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PREVENTION OF CORROSION AND FATIGUE FAILURE OF HELICOPTER GAS TURBINE COMPRESSORS

by

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Corrosion pitting leading to fatigue cracking and failure of a rotor blade or stator vane was found to be the most probable cause of disintegration of a helicopter gas turbine compressor during normal operation in The Netherlands.

A subsequent corrosion investigation showed that the corrosion resistance of compressor rotor blades, which are manufactured from the same material as the rest of the compressor, could be much improved by applying commercially available protective coatings. In particular, this was confirmed by evaluation in a compressor test rig which allowed simulation of the polluted service environment.

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1 INTRODUCTION

Acid precipitation owing to sulphur dioxide (SO_2) and nitrogen oxides (NO, NO_2) emissions is widespread in Western Europe. The Netherlands is the most affected country and is likely to remain so for the foreseeable future (Ref.1). Average pH values of the rainwater, even in rural areas, are less than 4, figure 1. Within the last five years it has become apparent that besides actual and potential serious ecological damage (Ref.1) this environmental pollution has an especially detrimental effect, i.e. enhanced corrosion, on aircraft gas turbines operating in The Netherlands. Recognition of this problem led to the NLR constructing two test rigs for evaluating the corrosion resistance of compressor and turbine components under close simulation of service conditions.

Following disintegration of the compressor section of a helicopter gas turbine during normal flight and subsequent analysis of the failure as being due to corrosion pitting and fatigue, corrosion tests were carried out on rotor blades from the same type of compressor. Besides evaluation in the compressor rig the tests included exposure to neutral and acid salt spray environments, which are conventionally used to determine corrosion resistance. Both uncoated blades, as used in service, and blades with commercially available protective coatings were tested.

For the uncoated blades compressor rig testing proved to be severest and resulted in pitting corrosion most representative of that found for service components. However, the coatings afforded complete protection under all conditions. Investigation is continuing with particular attention to the influence of these coatings on the fatigue properties per se.

2 THE SERVICE FAILURE

The compressor rotor assembly and one of the two sections of compressor casing are shown in figure 2, and a summary of the damage is given in table 1. The most significant features of this list are the occurrence of corrosion pitting and fatigue cracks initiating from corrosion pits. An example of this is given in figure 3.

The entire compressor assembly had been manufactured from 17 Cr- 4 Ni precipitation hardening martensitic steel, which has nominally good resistance to corrosion. However, it is known that corrosion pitting can occur in service, and the maintenance manuals prescribe regular water rinse and wash procedures to inhibit corrosion.

At failure the compressor had undergone 757 hours in service, while the time between overhaul (TBO) is 3000 hours. The engine operator had followed a recommended schedule of rinsing weekly and washing once a month. This schedule was clearly insufficient to prevent corrosion which, in our opinion, led to fatigue failure of either a rotor blade or stator vane and subsequent disintegration of the compressor.

The engine manufacturer proposed rinsing daily as a remedial action for other compressors of the same type. We considered this proposal to be inadequate on two counts. First, although more frequent rinsing probably would retard corrosion, there is no guarantee that the TBO can be achieved, especially since environmental pollution in The Netherlands is so severe, figure 1. Second, the service failure investigation showed that corrosion pitting had occurred in the crevices formed by decohesion of plastic sealant at vane roots, and a simple rinse is unlikely to remove environmentally polluted moisture from such crevices.

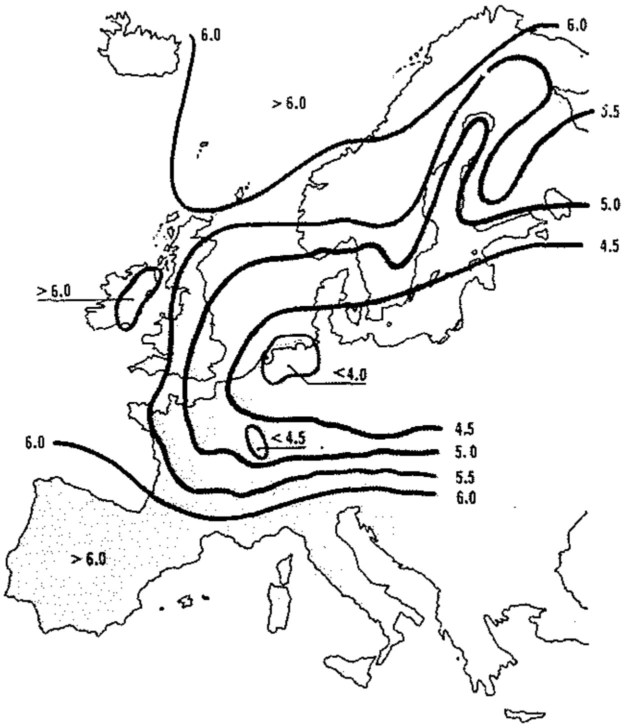
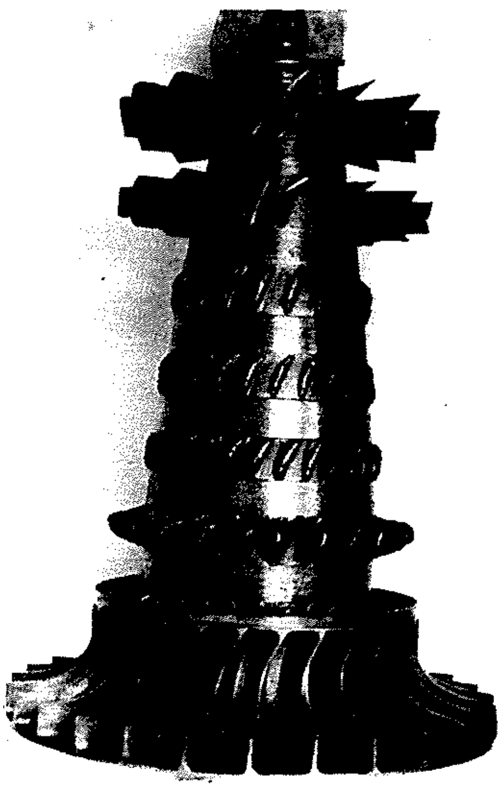


Fig. 1 Iso-pH lines indicating acidity of precipitation in Western Europe

rotor assembly



casing

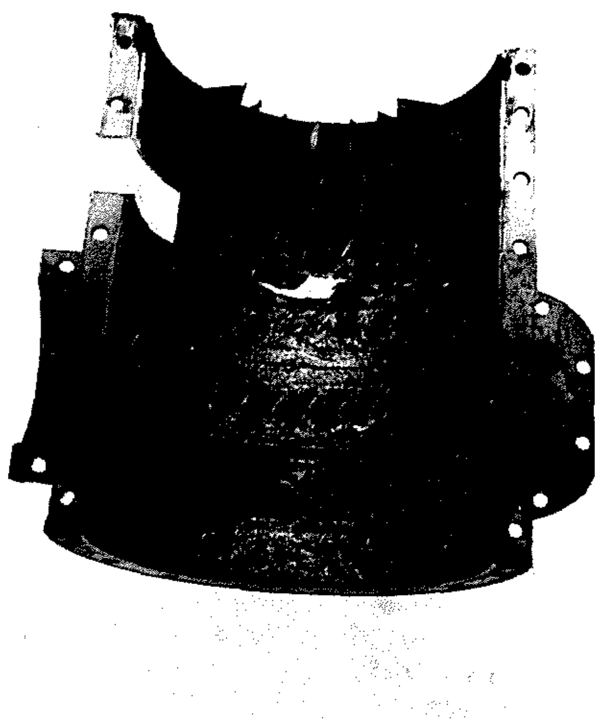


Fig. 2 Service failure compressor rotor assembly and one of the two compressor casing sections

TABLE 1

COMPRESSOR SECTION DAMAGE LIST

ROTOR ASSEMBLY	FIRST STAGE	• blade tips rubbed against casing • corrosion pitting on concave sides of airfoils
	SECOND STAGE	• blade tips rubbed against casing • trailing edges heavily damaged • severe corrosion pitting on concave sides of airfoils • fatigue cracks originating at corrosion pits
	THIRD STAGE	• airfoils missing • severe corrosion pitting on concave sides of blade remnants • corrosion pitting on convex sides of blade remnants
	FOLLOWING STAGES	• fourth and fifth stage airfoils missing • sixth stage airfoils heavily damaged • inlet side of centrifugal compressor heavily dented
STATOR VANE AND CASING ASSEMBLY	FIRST STAGE	• vane tips rubbed against rotor hub • corrosion pitting at vane roots • decohesion of plastic sealant at vane roots
	SECOND STAGE	• all but four airfoils missing • one identifiable airfoil fracture: fatigue originating at corrosion pits on convex and concave sides • fatigue cracks originating at corrosion pits on concave sides of two of the remaining airfoils • corrosion pitting at vane roots • decohesion of plastic sealant at vane roots
	FOLLOWING STAGES	• airfoils missing • vane platform bands torn out of casing • casing penetrated

It was our opinion that the most effective way of counteracting corrosion would be to apply protective coatings. Accordingly, we evaluated the corrosion resistance of components from the same type of compressor with and without coatings. The results are reported in the next section.

3 THE CORROSION INVESTIGATION

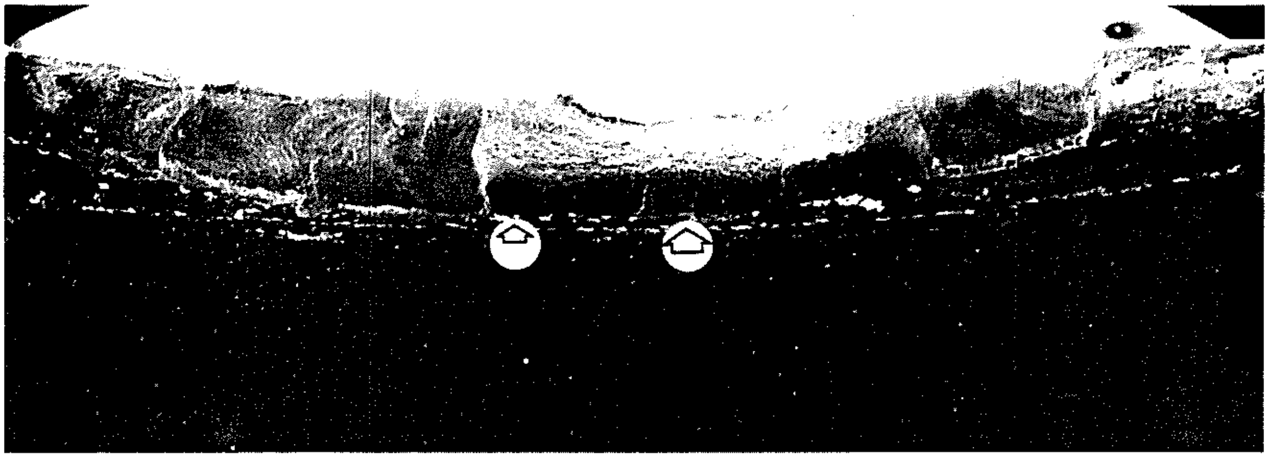
3.1 Test methods

Three types of test method were used:

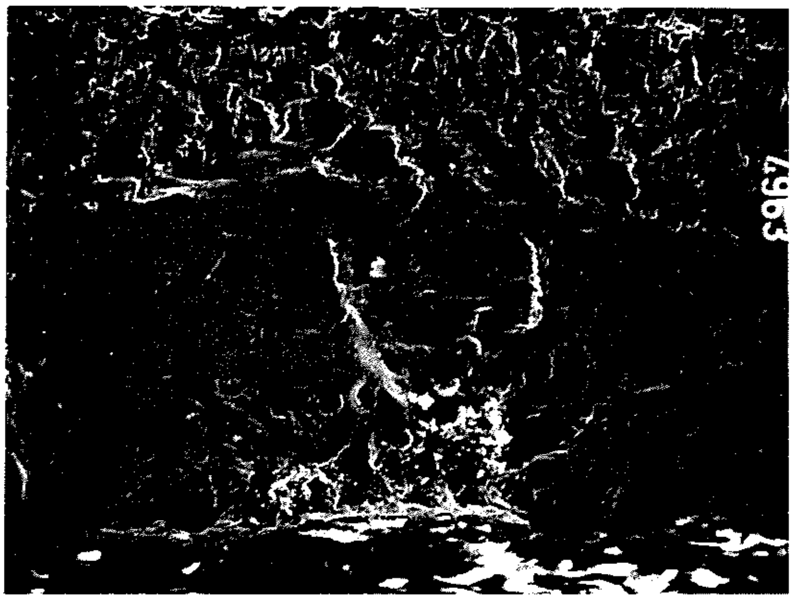
(1) Neutral salt spray exposure for 200 hours according to ASTM standard B-117 (Ref.2).

(2) Acid salt spray exposure for 311 hours. Acidification was by addition of equal amounts of 1N H_2SO_4 and 1N HNO_3. The collected solution pH was maintained between 3.0 and 3.15. All other requirements conformed to ASTM Standards B-117 and B-287 (Ref.2).

(3) Evaluation with the NLR compressor rig, figure 4. Testing involved



(a) Overview of the fracture surface: fatigue initiation sites arrowed (x17)



(b) Detail of figure 3a: corrosion pit at fatigue initiation site (x180)

Fig. 3 Forcibly opened crack in a second stage stator vane from the service failure

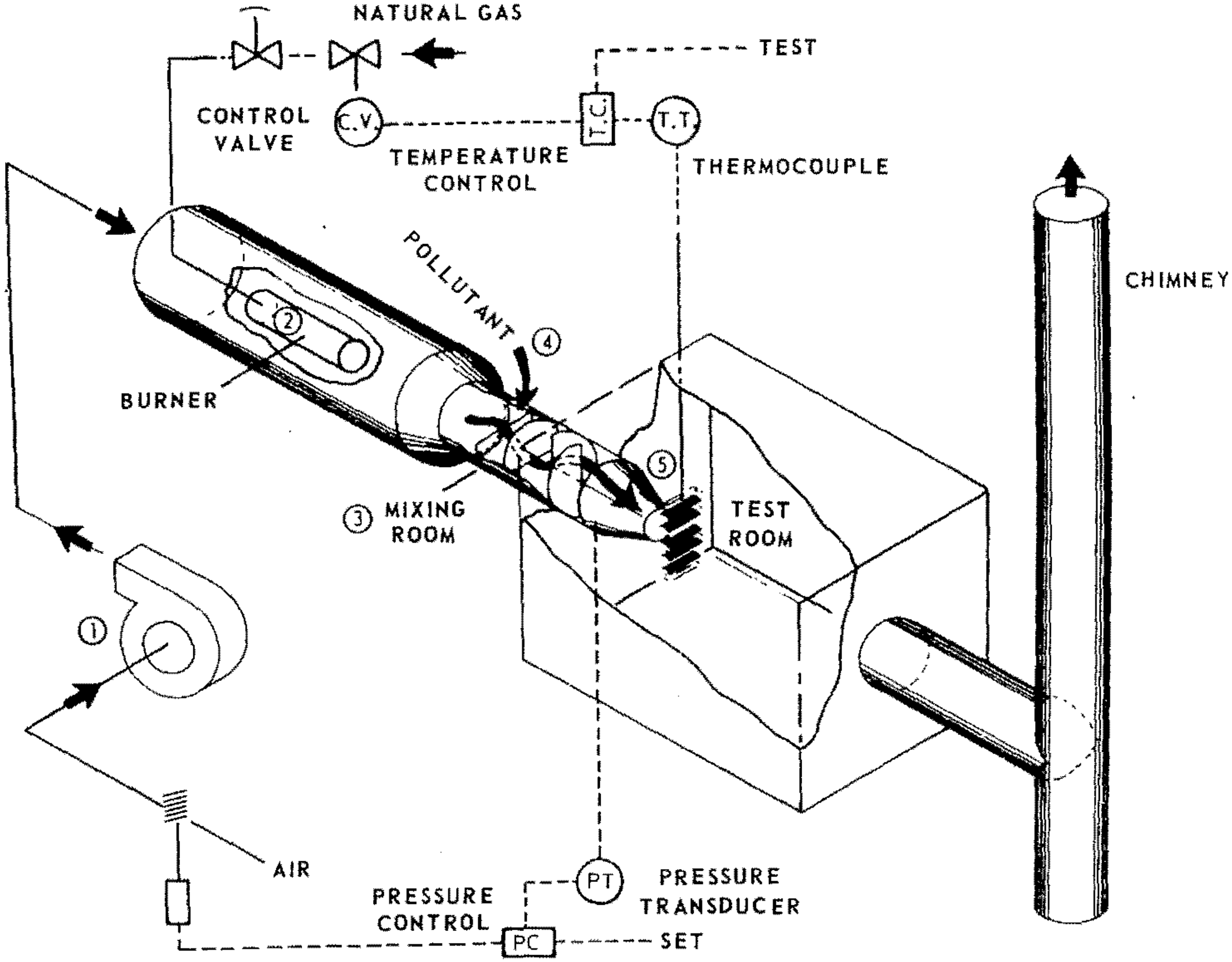


Fig. 4 The NLR compressor test rig (Ref. 3)

working day exposure in the compressor rig plus storage in a controlled climate room overnight and during weekends. The test cycle during working days is shown in figure 5. A total of 19 cycles was applied. Compressor rig temperatures were based on manufacturer's data for intermediate stages in the helicopter gas turbine compressor. During exposure 5 ppm NaCl and 3 ppm SO_2 were continuously injected into the hot air stream.

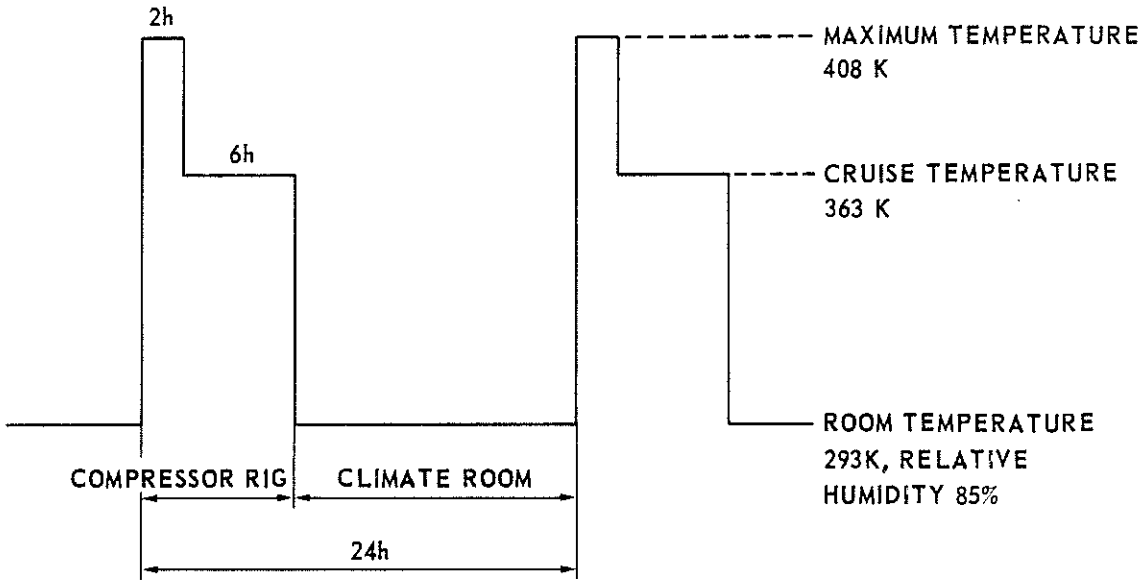


Fig. 5 Compressor rig test cycles during weekdays

3.2 Specimens

One first stage compressor rotor and one combined second and third stage compressor rotor were made available to the NLR. Both components had seen service, but not in the same engine. Corrosion pitting was found on the concave sides of airfoils, as was the case for the service failure, table 1.

First and second stage blades were sawn out of the rotors. Some of these blades were coated either with Chromalloy A-12 or Sermetel 735, which are proprietary self-sacrificial aluminium type coatings widely used in aircraft gas turbine compressors. Half the coated airfoils were inscribed with St. Andrew crosses penetrating the coatings on the sides to be exposed: coating thicknesses typically do not exceed 20 µm.

3.3 Results

Corrosion test results are summarised in table 2. Pitting measurements excluded the airfoil leading edges, which had been the most severely pitted regions in actual service.

Table 2 shows the following:

(1) The coatings protected the airfoils completely under all test conditions.

(2) Neutral salt spray testing did not pit uncoated specimens.

(3) In terms of average pit depth acid salt spray testing and compressor rig testing were similarly detrimental. However, compressor rig testing resulted in many more pits on uncoated airfoils.

TABLE 2

CORROSION TEST RESULTS

TEST METHOD	SPECIMEN	AVERAGE PIT DEPTH (μm) EXCLUDING LEADING EDGE		REMARKS
		AIRFOIL	COATING	
UNTESTED	U-8	14	-	pitting on concave side only
	A-8	-	$\sim$0	
	S-7	-	$\sim$0	
NEUTRAL SALT SPRAY ON CONVEX SIDES	U-33	$\sim$0	-	
	U-34	$\sim$0	-	
	A-1	-	$\sim$0	
	A-2-X	-	12	coating pitting near cross
	S-2	-	16	
	S-1-X	-	18	coating pitting random
ACID SALT SPRAY ON CONVEX SIDES	U-35	20	-	very few pits
	U-58	17	-	
	A-3	-	11	
	A-4-X	-	8	coating pitting especially near cross
	S-4	-	17	
	S-3-X	-	15	coating pitting random
COMPRESSOR RIG ON CONVEX SIDES	U-4	22	-	airfoil pitting extensive and random
	U-5	22	-	
COMPRESSOR RIG ON CONCAVE SIDES	U-1	18	-	airfoil pitting extensive and random
	U-2	18	-	
	A-6	-	15	coating pitting random
	A-5-X	-	13	
	S-6	-	17	
	S-5-X	-	20	

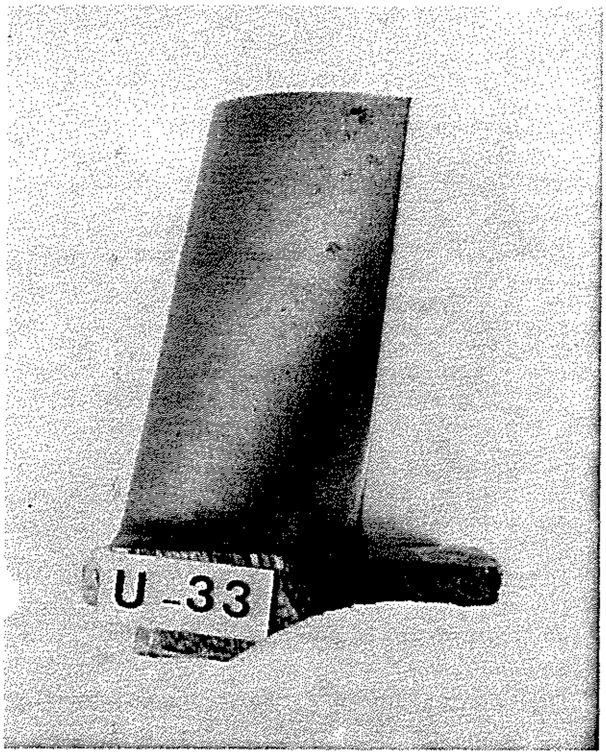
KEY

U = uncoated
A = Chromalloy A-12 coated
S = Sermetel 735 coated
X = inscribed with cross

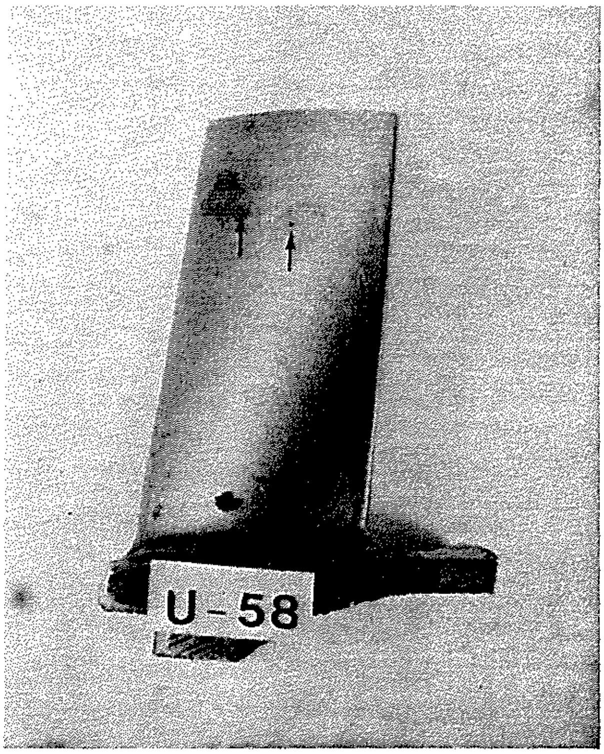
Figure 6 compares the appearances of three uncoated airfoils exposed to neutral and acid salt sprays and compressor rig testing. The much greater amount of pitting owing to compressor rig testing is evident. In this respect compressor rig testing was more representative of corrosion pitting in service.

4 SUMMARY

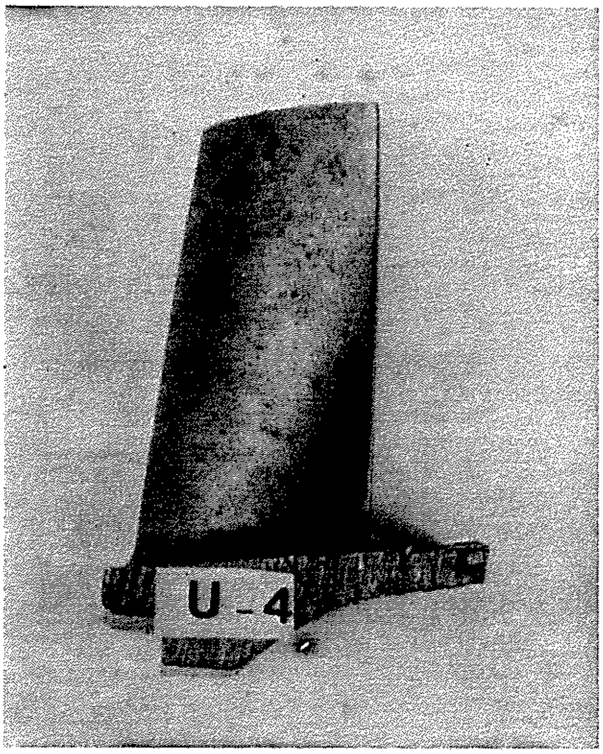
Corrosion pitting leading to fatigue cracking and failure of a rotor blade or stator vane was found to be the most probable cause of disintegration of a helicopter gas turbine compressor during normal operation in The Netherlands.



neutral salt spray



acid salt spray
corrosion pits arrowed



compressor rig

Fig. 6 Convex sides of uncoated airfoils after corrosion testing (x2)

A subsequent corrosion investigation showed that the corrosion resistance of compressor rotor blades, which are manufactured from the same material as the rest of the compressor, could be much improved by applying commercially available protective coatings. In particular, this was confirmed by evaluation in a compressor test rig which allowed simulation of the polluted service environment.

Currently the helicopter gas turbine compressors are still operating in the original, uncoated condition. Owing to the severity of environmental pollution in The Netherlands it is doubtful whether more frequent water rinsing of the engines will retard corrosion sufficiently to prevent further failures. In our opinion the application of protective coatings would be more effective.

There is, however, one potential caveat. The engine manufacturer raised the question of coatings possibly being detrimental to the fatigue resistance per se. This has resulted in a continuing investigation specifically directed to comparing the fatigue properties of coated and uncoated rotor blades (Ref.4).

5 ACKNOWLEDGEMENT

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