NACA

RESEARCH MEMORANDUM

IDENTIFICATION OF FOREIGN OBJECTS DAMAGING

COMPRESSOR BLADES IN TURBOJET ENGINES

By A. E. Spakowski and J. Graab

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

January 7, 1957

4230

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

IDENTIFICATION OF FOREIGN OBJECTS DAMAGING COMPRESSOR BLADES IN TURBOJET ENGINES

By A. E. Spakowski and J. Graab

SUMMARY

Damage to the compressor blades of turbojet engines due to ingestion of foreign objects is a growing problem. The solution of the problem has been made more difficult by the large percentage of damaging materials that have remained unknown. A rapid emission spectroscopic method was devised to identify the chemical composition of these foreign objects from the trace of material left behind on the damaged blade. Results were obtained on laboratory-prepared specimens and on the damaged compressor blades from two turbojet engines with known histories. The results of the investigation show that the method can be utilized to determine the nature of the ingested foreign objects.

INTRODUCTION

One of the principal maintenance problems that has developed with the large-scale use of turbojet aircraft is compressor-blade damage resulting from the ingestion of foreign objects into the compressor section of the engine (refs. 1 to 4). The high rotational speeds and the thinness of the compressor blades, particularly at the edges, make them especially likely to fail through impact damage. Thus any entering material, however small, can cause some degree of damage. This damage can range from a minor nick or scratch on the rotating blade to complete failure of the blade. A nick or scratch, although the damage may appear minor, can shorten the blade fatigue life (ref. 5) to such an extent that complete engine destruction may occur if running is continued with the damaged blade.

The problem of coping with foreign-object damage has been made more difficult because the identity or nature of the foreign objects have remained unknown in a majority of cases. It would be quite advantageous, therefore, if a method were devised which could be used to determine the specific material that had inflicted the damage on the blade. With this added data airbases and overhaul depots could concentrate inspection and cleanup efforts to reduce the most important sources of damage. Additional advantages stemming from this information might be the design of more efficient inlet screens and clues to the cause of engine failure where it is not apparent from other data.

The possible sources of foreign objects include (1) inlet duct components that fail, i.e., wire, bolts, etc.; (2) materials, i.e., tools and excess parts, left in the inlet by maintainence personnel; and (3) airbase debris, including stones, gravel, and metallic objects.

As part of the NACA turbojet-engine-reliability program, a study was undertaken to determine from damaged blades the nature of the foreign objects entering turbine engines. A foreign material passing through the compressor leaves a small amount of itself wherever contact is made with the assembly. This contact area is the vital key to the solution, and the problem then resolves itself into one of identifying a trace of material on the surface of an alloy. This paper describes the development of an emission spectroscopic technique for determining the chemical composition of the trace material on the surface of a damaged compressor blade. The analysis was concentrated on 14 elements that are common to the many possible foreign-object materials, and from these results the type of foreign material is deduced. The method is first applied to laboratory-prepared specimens and then to the compressor blades from two damaged turbojet engines.

APPARATUS AND STANDARD PROCEDURES

The apparatus and procedure used are described as follows:

Spectrograph: Grating spectrograph, 1.5 meters

Excitation source: High-voltage a.c. arc; input 230 volts a.c.; 60 cycle single phase; output 2.5 kilovolt-amperes

Exposure: 3 Seconds; no pre arc

Electrode holder: Petrey spark stand

Analytical gap: 3 Millimeters

Wavelength range: 2220 to 4350 A

Photographic processing:

(1) Developer, D-19, 3 minutes
(2) Short stop, 1 minute
(3) X-ray fixer, 5 minutes
(4) Wash, 5 minutes
(5) Dry, 1 minute

Densitometry: Comparator-densitometer

Emulsion: Eastman spectrum analysis number 1; 35-millimeter film

Slit: 0.055 Millimeter

Electrode: Regular spectrographic carbon rods 12 by 1/4 inches; pointed electrode

Grating doors: Wide open

Preparation of sample: Compressor blades set on the flat plate of the Petrey stand. Blades held in position desired by supporting blade with plasticine clay.

EXPERIMENTAL PROCEDURE

A high-voltage a.c. arc was used since it is especially adapted to measurement of low-concentration impurities. This measurement was accomplished by keeping the specimen relatively cool, and thus the background was held to a minimum. The compressor blade was placed on the Petrey stand with the damaged area directly above the pointed lower electrode. Plasticine modeling clay was most convenient for holding the blade in any desired position on the stand. The specimen was arced for 3 seconds. Spectra of other damaged areas on this blade or any other areas of similar blades and a control spectrum from an undamaged portion of the blade were recorded on the same film. The exposed film was developed using standard conditions.

The presence of foreign material on the compressor blade was noted by comparing the damaged-area spectrum with that of the base alloy. The spectrogram was alined with the master plate of the densitometer using the iron lines in the steel specimens. The technique of identifying foreign elements is illustrated in figure 1. In figure 1(a), the 2881.578 A silicon line, placed under the cross hair, is found present in the unknown spectrum and not found present in the base-material spectrum. This line together with the other silicon lines found present is recorded on a data sheet, such as that shown in figure 2. Two spectral lines of copper are identified in figure 1(b). Here again the unknown spectrum contains the lines of the element in question, while the spectrum of the base material does not. The process is continued until all the lines of interest have been examined and the results recorded.

These data and any other bits of evidence obtained from a visual observation of the damaged areas are used to deduce the nature of the foreign material. However, it is apparent that a number of different foreign objects may be indicated from the same spectroscopic data; all the possibilities should be given careful consideration. In many cases the past history of the engine can contribute substantially to the solution.

RESULTS AND DISCUSSION

The determination of the foreign material damaging compressor blades was, first, a problem of detecting a trace of material on the surface of an alloy, and second, a problem of devising a rapid method because of the large number of samples that may have to be analyzed. Because of the many and varied sources of foreign objects, it is necessary to examine a large number of samples (damaged areas) from different engines before satisfactory remedial measures can be successfully outlined.

The type of samples that were studied is shown in figure 3, which is a photograph of a typical compressor blade damaged by material ingested through the engine inlet. Damaged areas include nicks in the leading edge of the blade, pits in the body, and dents in the trailing edge. The materials inflicting this damage would leave behind small fragments of themselves, depending, of course, upon their relative hardnesses and striking forces, among other things. A spectroscopic technique was chosen as the one offering the most advantageous approach to the problem. In this method the sample preparation would be negligible, actual analysis time short, and low concentrations of chemical elements could be detected. The first approach was to set up a standard procedure and then attempt to evaluate its merits.

A series of standards was made with which various techniques could be tested. In table I is shown a list of materials that were used. These materials were selected on the basis of their being common materials used in jet engines or common foreign objects damaging engines. The 403 stainless steel is one of the more common stock materials used for compressor blades, and was used as the base alloy in this investigation. In addition to iron and chrominum, the major constituents, 403 stainless steel contains a wide variety of trace impurities. The laboratory specimens were made from 1/4-inch 403 stainless-steel rod, cut into 3-inch lengths and ground to a wedge shape on one end. The specimens were impregnated with the foreign material by striking the wedge edges a glancing blow with the foreign material. This procedure yielded reasonable facsimiles of the damage to the blade.

The spectroscopic method used consisted of standard techniques with a short duration (3 sec) d.c. arc initially tried. This type of excitation worked quite satisfactory during the preliminary tests, but later difficulties were encountered with several elements. Better results were then obtained with the hotter a.c. arc. The results using both excitation sources on the laboratory specimens are shown in table II. The spectral lines that have been found most useful during the course of the study are listed in table III. Most of these lines are known as the raies ultimes, or persistent lines.

Some precautions must be observed in the identification of chemical elements. The more spectral lines of any one element that can be seen, the more positive will be the identification. However, when only a single faint line is visible, there is the possibility that it may be a faint line from the spectrum of another element and therefore should be carefully checked for interferences. Another difficulty arises quite often when the arc does not vaporize the damaged area but an adjacent area. This results when the area of interest is a nick with sharp, protruding edges that sometimes act as the electrodes. The difficulty was overcome by grinding the edges away if contamination of the target area could be avoided.

When a large number of samples is to be processed, the time required to read the spectrograms becomes time consuming. A simple chart that has helped to speed up the "readout" time is illustrated in figure 2. The chart, containing all the spectral lines from table III rearranged in order of increasing wavelength and with any number of extra columns for individual samples, can be readily reproduced. In use the operator sets a particular wavelength and then scans each spectrogram position for its presence, recording the results as check marks on the chart. Large and small checkmarks can be utilized to denote the intensity of the line, and a question mark if the line is in doubt. The completed charts can be held for interpretation at a later time. As experience with the method is accumulated the number of spectral lines required can be varied and reduced to a minimum.

During the course of this study compressor blades became available from two engines that had suffered damage due to the ingestion of foreign objects. These engines were received new and were run entirely in jet, static test stands. The results of the analysis of the damaged compressor blades from these two engines (labeled A and B) are shown in table IV. The compressor of engine A had been severely damaged, and damaged areas where copper and aluminum metal were clearly visible could be easily observed. In testing the spectroscopic method, however, only those areas where minor damage occurred were used. In actual practice every available means would be used to aid in the identification of the foreign material. The compressor of engine A has aluminum blades in the first stages and 403 stainless-steel blades in the remaining stages. A number of damaged areas on each type blade was analyzed; the results in table IV show that the principal element in each foreign material was found. It was known beforehand that engine B was damaged by a titanium carbide cermet with nickel as the binding agent. Upon analysis large quantities of titanium and nickel were found with trace amounts of aluminum and magnesium. The origin of the aluminum and magnesium is unknown.

CONCLUDING REMARKS

A spectroscopic method was set up to analyze rapidly for trace impurities on the surface of damaged compressor blades. From limited experience on laboratory and engine samples, it appears that this approach to the foreign-object-damage problem can be utilized. As experience is gained, the method can be substantially improved, i.e., by shortening the time of analysis, improving the sensitivity, or varying the elements and spectral lines sought. The simplicity of the method is important for, from the nature of the foreign-object-damage problem, the attack must be carried out on a large number of damaged engines and should then be followed by a statistical analysis of the results.

The method will furnish information which together with other data can result in positive identification of the foreign objects. Although positive identification cannot be made in all cases, this method does identify some damage causes and thus decrease the statistical unknowns. It may also find use in determining the cause of engine failure, i.e., differentiating between fatigue and impact damage. The method can be used in conjunction with fatigue-strength studies to correlate the source of damage and the type of material with its effect on the life of the compressor blade. From these studies can come the recommendations to initiate remedial measures that will lead to more reliable and economical turbojet operation of both the military and the commercial air-transport industry.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 16, 1956

REFERENCES

1. McCombs, Dale E.: The Giant Problem. Aircraft Accident and Maintenance Rev., vol. XI, no. 4, Apr. 1956, pp. 12-17.

2. Anon.: Aircraft Gas Turbine Engine Foreign Object Damage Protection. Oklahoma City Air Materiel Area, Tinker Air Force Base, May 1, 1956.

3. Anon.: Foreign Object Damage. Northrop Service News, vol. IV, no. 7, Aug. 1954, pp. 6-7; 9.

4. Cord, H. E., and Mathias, R. L.: Foreign Object Ingestion in Turbojet Engines. Preprint No. 702, SAE, 1956.

5. Kaufman, Albert, and Meyer, André J., Jr.: Investigation of the Effect of Impact Damage on Fatigue Strength of Jet-Engine Compressor Rotor Blades. NACA TN 3275, 1956.

TABLE I. - MATERIALS INVESTIGATED DURING THE FOREIGN-OBJECT-DAMAGE STUDY

Composition	Type of material								
	403 Stainless steel, percent	347 Stainless steel, percent	Inconel X, percent	Hastelloy B, percent	S-816, percent	Magnesium alloy	Aluminum alloy	Concrete	Sand, percent
Chromium	11.0-13.0	17.0-19.0	14-17		20				
Nickel		9-12	[a]72	[a]65	20				
Molybdenum		0.5 max		[a]28	4				
Cobalt					44				
Magnesium						√(a)		√(a)	
Silicon	0.5 max	0.5-1.0	0.5 max					√(a)	[a]47
Iron			6-10	5	28				
Others	Mn 1.0 max	Mn 2.0 max Cu 0.5 max	Mn 1.0 max	V 0.04	W 4		[a]Al	[a]Ca	

[a]Most likely to be detected when the alloy is present as a trace on the blade.

TABLE II. - SPECTROSCOPIC ANALYSIS FOR MAJOR COMPONENTS

OF LABORATORY-DAMAGED BLADE SPECIMENS

Damaging material	Elements found not present in 403 stainless steel (a)	
	a.c. Arc	d.c. Arc
Inconel X	Ni	Ni
Hastelloy B	Ni,Mo	Ni,Mo
S-816	Co	-----
347 Stainless steel	--------	-----
Magnesium alloy	Mg	Mg
Aluminum alloy	Al	-----
Concrete	Si,Mg,Ca	Si
Sand	(b)	Si

[a]Three samples of each type run.
[b]Not tested.

TABLE III. - WAVELENGTH OF LINES IN EMISSION SPECTRA OF VARIOUS ELEMENTS

Aluminum	Calcium	Cadmium	Chromium	Cobalt
3082.155 3092.713 3944.032 [a]3961.527	[a]3933.666 3968.468 4226.728	3403.653 3610.510	[a]4254.346 4274.803 4289.721	3405.120 [a]3453.505 3465.800 3529.813
Copper	**Iron**	**Lead**	**Magnesium**	**Manganese**
2492.15 2824.37 3247.540 [a]3273.962	2382.039 [a]3719.935 3737.133 3745.903	2833.069 3639.580 3683.471 4057.820	2795.530 [a]2802.695 2852.129	[a]4030.755 4033.073 4034.490
Molybdenum	**Nickel**	**Silicon**	**Titanium**	**Tungsten**
[a]2816.154 2848.232 3170.35 3193.97	[a]3414.765 3492.956 3515.054	2506.899 2516.123 [a]2881.578 3905.528	3349.035 3361.213 3372.800 [a]3653.496	[a]3613.790 4008.753 4294.614

[a]Most sensitive.

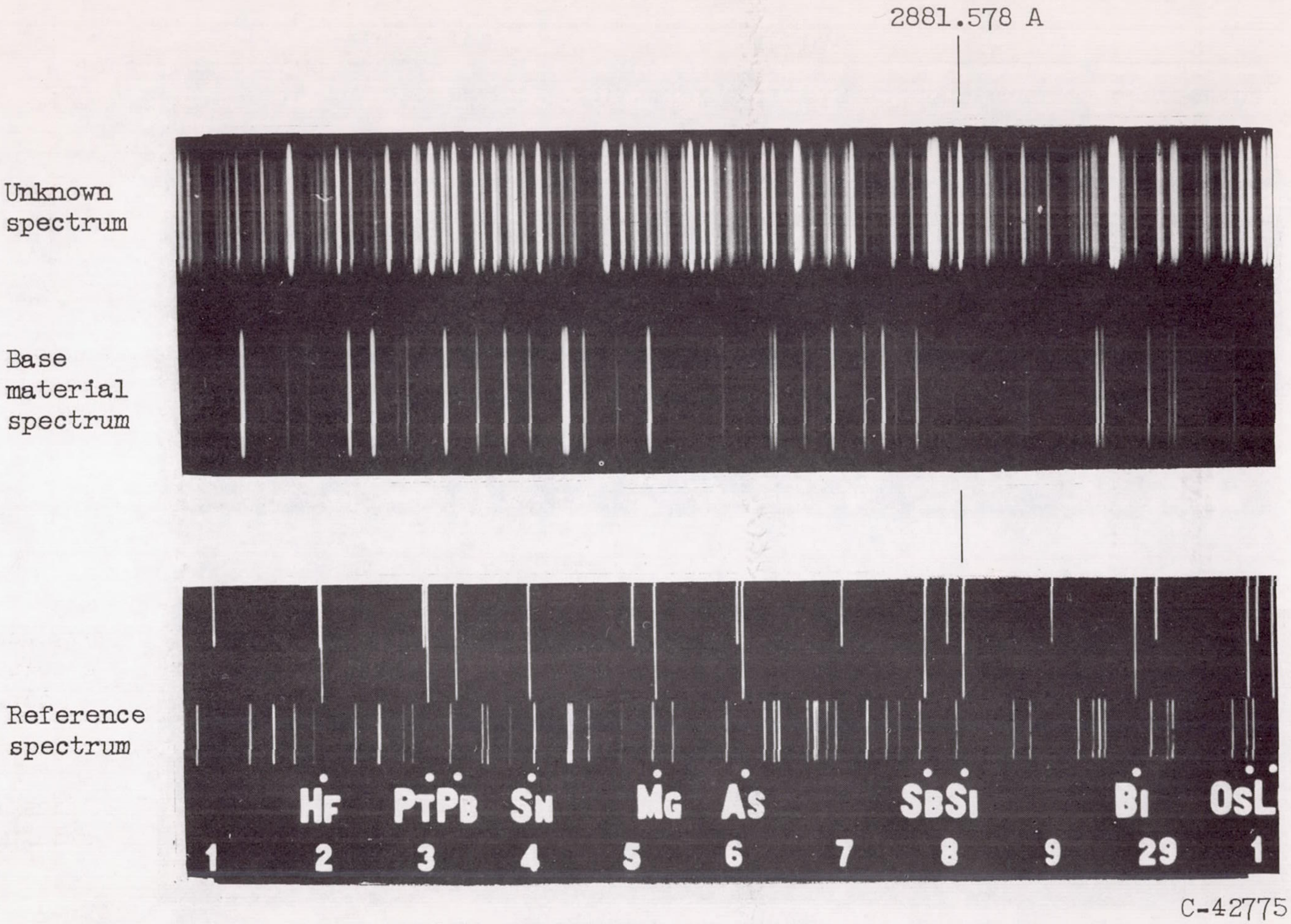
TABLE IV. - ANALYSIS OF COMPRESSOR BLADES FROM ENGINES DAMAGED BY INGESTION OF FOREIGN OBJECTS

Engine A	Damaging material known	Elements found	
		Aluminum blades (a)	403 Stainless-steel blades (b)
	Copper Magnesium alloy Aluminum alloy Stainless steel	Cu Mg Si Cr,Fe	Cu Al,Si
[c]Engine B	Cermet (TiC and Ni)		Ti Ni Al Mg

[a]Six damaged areas examined.

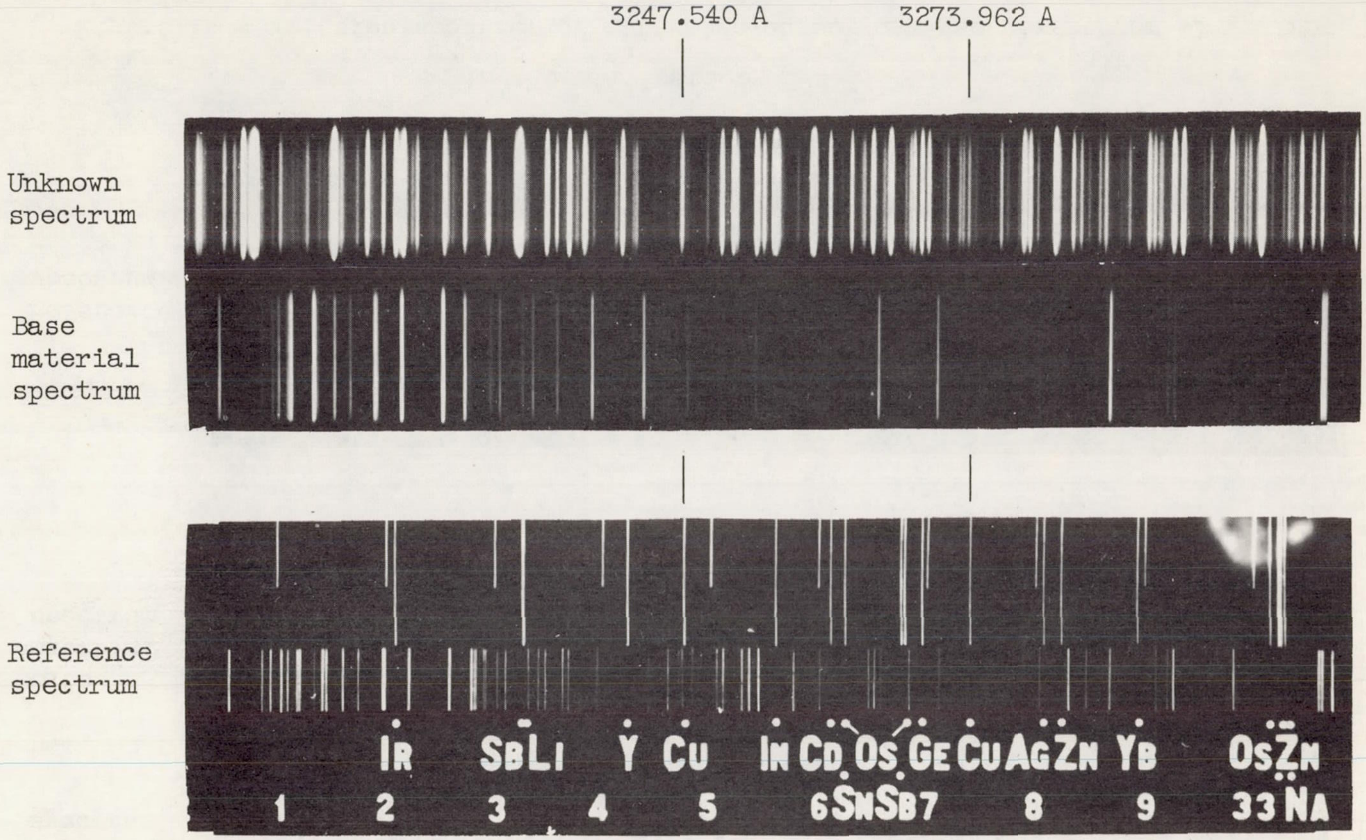
[b]Seven damaged areas examined.

[c]Twelve damaged areas examined.



(a) Identification of silicon.

Figure 1. - Emission spectrum of a foreign-object-damaged compressor blade from engine A.



C-42774

(b) Identification of copper.

Figure 1. - Concluded. Emission spectrum of a foreign-object-damaged compressor blade from engine A.

Engine Identification____________________ Date______________________________

Compressor blade composition_____________ Observer______________________________

Spectral lines	Element	Damaged area										Spectral lines	Element	Damaged area									
		1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10
2382.039	Fe											3465.800	Co										
2492.15	Cu											3492.956	Ni										
2506.899	Si											3515.054	Ni										
2516.123	Si											3529.813	Co										
2795.530	Mg											3610.510	Cd										
2802.695	Mg											3613.790	W										
2816.154	Mo											3639.580	Pb										
2824.37	Cu											3653.490	Ti										
2833.069	Pb											3683.471	Pb										
2848.232	Mo											3719.935	Fe										
2852.129	Mg											3737.133	Fe										
2881.578	Si											3745.903	Fe										
3050.819	Ni											3905.528	Si										
3082.155	Al											3933.666	Ca										
3092.713	Al											3944.032	Al										
3170.35	Mo											3961.527	Al										
3193.97	Mo											3968.468	Ca										
3247.540	Cu											4008.753	W										
3273.962	Cu											4030.755	Mn										
3349.035	Ti											4033.073	Mn										
3361.213	Ti											4034.490	Mn										
3372.800	Ti											4057.820	Pb										
3403.653	Cd											4226.728	Ca										
3405.120	Co											4254.346	Cr										
3414.765	Ni											4274.803	Cr										
3453.505	Co											4289.721	Cr										
												4294.614	W										

Figure 2. - Spectropic data sheet.

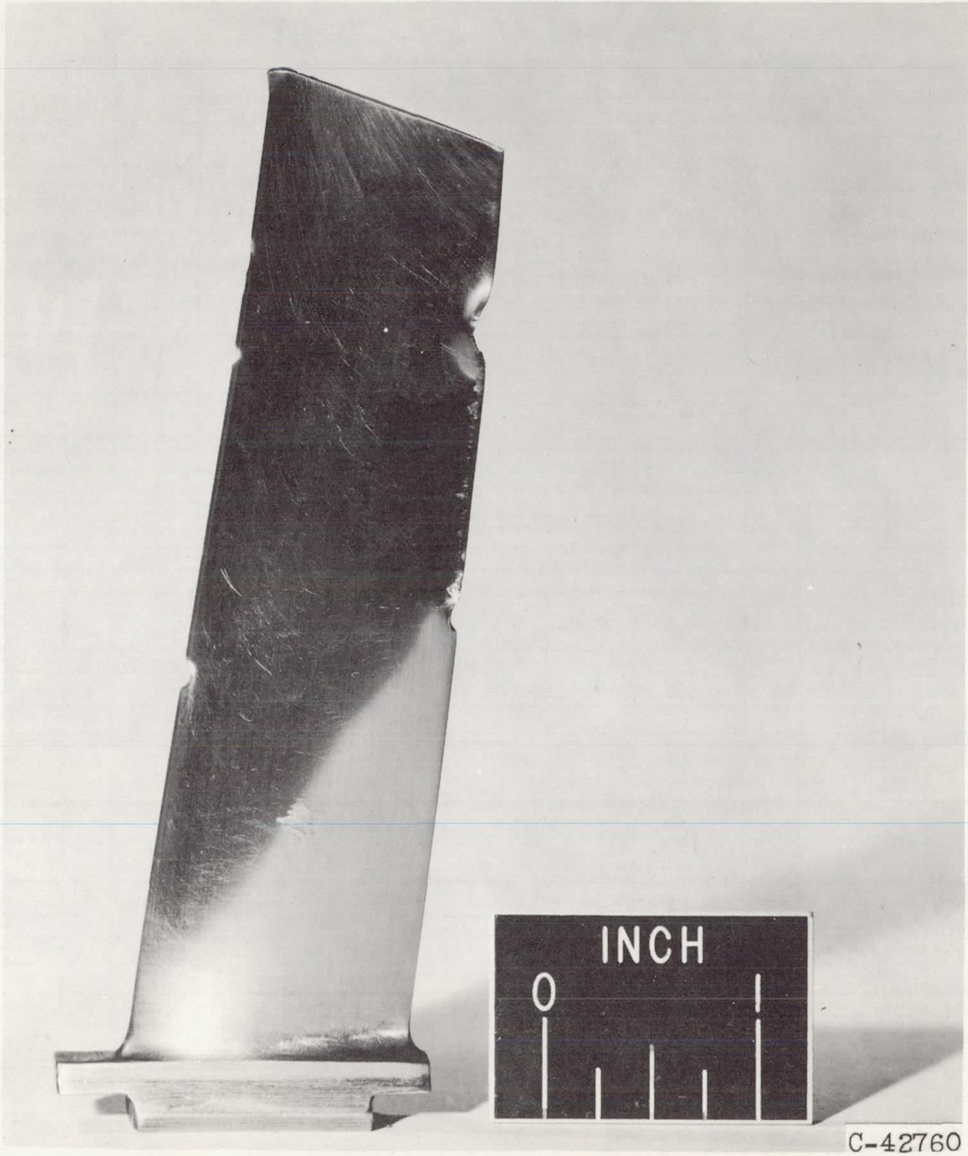


Figure 3. - Compressor-blade damage caused by foreign objects ingested by the engine.