluded. Failure of curved-root cermet blades after 142 hours and 58 minutes at rated speed. Run 4.

3385

Figure 9. - Failure of turbine wheel containing curved-root cermet turbine blades after 102 hours at rated speed. Run 5.