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RESEARCH MEMORANDUM

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AN EXPERIMENTAL INVESTIGATION OF HOLLOW TURBINE BLADES FOR EXPENDABLE JET ENGINES

By W. C. Morgan and C. R. Morse

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF HOLLOW TURBINE BLADES FOR EXPENDABLE JET ENGINES

By W. C. Morgan and C. R. Morse

SUMMARY

An experimental investigation was made to determine the feasibility of using hollow turbine blades in engines designed for short service life. Airfoils were fabricated from sheet material and techniques of welding and brazing attachment were investigated.

The airfoils were not intended to be cooled. A principal objective was the reduction of strategic material requirements primarily as a function of direct weight reduction. The materials considered were in the density range 0.28 to 0.31 pound per cubic inch.

Three materials were used for airfoils: N-155, Inconel X, and L-605. These were attached to J47 turbine blade bases and operated to destruction at maximum service conditions of turbine speed and temperature.

It was found that L-605 airfoils brazed to suitable bases satisfied the requirements assumed for expendable engines. Service life varied from 11 to 40 hours.

INTRODUCTION

A program of research has been in progress at the NACA Lewis laboratory to examine problems associated with the reduction of weight and strategic material in the components of aircraft engines. As a part of this general program, the possibility of using hollow turbine blades and lightweight wheels for expendable engines is being investigated.

The specific purpose of the experimental investigation described in this present report was the development of an airfoil that (1) could be fabricated by standard shop techniques from presently available materials; (2) that the service life should be commensurate with the requirements assumed for an expendable-missile engine; and (3) that the attachment between airfoil and base should be adaptable to any of several lightweight wheel designs.

The initial phase of the investigation was the selection of materials and fabrication methods. A review of previous work accomplished in this field indicated that airfoils made from high-temperature alloys in rolled-sheet form would satisfy the requirements (refs. 1 to 3).

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Three alloys were selected for service-operation investigation. The selection was based on published strength values at elevated temperature, favorable qualities with regard to welding and brazing requirements, and availability in rolled-sheet form.

Airfoils were made from these materials and attached to bases by several methods of welding and brazing. The finished turbine blades were then inserted in a standard turbine wheel and operated at service conditions of turbine speed and gas temperature.

Engine operation was continued until a failure occurred or until a minimum service life of 10 hours had been achieved.

DESCRIPTION OF BLADES

The three materials selected for investigation were N-155, Inconel X, and L-605. Technique of forming the airfoils was the same throughout the investigation. The suction and pressure sides of each airfoil were formed by die-pressing; separate dies were required for the two sides. The two sides were welded along the leading and trailing edges. After this operation had been finished, a cap was welded at the tip in order to provide stiffness and to alleviate the effects of vibration. The configuration of the finished airfoil was similar to the shape of the J47 turbine blade.

Details of blade construction. - Figure 1 shows an exploded view of the components of a typical hollow blade. Standard S-816 turbine-blade bases were modified to provide attachment for the hollow airfoils. The solid airfoil was removed a short distance above the base platform. The stub section was then machined to a shape geometrically similar to the inside of the hollow airfoil base section. In the initial test, a stub height of 0.25 inch was used; subsequently, a height of 0.13 inch was employed.

A vibration damper of N-155, 0.050 inch in thickness, was inserted in several of the blades. This member was a cantilever welded to the base stub. It was intended that the damper should be in contact with the sides of the airfoil. Coincident with stub-height reduction from 0.25 to 0.13 inch, this damper was abandoned.

A minor part of the design was the provision of a vent in order to avoid excessive pressure within the airfoil at operating temperature. The first blades were vented in the tip, but it was found that this location was undesirable because the small hole created a nucleus for cracks. A vent provided in the blade base gave satisfactory results.

Investigation directed toward determination of an optimum airfoil wall thickness was limited in scope. The N-155 airfoils were made from stock 0.020 and 0.030 inch in thickness; in the case of Inconel X, airfoils were formed from stock thickness of 0.030 and 0.040 inch, as well as tapered sheet that varied in thickness from 0.040 inch at the blade base to 0.020 inch at the tip. All the L-605 airfoils were fabricated from uniform 0.030-inch-thick material.

Methods of attachment. - Two methods of attachment between airfoil and base were considered: welding and brazing. It was intended that both methods should be investigated, although it was anticipated that the titanium present in Inconel X would make brazing difficult in the case of that alloy. No attempt was made to test brazed attachment of the N-155 airfoils. The evident superiority of L-605 in welded attachment resulted in a concentration of research effort on the investigation of attachment by brazing for airfoils of this alloy.

In the welded attachment, the heliarc process was used. A rod of the same alloy as the airfoil was employed, and helium was directed into the interior of the airfoil during welding in order to provide an inert atmosphere.

The material used in the brazing process was Nicrobraz. Detailed information on this subject and on the methods of application are contained in reference 4. Several different techniques were employed in the course of the present investigation. Airfoils were positioned on the bases by tack-welding, and the brazing process was completed in either hydrogen atmosphere, vacuum, or in a salt bath. One attempt was made to braze an airfoil without prior tack-welding.

EXPERIMENTAL PROCEDURE

The blades were inserted in the turbine wheel of a J47-25 engine. The hollow turbine blades were operated in the engine in groups varying from two to six blades, placed at various locations in the turbine wheel, with standard solid blades making up the remainder of the blade complement.

A special thin shroud section was used to reduce the impact damage after a failure.

Procedure of engine operation consisted of gradual acceleration to rated turbine speed, 7950 rpm. Tail-pipe temperature was adjusted to 1260° F and operation was continued until failure of a turbine blade occurred or until it was considered that the objectives of the program would not be served by further operation.

RESULTS AND DISCUSSION

The results of the experimental investigation are presented in table I. The order of listing is not chronological in all cases. For convenience in discussion, the tests of N-155 and Inconel X may be considered together, on the basis of similarity in construction and mechanism of failure.

Tests of N-155 and Inconel X. - The initial engine operation of N-155 blades with wall thickness of 0.020 inch was terminated by a blade failure after 23 minutes at rated speed and temperature. The failure originated in the trailing edge at the welded juncture between airfoil and base, as shown in figure 2.

There were fatigue cracks at the tips of the other blades of 0.020-inch wall thickness, and in the subsequent N-155 test blades, the wall thickness was made 0.030 inch. These blades withstood operation for 6 minutes. Failure was attributable to weld failure at the base.

Service-operation history was similar in the case of the blades formed from Inconel X. A blade with 0.030-inch wall thickness failed after 31 minutes (fig. 3(a)); another blade formed from material of 0.040-inch thickness was destroyed after 1 hour and 31 minutes (fig. 3(b)). An attempt to alleviate stress failure by the use of tapered stock was unsuccessful; failure occurred after 1 hour and 45 minutes. Figure 4 shows an undamaged blade together with the one that failed. The failures were attributed to a lack of strength in the weld between the airfoil and base.

Tests of L-605. - More favorable results were obtained from the engine operation of the L-605 blades. Two blades with welded base attachment were tested: One blade failed at the base after 33 hours and 3 minutes; a second blade was removed from the turbine because of mechanical impact damage after 32 hours and 17 minutes.

In the initial engine operation of L-605 blades brazed to stub bases, a service life was obtained of 15 hours and 39 minutes. The failure occurred in the central region of the airfoil. Figure 5 shows this blade together with one that had received impact damage.

The construction of the blades was altered slightly for the remainder of the investigation. The stub bases were reduced to 0.13 inch in height, and the vibration damper was abandoned. Examination of previous failures indicated that the damper was not operating effectively.

Several variations in brazing technique were employed in the base attachment. These appear in table I and a more complete discussion may be found in reference 4. Service-operation life prior to failure varied from 11 hours and 2 minutes to 40 hours and 2 minutes where the airfoils were tack-welded to the bases prior to brazing. Data were incomplete on several blades as a result of a compressor failure.

The blade that was not positioned by tack-welding before brazing failed after 7 hours and 46 minutes. It was found on examination that the quality of the brazed joint was relatively poor.

CONCLUSIONS

An investigation was initiated to determine the feasibility of using hollow blades for lightweight turbine wheels. Service life was to be commensurate with the requirements assumed for an expendable missile application.

Airfoils were fabricated from sheet material, and techniques of attachment between airfoil and base were tested. Three materials were used for the airfoils: N-155, Inconel X, and L-605. The airfoils were attached to turbine-blade bases by welding or brazing, and the complete blades were operated to destruction in an engine at a turbine speed of 7950 rpm and a tail-pipe temperature of 1260° F.

On the basis of the results obtained from the investigation, it appeared that L-605 proved to be more satisfactory than either N-155 or Inconel X. The use of tapered blade walls did not afford sufficient reduction in centrifugal stress to overcome the problem of weld-attachment failure. Tack-welding of airfoils to bases prior to brazing appeared to be a satisfactory method of holding base and airfoil in correct position during the process.

It was found that service life of the L-605 blades ranged from 11 to 40 hours. The results indicate reasonable promise for hollow blades formed from sheet stock to be satisfactory for use in turbines designed for short service life when material properties are equivalent or superior to L-605 of 0.030-inch uniform thickness.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 7, 1953

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3. Petrick, E. N.: A Survey of German Hollow Turbine Blade Development. Pt. III - Turbine Blade Vibrations; Materials Used on the Construction of Gas Turbine Engines; Considerations on the Improvement of Hollow Blade Designs. Purdue Univ., Purdue Res. Foundation, USAF-AMC, Wright-Patterson Air Force Base, Dayton (Ohio), Mar. 1950. (USAF Contract No. W33-038-ac-17625.)

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TABLE I. - RESULTS OBTAINED FROM ENGINE OPERATION OF HOLLOW TURBINE BLADE AT TURBINE SPEED OF 7950 rpm AND TAIL-PIPE TEMPERATURE OF 1260° F

Material	Wall thickness, in.	Description of fabrication	Time at test conditions		Reason for termination of blade operation
			hr	min	
N-155	0.020	All-welded with vibration damper	0	23	Weld failure in attachment of base at trailing edge
N-155	.020	All-welded with vibration damper	0	23	Fatigue cracks in blade tip
N-155	.020	All-welded with vibration damper	0	23	Fatigue cracks in blade tip
N-155	.030	All-welded with vibration damper	0	6	Weld failure in attachment of base to airfoil
N-155	.030	All-welded with vibration damper	0	6	Definite cracks in weld at base
N-155	.030	All-welded with vibration damper	0	6	Suspected cracks in weld at base
Inconel X	.030	All-welded with vibration damper	0	31	Weld failure in attachment of base to airfoil
Inconel X	.030	All-welded with vibration damper	0	31	Removed; no visible failure
Inconel X	.040	All-welded with vibration damper; heat-treated	1	31	Weld failure in attachment of base to airfoil
Inconel X	.040	All-welded with vibration damper; heat-treated	1	31	Removed; no visible damage
Inconel X	.040-.020	All-welded with vibration damper; heat-treated Tapered wall from base to tip	1	45	Weld failure in attachment of base to airfoil
Inconel X	.040-.020	All-welded with vibration damper; heat-treated Tapered wall from base to tip	1	45	Removed; impact damage
L-605	.030	All-welded with vibration damper	33	3	Weld failure in attachment of base to airfoil
L-605	.030	All-welded with vibration damper	32	17	Removed; impact damage
L-605	.030	Welded airfoil vacuum brazed to 0.25-in. stub with vibration damper	15	39	Airfoil failure in central region of airfoil
L-605	.030	Welded airfoil vacuum brazed to 0.25-in. stub with vibration damper	15	39	Removed; impact damage
L-605	.030	Welded airfoil vacuum brazed to 0.13-in. stub	11	2	Braze failure
L-605	.030	Welded airfoil vacuum brazed to 0.13-in. stub	22	58	Removed; no visible damage
L-605	.030	Welded airfoil vacuum brazed to 0.13-in. stub	22	58	Removed; no visible damage
L-605	.030	Welded airfoil vacuum brazed to 0.13-in. stub	40	2	Braze failure
L-605	.030	Welded airfoil hydrogen brazed to 0.13-in. stub	25	15	Fatigue cracks in blade tip
L-605	.030	Welded airfoil hydrogen brazed to 0.13-in. stub	29	48	Blade tip failure
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub, not tack welded to base prior to brazing; 10 percent Ni added to braze	7	46	Braze failure
L-605	.030	Welded airfoil hydrogen brazed to 0.13-in. stub	3	58	Engine failure; no visible damage
L-605	.030	Welded airfoil hydrogen brazed to 0.13-in. stub	3	58	Engine failure; no visible damage
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub	29	48	Engine failure; no visible damage
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub	29	48	Engine failure; no visible damage
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub; acid-cleaned; 10 percent Ni added to braze	29	48	Engine failure; no visible damage
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub; acid-cleaned; brazed twice	29	48	Engine failure; no visible damage
L-605	.030	Welded airfoil salt-bath brazed to 0.13-in. stub; brazed three times	29	48	Engine failure; no visible damage

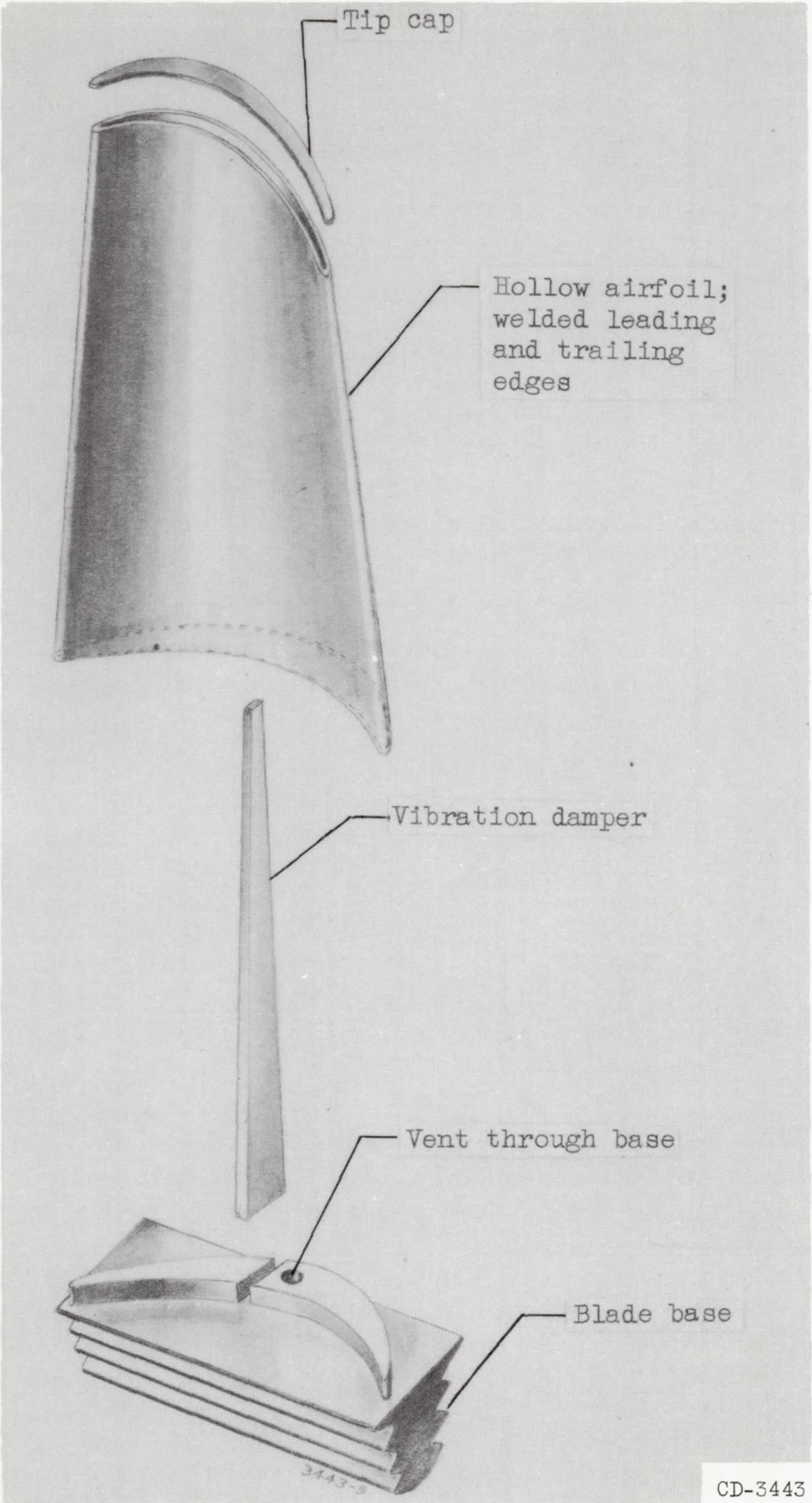

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Figure 1. - Exploded view of typical hollow turbine blade.

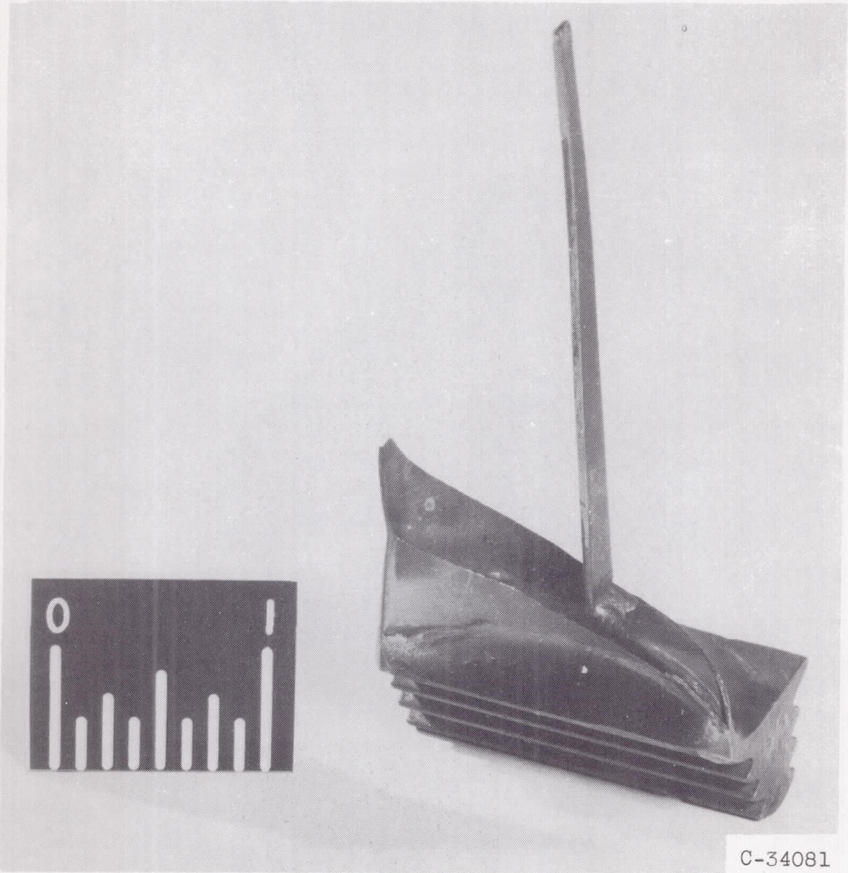

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Figure 2. - Failure of N-155 airfoil (0.020-in. wall thickness).

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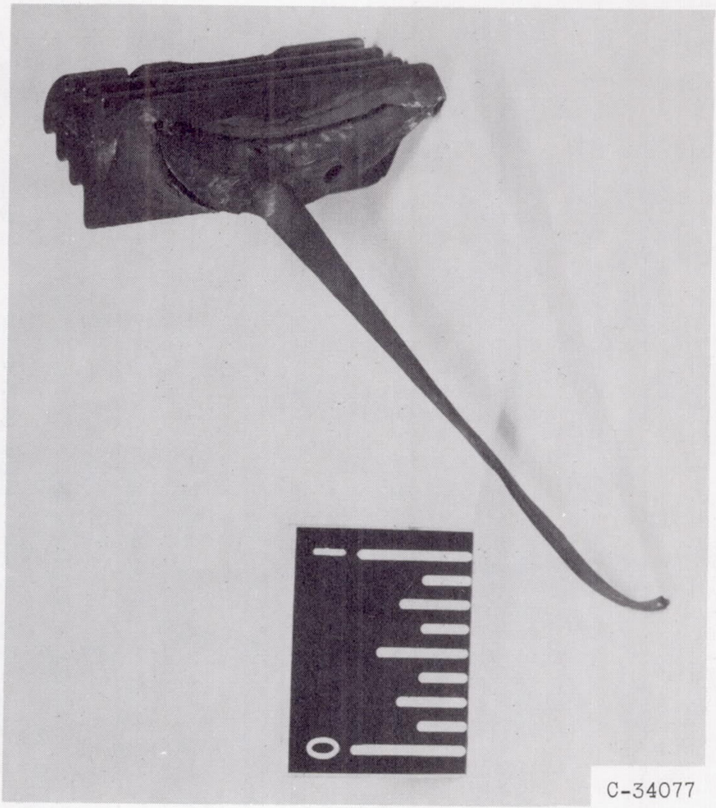
(a) 0.030-Inch wall thickness

Figure 3. - Failure of Inconel X airfoil.



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(b) 0.040-Inch wall thickness.

Figure 3. - Failure of Inconel X airfoil.

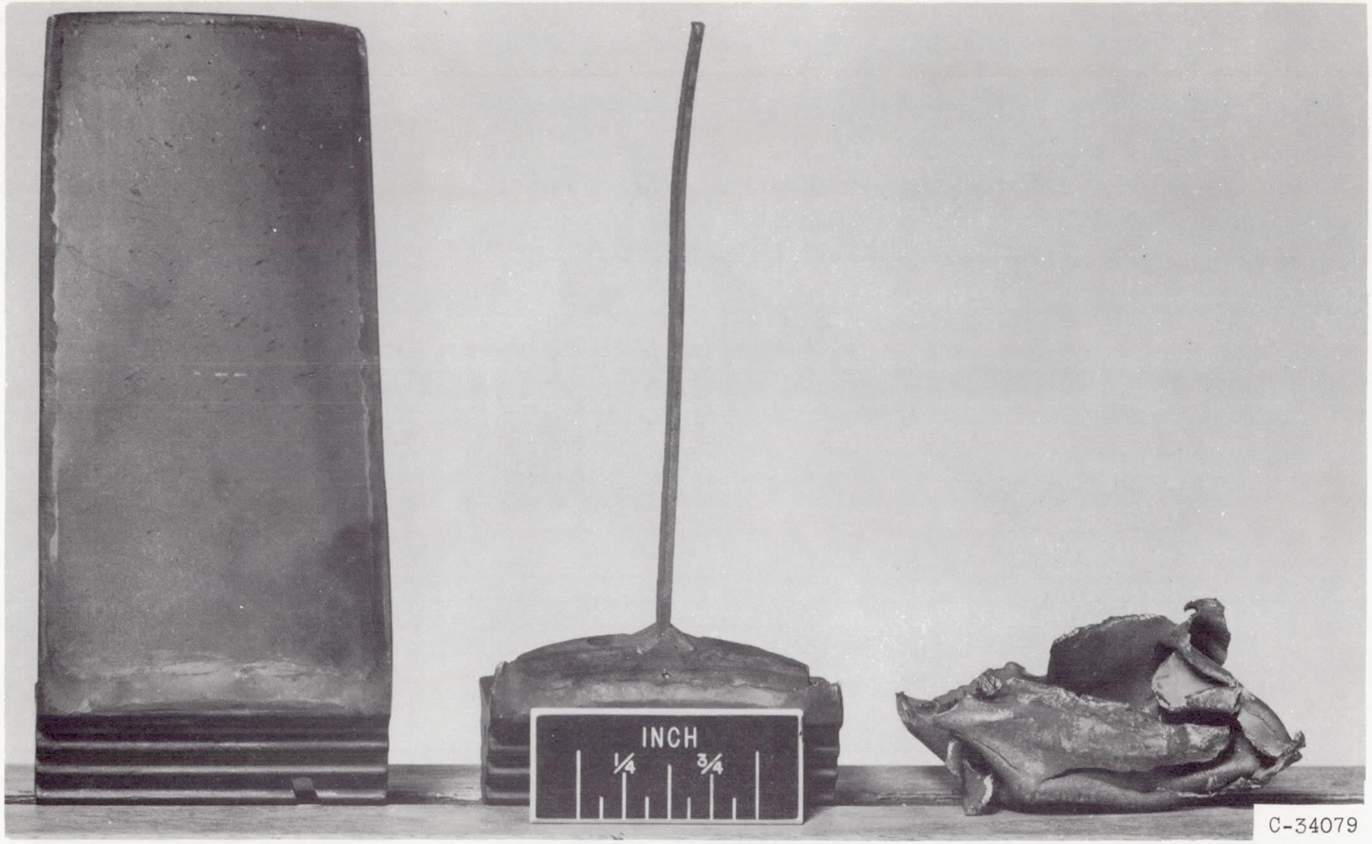

Figure 4. - Inconel X blade (0.040 - 0.020 in. tapered wall) before and after failure due to operation.

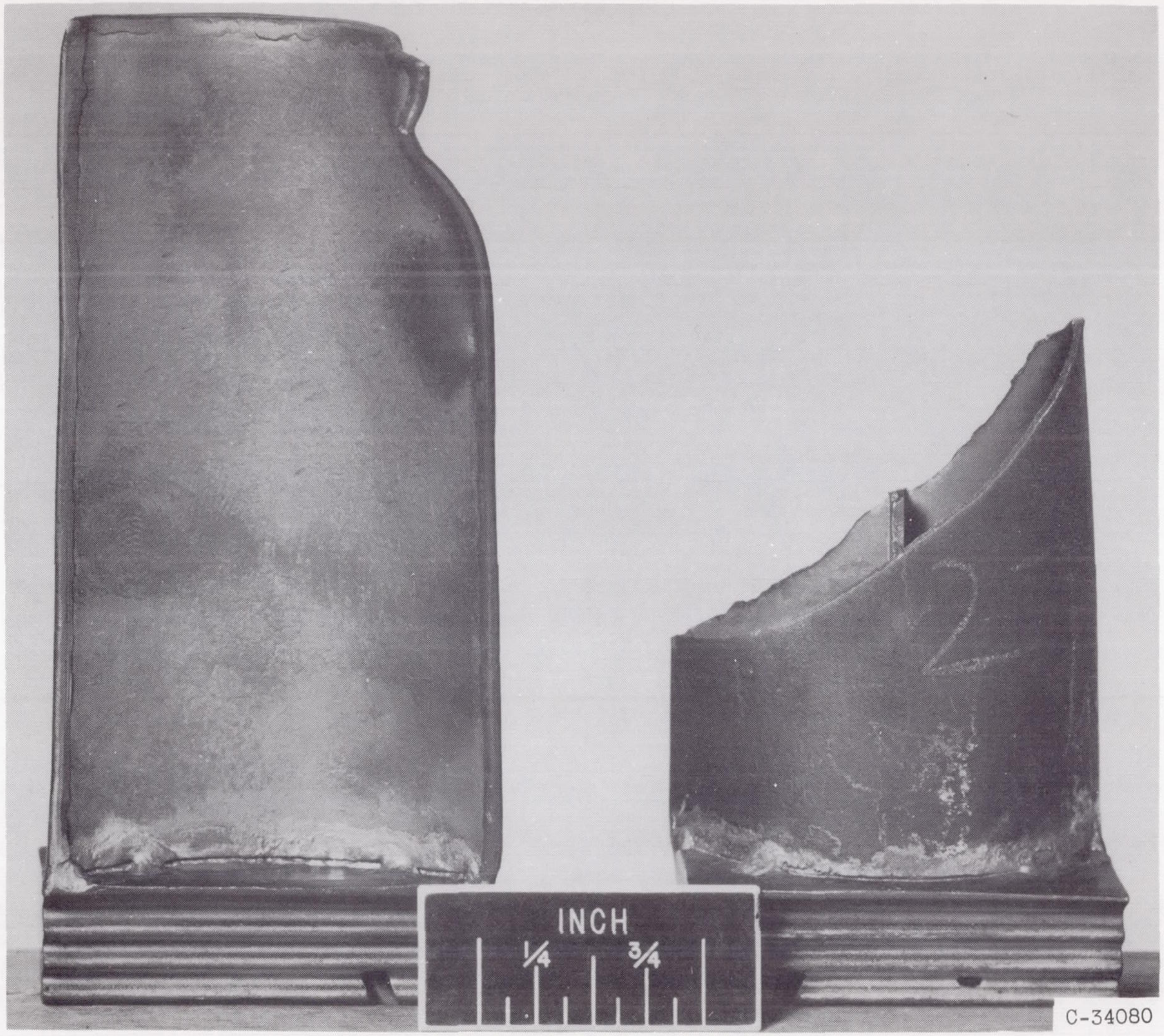

Figure 5. - Failure of L-605 airfoil (0.030-in. wall thickness) and similar blade with impact damage.

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