NASA TECHNICAL MEMORANDUM

NASA TM X-71844

NASA TM X-71844

(NASA-TM-X-71844) TURBINE BLADE METAL TEMPERATURE MEASUREMENT WITH A SPUTTERED THIN FILM CHROMEL-ALUMEL THERMOCOUPLE (NASA) CSCL 21E

N76-14124

Unclas
G3/07 06786

TURBINE BLADE METAL TEMPERATURE MEASUREMENT WITH A SPUTTERED THIN FILM CHROMEL-ALUMEL THERMOCOUPLE

by Curt H. Liebert, George A. Mazaris and Henry W. Brandhorst
Lewis Research Center
Cleveland, Ohio 44135
December 1975

This information is being published in preliminary form in order to expedite its early release

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TURBINE BLADE METAL TEMPERATURE MEASUREMENT WITH A SPUTTERED THIN FILM CHROMEL-ALUMEL THERMOCOUPLE		5. Report Date
		6. Performing Organization Code
7. Author(s) Curt H. Liebert, George A. Mazaris, and Henry W. Brandhorst		8. Performing Organization Report No. E-8569
		10. Work Unit No.
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A technique for fabricating Chromel and Alumel thin film thermocouples has been developed. Turbine blade metal temperatures measured with the thin film thermocouple installation were compared with those of a reference sheathed (wire) thermocouple. Good agreement was obtained and the results are encouraging.

PRICES SUBJECT TO CHANGE

17. Key Words (Suggested by Author(s))	18. Distribution Statement Unclassified - unlimited STAR Category		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-C-168 (Rev. 10-75)

TURBINE BLADE METAL TEMPERATURE MEASUREMENT WITH A SPUTTERED THIN FILM CHROMEL-ALUMEL THERMOCOUPLE

by Curt H. Liebert, George A. Mazaris, and Henry W. Brandhorst

Lewis Research Center

E-8569

SUMMARY

A technique for sputtering thin film materials to form thermocouples has been developed. The thin film thermocouple consisted of a composite of an electrically insulating layer of aluminum oxide deposited onto a turbine blade wall over which Chromel and Alumel thermoelectric elements were deposited and covered with another layer of aluminum oxide for corrosion protection.

The output of the thin film thermocouple on a blade was compared to that of a reference sheathed (wire) thermocouple during tests in an electric furnace at room temperature to 1050 K (1430° F). The temperatures measured by the two methods agreed well. At a steady temperature level of 1020 K (1380° F) the thin film thermocouple temperature was about 9 K (16° F) lower than that of the reference thermocouple. During transient operation the thin film thermocouple measurement was at most 25 K (45° F) lower than that of the reference thermocouple. The agreement was within 2.5 percent at the highest measured transient temperature of 1050 K (1430° F).

INTRODUCTION

A method was developed for the deposition of thin film thermocouples onto turbine blades and comparisons were made of temperatures measured by this type of thermocouple with those of a sheathed (wire) thermocouple.

A method currently used for determining turbine blade metal temperatures utilizes sheathed Chromel-Alumel thermocouples imbedded in grooves machined in the airfoil metal walls (ref. 1). This type of thermocouple and its installation present several problems. The grooves for example tend to change the heat flow pattern in the blade, weaken the blade, and make it more susceptible to early failure. This is especially a concern for full coverage film cooled blades and vanes with their multiplicity of holes in the airfoil which restrict the grooving of the walls for thermocouple installation. Also, the temperature-time response of the sheathed thermocouples is limited because of their mass, and their construction makes them susceptible to failure under conditions of high thermal gradients and high rotational speeds. These problems will become more severe with expected future increases in turbine heat flux and tip speed.

An alternative to machining grooves and imbedding relatively bulky sheathed thermocouples in blade metal walls is the deposition of thin film thermocouples on the surface. Such thin film thermocouples would result in more accurate temperature measurements than the sheathed type because they should have a faster temperature-time response, will need no grooves machined into the metal, and the location of the thin film thermocouple junction should be accurately known. Also because the thin film thermocouple is intimately bonded to the surface by the deposition process, it is less likely to be destroyed at high rotational speeds and by thermal gradients.

There has been much interest in the development of thin film thermocouples. In reference 2, for example, thin film platinum and platinum/rhodium thermocouples were sputtered onto the surface of a metal cylinder and exposed to combustion exhaust gases. Although the thermoelectric performance of the thermocouples was qualitatively determined, no direct comparison of the metal temperature levels was made with a calibrated reference sensor. The thermocouple failed after 100 hours of operation because of erosion of the materials. In reference 3 investigations were made for temperature sensor systems which used a platinum film for one thermoelectric element and the material of the blade as the other element. The measured thin film and calibrated wire thermocouple output agreed within 7 percent. Preparation of thin film thermocouples by vacuum deposition is described in reference 4. Thermocouple combinations were constructed from nickel, iron, copper, constantan, Chromel, and Alumel. The thin film thermocouples were deposited onto glass slides and their output was compared to reference Chromel-Alumel wire thermocouples clipped to the substrate surface. Tests made to temperatures of 573 K (571° F) showed poor agreement. The inconsistency between thin film and wire thermocouple output was attributed to changes in stoichiometry of the materials during their evaporation and to insufficient film thickness.

The purpose of this investigation was to (1) investigate Chromel-Alumel thin film thermocouples deposited by a sputtering process, (2) determine the feasibility of applying such thin film thermocouples onto the curved surfaces of turbine blades, (3) develop a scheme for making an electrical terminal or contact between the sputtered thermocouple legs and the lead wires which are attached to readout instrumentation, and (4) experimentally compare the metal temperatures sensed by the thin film thermocouple and a reference sheathed (wire) thermocouple at steady and transient temperature conditions.

Measurements were made at several levels of metal temperatures between room temperature (300 K (80° F)) and 1020 K (1380° F). Temperature response was also determined during changes in level to 1050 K (1430° F).

APPARATUS AND PROCEDURE

Test Equipment

Figure 1 shows a schematic diagram of the commercial RF (radio frequency) sputtering apparatus used to deposit the thin film thermocouple materials onto the blade metal surface. Further details of the sputtering apparatus and procedure are given in reference 5.

A hot plate and an impinging air jet were used to check the continuity and junction location of the thin film thermocouple. A digital voltmeter was used to register the thermocouple output.

A fire brick lined electric furnace was used to test the thin film thermocouple and compare its performance with that of a calibrated wire thermocouple. A strip chart recorder provided with a null balance potentiometric circuit and a cold junction was used to record the thermocouple outputs. The furnace temperature was measured and controlled with a calibrated sheathed thermocouple supplied with the furnace and located about 2.54 centimeters (1 in.) above the thin film thermocouple junction.

A group of six calibrated sheathed (wire) thermocouples positioned within the furnace prior to initiating tests on the thin film thermocouple indicated spatial temperature variations of ±10 K (18^{o} F) at 550 K (530^{o} F) and ±30 K (54^{o} F) at 1050 K (1430^{o} F). These data indicate that spatial thermal gradients existed which could effect the performance of the thermocouple system if duplicate junctions or variations in the composition of the deposited alloys existed.

Thermocouple Fabrication Procedure

Thin film thermocouple composite. - A sketch of the cross section of the thin film Chromel-Alumel thermocouple composite on a turbine blade metal wall is presented in figure 2. The composite consists of aluminum oxide deposited onto the blade metal wall over which Chromel and Alumel legs are deposited and covered with an oxidation (and erosion) protection coating of aluminum oxide. The aluminum oxide deposited directly onto the blade serves as an electrical insulator between the blade and the Chromel and Alumel. The blade material was cast B-1900 and its composition is given in reference 6.

Figure 3 shows the thin film thermocouple legs deposited onto the insulated surface of the airfoil with the legs joined at one end to form the thermocouple hot junction. The other ends of the legs were connected to lead wires from the reference junction and strip chart recorder.

Thin film-lead wire contact pad assembly. - The thin film thermocouple legs were connected to the lead wires through use of an electrical contact pad (fig. 3). Figure 4 presents details of this contact pad assembly. A 0.0102-centimeter (0.004-in.) diameter lead wire of Chromel was spot welded to one surface of a 0.200 centimeter (0.080 in.) square by 0.0152 centimeter (0.006 in.) thick Chromel contact pad. Similarly, an Alumel lead wire was spot welded to a surface of an Alumel pad. The contact pads and wires were cemented into 0.254 centimeter (0.100 in.) square by 0.061 centimeter (0.024 in.) deep recesses which were overcoated with aluminum oxide. The cement was a high temperature ceramic intended for use to about 3000 K (4940° F) and was commercially obtained.

Thin film thermocouple deposition procedure. - RF sputtering was selected for deposition because the process permits sputtering of both alloy and ceramic materials with good adhesion. Furthermore, RF sputtering does not significantly change the stoichiometry of the materials to be deposited (ref. 7). As a consequence, the thermoelectric emf output variation with temperature for the deposited alloys is expected to be similar to the bulk materials. All sputtering was done at 800 watts and a frequency of 13.56 megahertz using argon gas at a pressure of 0.13 N/m^2.

Prior to deposition of the initial layer of aluminum oxide, the turbine blade was cleaned with detergent in an ultrasonic bath and dried in a vacuum oven at 473 K (391° F) for 2 hours. Aluminum oxide was then deposited in amorphous form onto the airfoil surface and into the small contact pad recesses. The aluminum oxide coating was sputtered to a thickness of 11 micrometers (4.3×10^{-4} in.). The distance between the aluminum oxide target and the blade metal surface was maintained at about 10.2 centimeters (4 in.). During sputtering of the aluminum oxide the blade metal temperature rose from 300 K (80° F) to about 500 K (440° F). After deposition, the resistance between the aluminum oxide and the metal was measured. This was done by covering the coated surface with a conducting salt solution and measuring the resistance between the solution and the base of the blade. The resistance was in excess of 1.8×10^{7} ohms indicating that good electrical insulation was provided by the coating.

Chromel and Alumel alloy materials were sputtered onto the aluminum oxide and lead wire contact pads (figs. 3 and 4) through 0.3 centimeter (0.12 in.) wide slits in the 0.10 centimeter (0.040 in.) thick tantalum masks. A separate mask was used for sputtering each leg. The masks and turbine blade are shown in figure 5. The deposited legs were 0.32 centimeter (0.126 in.) wide, 5.1 centimeters (2 in.) long, and 3.6 micrometers (1.4×10^{-4} in.) thick. The procedure was completed by sputtering an aluminum oxide corrosion resistant film over the entire blade surface to a thickness of 1 micrometer (3.9×10^{-5} in.).

Reference thermocouple and lead wire installation. - After the thin film thermocouple system fabrication was completed the blade suction surface was instrumented with a 0.051 centimeter (0.020 in.) diameter reference sheathed (wire) thermocouple assembly described in reference 1. This assembly was imbedded in a groove machined adjacent and parallel to the thin film thermocouple as shown in figure 3. The junction of the reference thermocouple was located 0.40 centimeters (0.16 in.) from the junction of the thin film thermocouple. The lead wires of the thin film and reference thermocouples were placed in slots machined along the turbine blade base platform and connected to the strip chart recorder.

Test Procedure

The thin film thermocouple continuity and junction location were verified by locally blowing cold air along the thermoelectric elements (ref. 8) and onto the junction pads while the blade was heated by a hot plate. These preliminary checks were performed over a temperature range of 300 K (80° F) to 600 K (620° F).

The output of the thin film thermocouple was then evaluated by heating the blade in a furnace for 99 minutes at temperatures ranging from 570 K (566° F) to 1050 K (1430° F). The temperature sensed by the thin film thermocouple was compared to that of the reference thermocouple. The test temperature-time history consisted of five steady levels which increased incrementally by about 100 K (180° F). The time at each steady temperature was about 15 minutes and the time of each transient operation was between 10 to 12 minutes.

RESULTS AND DISCUSSION

A technique has been developed for applying a thin film Chromel-Alumel thermocouple to turbine airfoils. The technique appears to have been successful in preserving the original properties of the alloy legs. The deposition process for the composite took about 23 hours but use of more recent commercial sputtering equipment could reduce the time by about one-half.

Figure 6 presents the results of furnace tests of the thin film thermocouple. For steady temperature conditions, the mean thin film temperature, $\overline{T}_{TF}$, was equal to the mean reference thermocouple temperature, $\overline{T}_R$, at all temperature levels except at the highest level of 1020 K (1380° F) where $\overline{T}_{TF}$ was about 9 K (16° F) or 1 percent lower than $\overline{T}_R$. At all temperature levels the furnace control thermocouple registered about 10 K (18° F) or 1 to 2 percent lower temperature than T_{TF}. During transient operation to 1050 K (1430° F) the temperatures measured by the reference thermocouple were about 2.5 percent higher than those of the thin film thermocouple.

The thin film thermocouple operated for a total test time of 99 minutes when it failed at 1050 K (1430° F) during transient heating. The failure was due to cracking of the ceramic cement surrounding the contact pad upon which the legs were deposited (fig. 3). The cracking appears to be due to the sharp corners and edges of the square pad design. Circular recesses and pads would have probably reduced this problem and provided a good thin film thermocouple installation. The results obtained herein are encouraging.

SUMMARY OF RESULTS

The following are the results of investigations on sputtered thin film Chromel-Alumel thermocouples on turbine blades.

1. A technique for RF sputtering of Chromel and Alumel thin film thermocouples onto turbine blades has been developed and the results obtained are encouraging.

2. Comparison of steady temperatures measured by a thin film thermocouple with a sheathed (wire) reference thermocouple in an electric furnace indicated good agreement. At 1020 K (1380° F) the temperature measured by the thin film thermocouple was about 9 K (16° F) lower than that of the reference thermocouple. During transient operation the maximum difference between the temperature measured by the thin film thermocouple and the reference thermocouple was 25 K (45° F) or about 2.5 percent at 1050 K (1430° F).

3. The thin film thermocouple circuit operated satisfactorily for 99 minutes in a furnace at temperatures from 570 to 1050 K (566° to 1430° F) before failure occurred in the lead wire contact pad location due to cracking of the ceramic cement.

REFERENCES

1. Crowl, Robert J.; and Gladden, Herbert J.: Methods and Procedures for Evaluating, Forming, and Installing Small-Diameter Sheathed Thermocouple Wire and Sheathed Thermocouples. NASA TM X-2377, 1971.

2. Dils, R. R.; and Follansbee, P. S.: High Temperature Sputtered Surface Sensors. Proceedings of the 21st International Instrumentation Symposium, B. Washburn, ed., Instru. Soc. Am., 1975, pp. 127-132.

3. Simbirskii, D. F.; et al.: Experimental and Theoretical Determination of Thermal Stress and Heat Transfer for a Turbine Blade Using High-Temperature Thin Film Thermocouples. Strength of Mat., vol. 6, no. 7, Apr. 1975, pp. 826-831.

4. Marshall, R.; Atlas, L.; and Putner, T.: The Preparation and Performance of Thin Film Thermocouples. J. Sci. Instrum., vol. 43, 1966, pp. 144-149.

5. Chopra, Kasturi, L.: Thin Film Phenomena. McGraw-Hill Book Co., 1969.

6. High Temperature High Strength Nickel Base Alloys. The International Nickel Co., Inc., 1964.

7. Wehner, Gottfried K.: Fundamentals of RF and DC Sputtering. NASA SP-5111, 1972.

8. Moffat, Robert J.: The Gradient Approach to Thermocouple Circuitry. Temperature, Its Measurement and Control in Science and Industry. Vol. 3, Charles M. Herzfeld, ed., Reinhold Publ. Co., 1962, pp. 33-38.

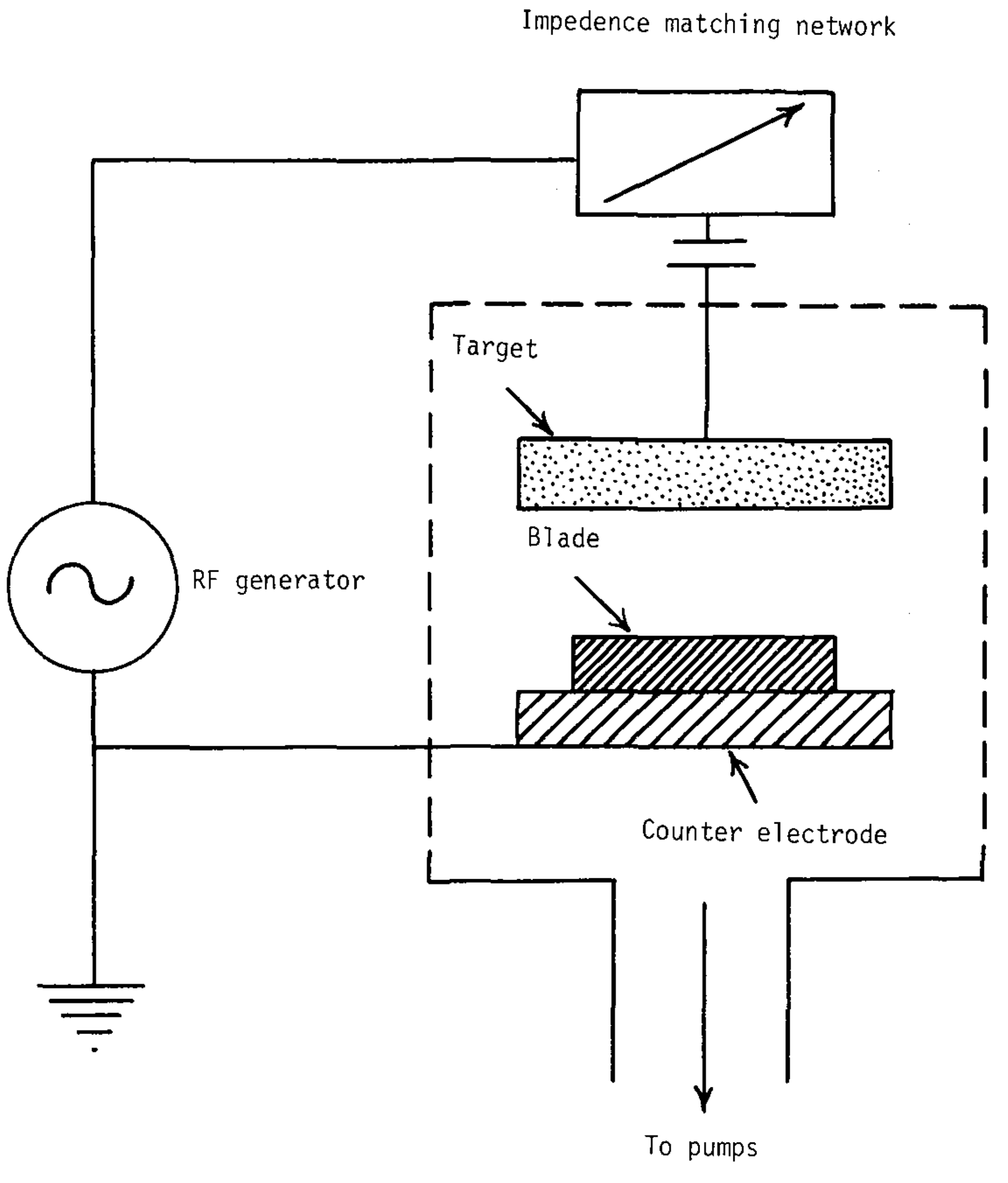


Figure 1. Schematic diagram of RF sputtering apparatus.

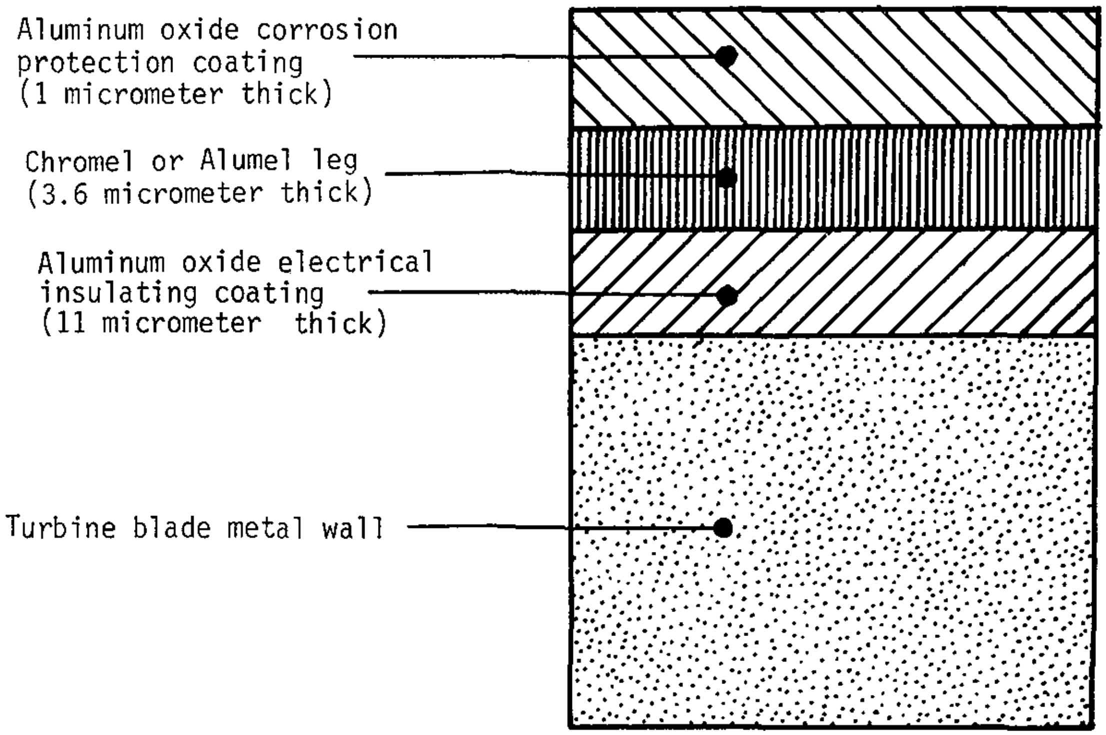


Figure 2. Cross section of thin film Chromel-Alumel thermocouple composite on turbine blade wall (not to scale).

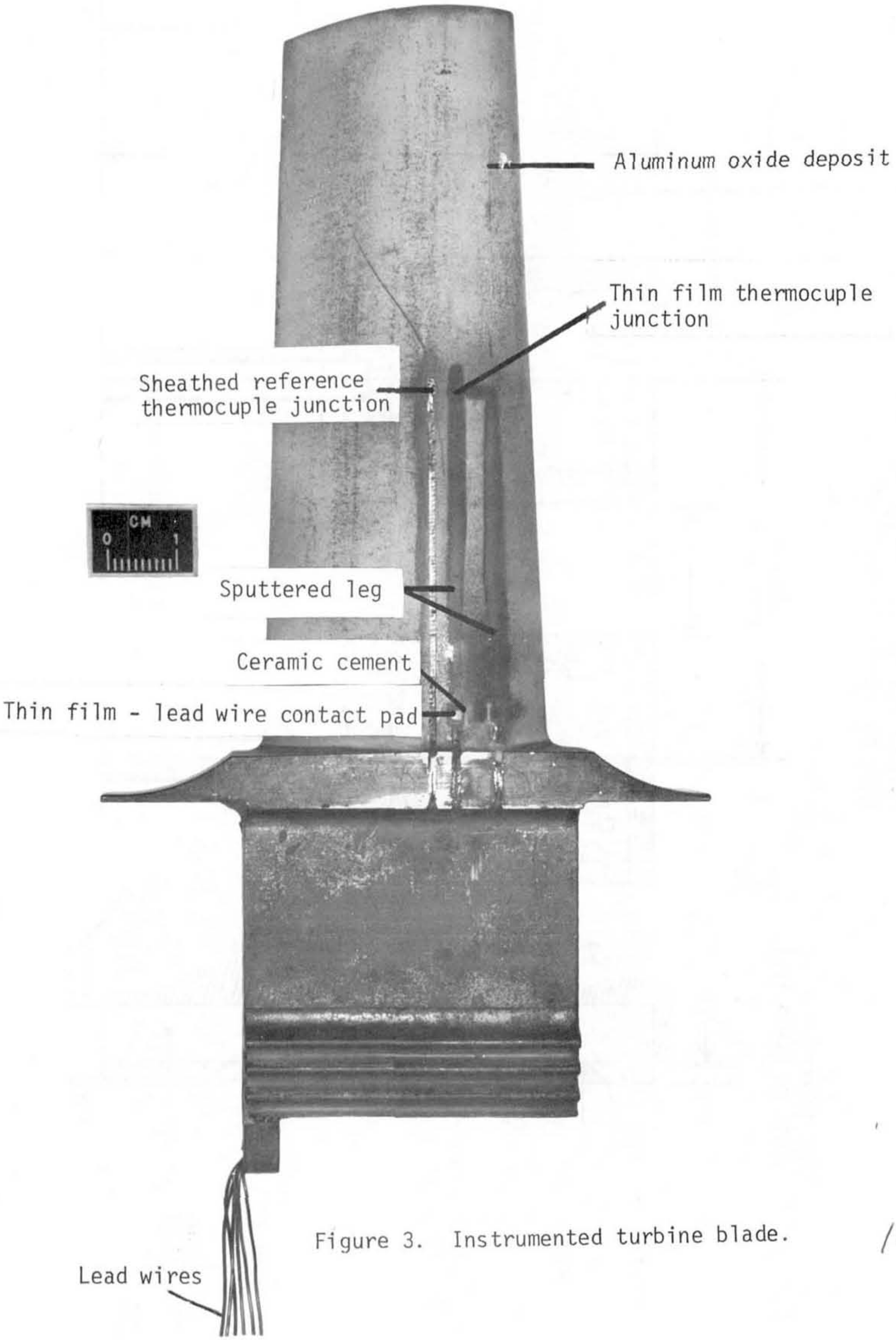


Figure 3. Instrumented turbine blade.

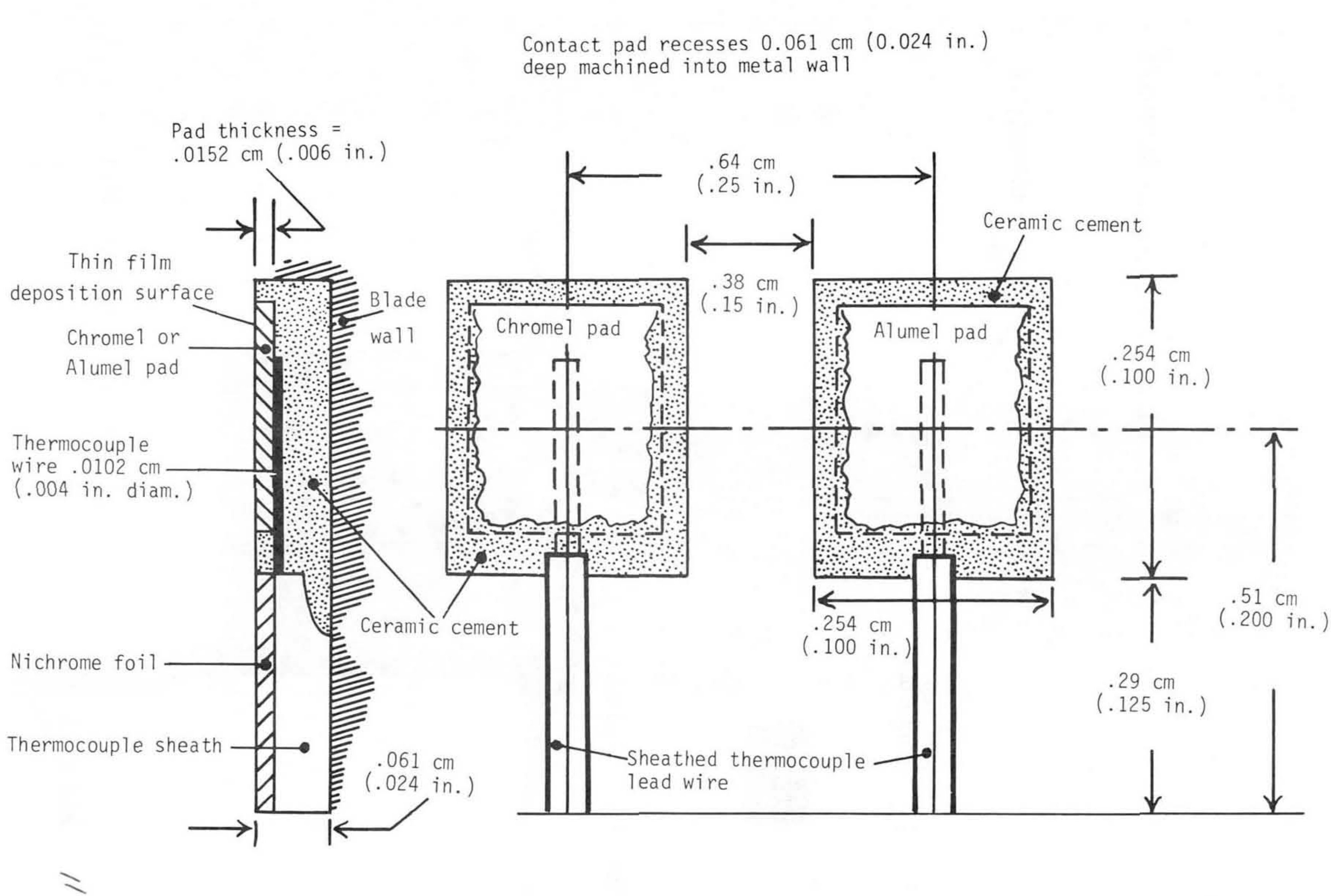


Figure 4. Details of contact pad assembly

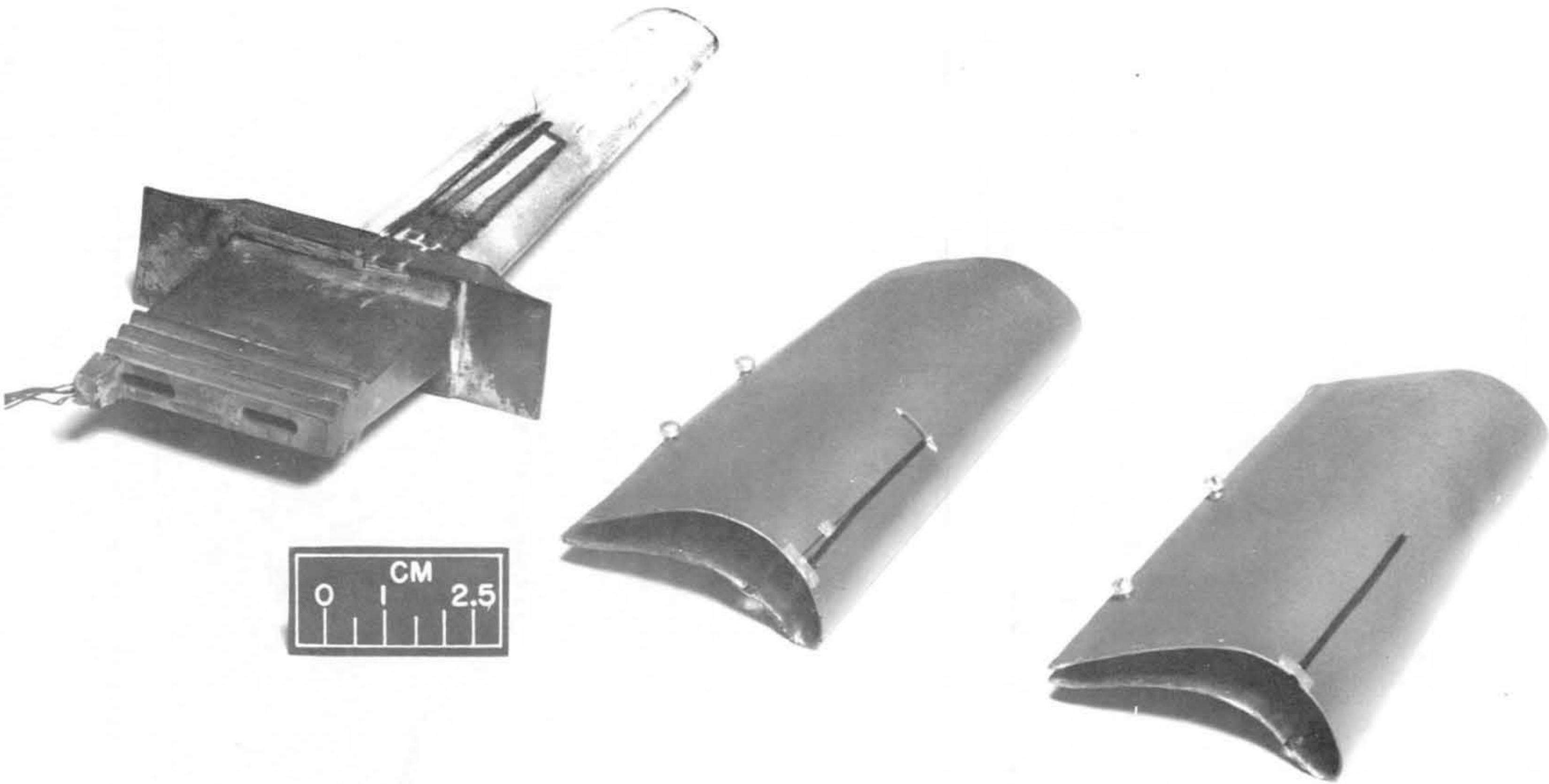
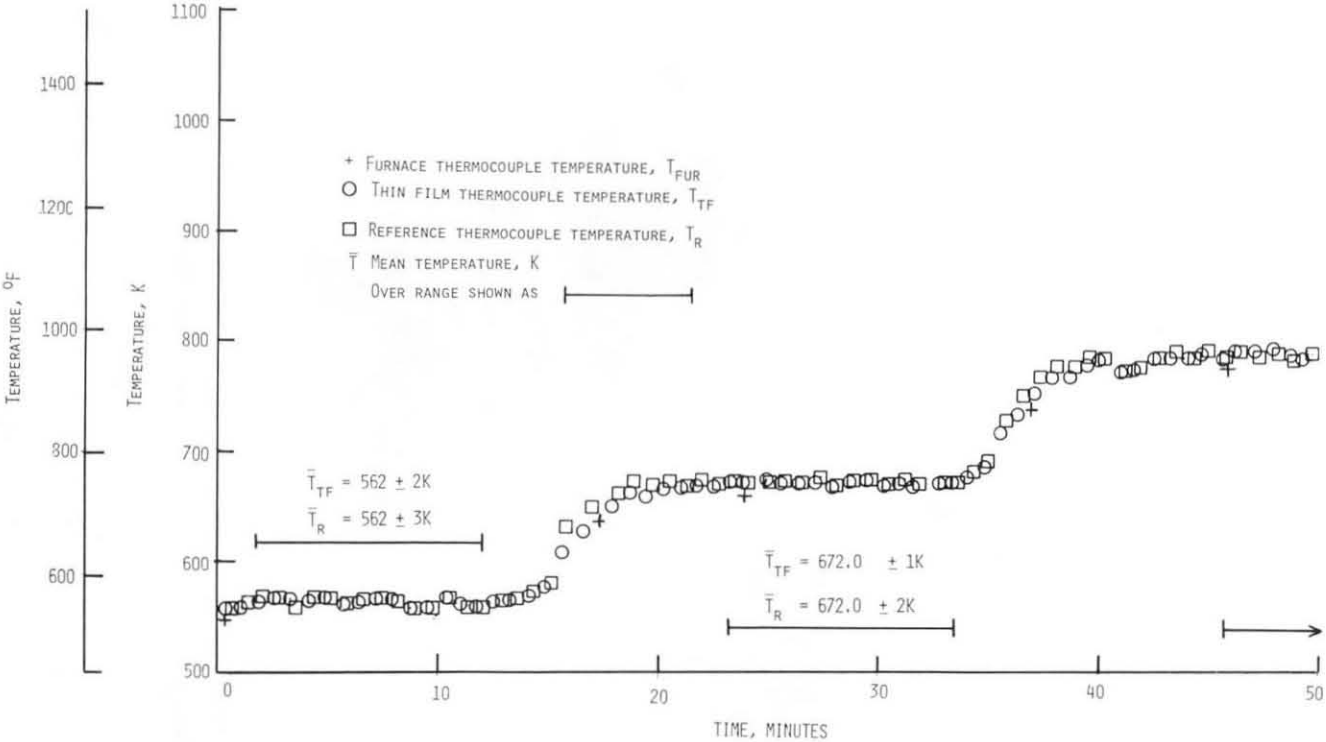
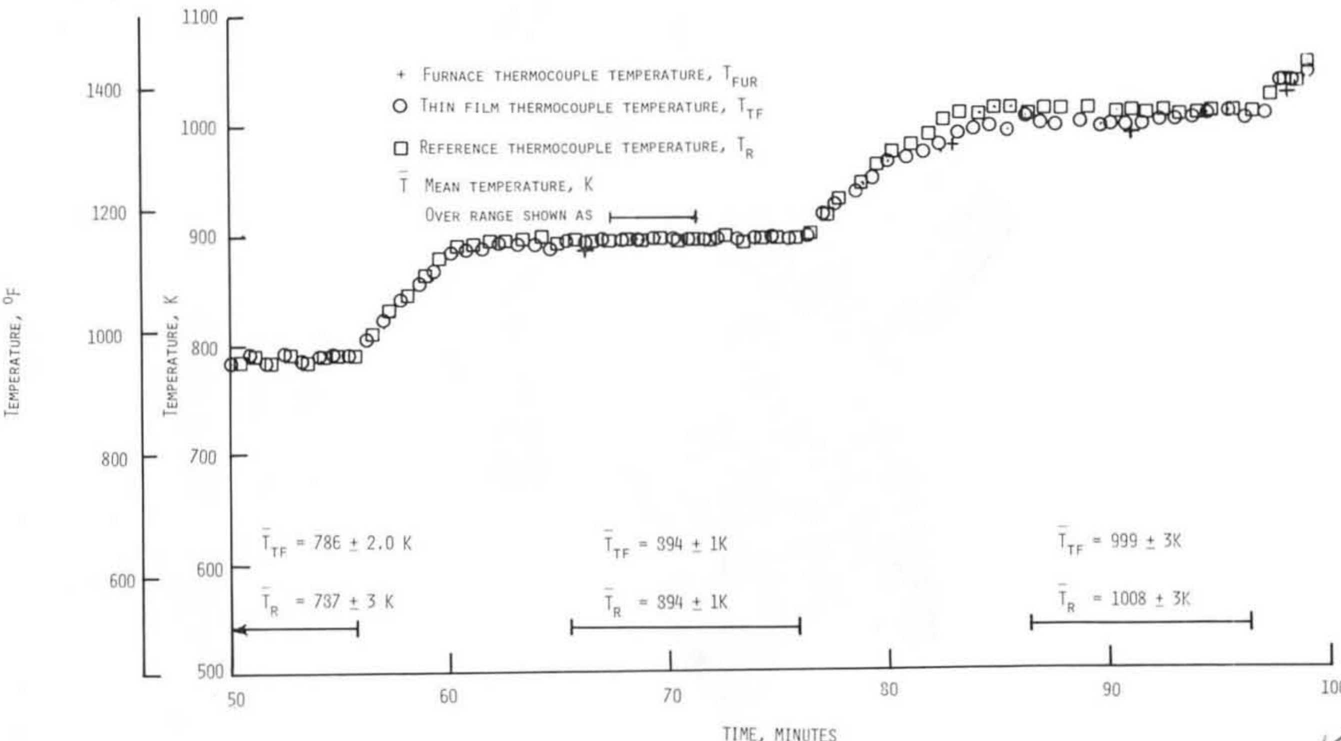


Figure 5. Turbine blade and masks



(A.) Soak time from 0 to 50 minutes



(B.) Soak time from 50 to 90 minutes

Figure 6. Comparison of reference and thin film thermocouple temperatures