OLYMPUS GAS TURBINES

RECENT PROBLEMS

BY

J. WALKER, B.SC., R.C.N.C.
(*Sea Systems Controllerate*)

Introduction

The marine Olympus gas turbine was introduced into service in 1968 and is generally regarded as a reliable engine giving satisfactory service. However 1985 was unusual in that a significant number of Olympus failures occurred in a short period. It is the purpose of this article to present the results of the investigation into these failures, their causes, and the actions taken to prevent recurrence.

During 1985, some twelve gas turbine change units were removed before the end of their release life and, at the time of writing, a total of six have been confirmed as having HP turbine blade failures. It is highly likely that defect investigations on three further units will also show this type of failure. The remaining three GTCUs failed due to bearing problems (two) and LP turbine failure (one) and will not be addressed in this article.

All the HP turbine blade failures occurred at fairly high powers but engine hours varied considerably from very low to near release life limit. The R.N., as the major shareholder within the Anglo Dutch Belgian and French MOU pool, suffered all the six confirmed and three suspect HP turbine blade failures. As is the case with any failure of HP turbine blades, the damage is often extensive and these engines ran true to form. In some cases power turbine replacement was found necessary due to secondary damage.

Mode of Failure

Almost all the Olympus gas turbines in R.N. service feature HP turbine blades to a forged Nimonic 115 standard and failures have been confined to these. The blade has a parallel shroud, and fir tree root attachment to its disc. A vibration characteristic is shown in FIG. 1. Readers will note the high peak at the first flexural mode, at approximately 7350 r.p.m. The resonant frequency at which this occurs will vary slightly from engine to engine and may be excited by sources such as a combustion defect. If the amplitude of vibration is sufficiently high then the ultimate result is a fatigue failure at the fir tree root of the HP turbine rotor blades.

The first warning the operator normally gets is high vibration level. Following this, instances have been reported of high power turbine entry temperature trip but this has not always been the case. At this stage, blade failure has already occurred and nothing can be done to avoid some secondary damage. Unfortunately, the current procedure of running on, albeit at reduced power whilst investigating the incident, can cause extensive secondary damage, particularly to the power turbine. This subsequent damage could be avoided and this will be discussed later.

As stated above, the vibration excitation normally results from a combustion defect. Two cases recently and three failures before 1985 (namely *Battleaxe* (1982), *Wielingen* (Belgian Navy) (1983) and *Brilliant* (1983)) showed no visible external excitation source. However it should be noted that, although combustion defects were not apparently present at the time of failure, it is highly likely that burner, combustion chamber or fuel problems had been present at periods during the lives of these engines. Indeed the straw that finally broke the camel's back was probably a very small effect which did not show itself at the time of defect investigation.

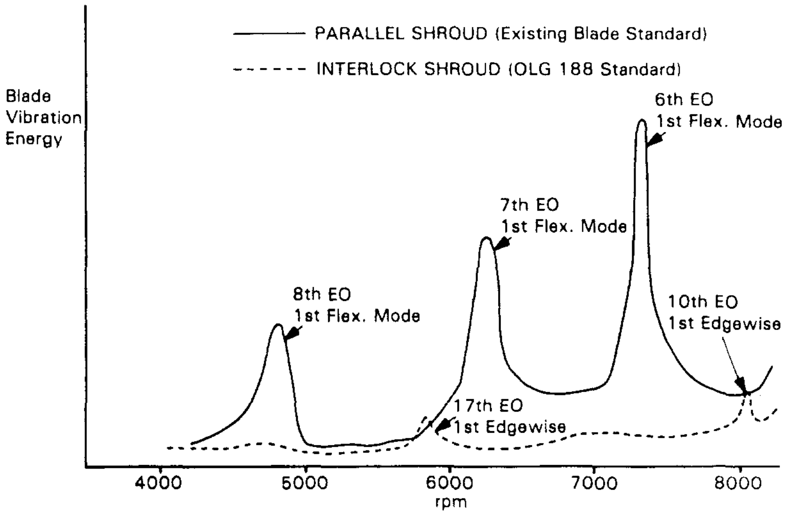

FIG. 1—TYPICAL VIBRATION CHARACTERISTIC OF OLYMPUS HP TURBINE BLADES
EO: HP spool order

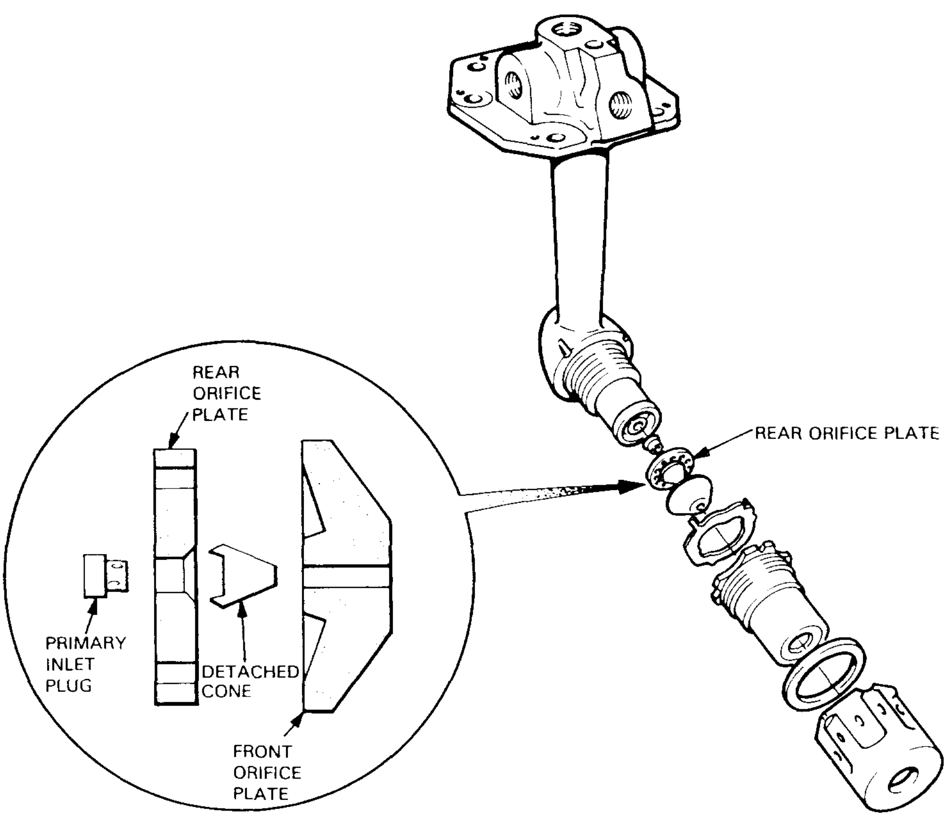

FIG. 2—OLYMPUS BURNER: EXPLODED VIEW, WITH FAILURE MODE

Combustion Defects that have caused Blade Failure

There are three main types of defects which might occur in the combustion areas:

(*a*) Burner blockage by dirty fuel.

(*b*) Burner blockage due to burner internal component failure.

(*c*) Blockage of HP turbine nozzle guide vanes by debris from upstream.

Any one of these faults can cause HP turbine blade excitation when the engine is run within the critical speed band. Burner blockage by dirty fuel is self-explanatory. This 'dirt' can take the form of carbon deposits or corrosion products detached from the ship's fuel system. Although only one defect analysis has shown this problem to be the final cause of failure, it is this author's belief that the history of our engines has included elements of this fault in more than just this one case.

There have been instances of burner atomizer (rear orifice plate) displacement, due to manufacturing errors, resulting in blocked or partially blocked burners. Apart from the recent series of GTCU failures, two failures in 1984 (both in H.M.S. *Newcastle*) were proved to be due to this defect. The burner cone becomes detached from the rear orifice plate in the burner atomizer pack (FIG. 2). An investigation into the cause revealed that there was no positive build check to ensure adequate clearance between atomizer components following lapping on assembly. The resulting interference was sufficient to cause stress corrosion and fracture of the rear orifice plate and displacement of the atomizer cone. It was also found that parts on the extreme of tolerance would interfere. This problem has now been understood by overhaul facilities and the introduction of a 'rock test', to prevent overstressing of orifice plates, has been introduced. A programme of burner change on a gradual basis has been set up by C-in-C Fleet.

Blockage of nozzle guide vane segments was in fact observed on two of the engines which suffered HP turbine blade failures in 1985. In both cases, the HP turbine nozzle blockage was caused by pieces of second splash cooling ring released from the Phase I combustion chambers.

The present design features splash cooling rings riveted to the combustion chamber barrel with the ends of the ring welded to the barrel wall. FIG. 3 shows the details of the combustion chamber splash cooling ring arrangements. Although recognized as 'old technology', there is no reason why the present Phase I chambers cannot stay the full course of 2000 service hours without coming apart, provided the can is made to drawing.

Failures of the splash cooling rings originate due to cracking of the welds retaining the ring ends, followed by flapping of the ring ends within the gas stream. Rivets may fail at this stage and pieces of ring can tear off and become lodged on the nozzle guide vanes. Although turbine damage caused by impact can occur, this is of relatively minor consideration compared to the excitation of HP turbine blades, caused by pressure fluctuations as the disc rotates, leading to eventual blade fatigue failure. The first failure of this type occurred at relatively high combustion chamber hours (1893 hours, of a release life of 2000 hours) and so there was no reason to suspect anything untoward. However a subsequent failure at 711 hours later in the year precipitated a keener interest in this type of failure. Although Rolls-Royce advise a release life of 1500 hours, experience by the Royal Navy has enabled a 2000 hour life to be reasonably expected and this is the adopted R.N. standard.

Owing to MOD concern a programme of checks was instigated on combustion chambers from the Fleet and on spares from Llangennech. The vast majority of cans held as spares (over 200) were rejected outright for totally inadequate second splash cooling ring securing welds and indeed the worst sample had not been welded at all! The difficult task of insepcting cans in service by flexible endoscope was also undertaken by the C-in-C Fleet COGOG team and a priority listing for can replacement drawn up.

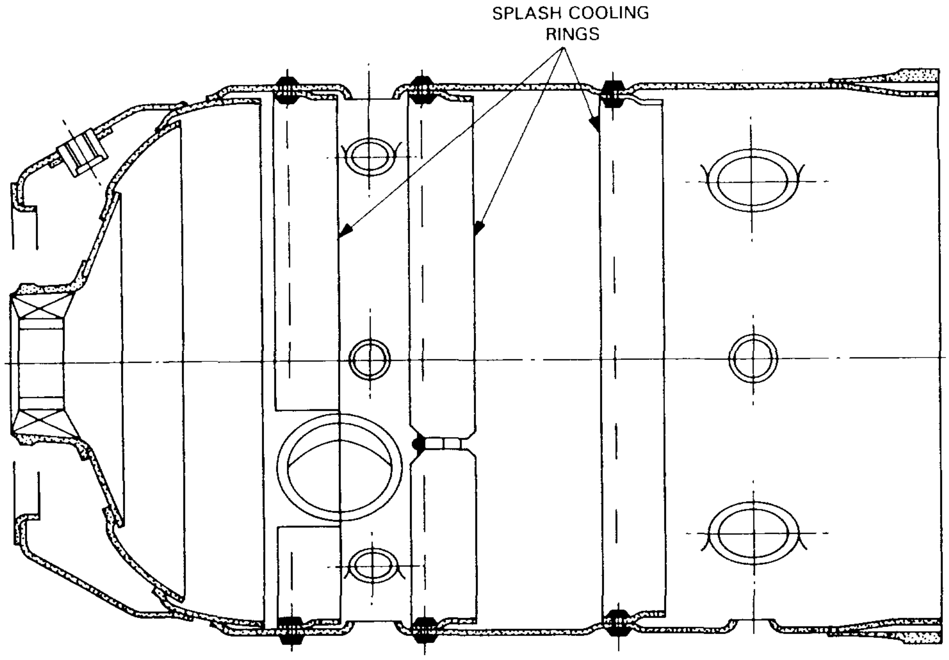

FIG. 3—PHASE I COMBUSTION CHAMBER: CROSS-SECTION AND INSIDE VIEW

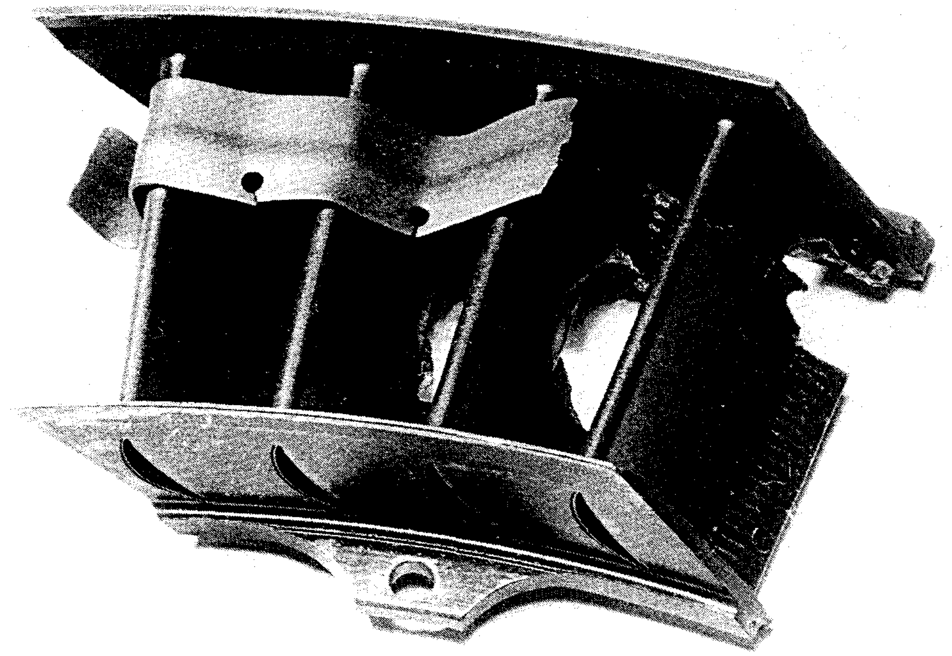

FIG. 4—PORTION OF SPLASH COOLING RING FROM COMBUSTION CHAMBER, ON HP NOZZLE GUIDE VANES IN THE POSITION WHERE MARKS INDICATED IT HAD BEEN LYING

Although convinced that, provided combustion chambers are produced to drawing, then no problems should occur during release life, it was felt prudent to introduce a modification which would provide a 'belt and braces' solution. The result was simplicity itself, namely two extra rivets at the ring ends together with extended end welds. The rework of existing cans (over 800 in service and over 500 in repair loop and spares) is a major logistic problem and will not be concluded for many mouths. The immediate requirements have been met and the rework programme should provide replacement cans to meet all future MOD requirements. It is also ironical to note that the earlier multiflame standard of combustion chambers was replaced by the current Phase I standard partly due to can flare detachment and HP nozzle guide vane blockage!

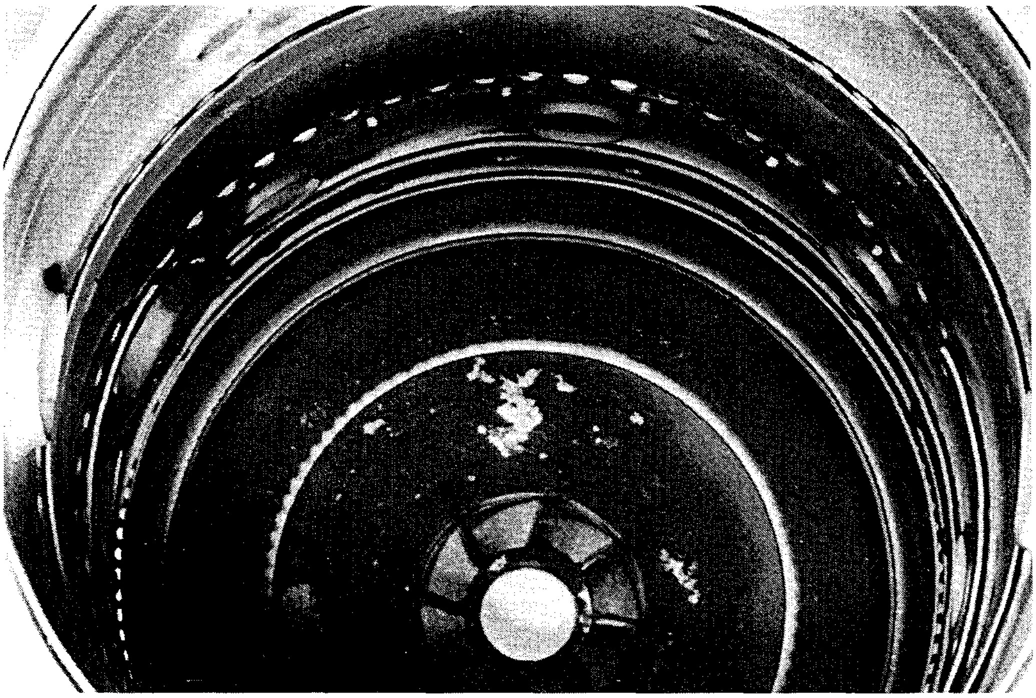

FIG. 5—INSIDE OF COMBUSTION CHAMBER, SHOWING REMAINS OF RIVETS WHERE THE 2ND SPLASH COOLING RING HAS BECOME DETACHED

Solutions to the Problem

Basically the lines of attack being pursued are as follows:

(*a*) Design out the vibrational sensitivity of the HP turbine blade and thereby harden the engine to combustion and gas stream defects.

(*b*) Improve detection methods for combustion defects.

(*c*) Improve quality assurance at manufacturer's works and overhaul facilities.

(*d*) Minimize damage if an HP turbine blade does fail.

The first item has been addressed and has culminated in modification OLG188. This introduces an interlocked shroud and cast inconel blade. Its vibration characteristic has been included in FIG. 1 as a dotted line. The interlocked shroud effectively damps out the 1st flexural mode of vibration and the decreased mass results of course in reduced vibration force. Marine experience of this standard of blade has been rather limited but it is intended that as soon as the new blades become available they will be fitted to all engines during overhaul.

Improvement of detection methods has been focused on the development of a method for automatically measuring the temperature spread variation of the gas stream entering the power turbine. This is known as PTET spread monitoring. Although the ideal spot for measurement is in fact the HP turbine nozzle guide vane entry duct, no thermocouples can survive at this spot. However, development trials of PTET spread monitoring have shown that adequate sensitivity exists at the PTET thermocouples to diagnose combustion defects and relate them to their source. At present R.N. ships are equipped with manual measuring equipment but an automatic method has been developed and so far proven successful in a limited trial at sea in a CVS. It is intended that all ships be equipped with automatic spread monitoring as a matter of urgency and furthermore, even with the fitting of OLG188, the automatic spread monitor will still be useful in diagnosing combustion problems from the point of view of engine and component efficiency.

The development of a vibration trip similar to that fitted in industrial Olympus applications is being pursued. It is the author's belief that the existing rules whereby an operator reduces to low power if high vibration levels are experienced are inadequate in the prevention of secondary damage. A vibration trip, equipped if necessary with a 'battle short switch' would seem a sensible measure. The loss of a GTCU is bad enough but the increased lack of ship availability caused by a power turbine change is obviously worse.

Other Observations

I have attempted in this paper to present the main failure modes and characteristics together with the solutions being pursued. During 1985 debates have taken place with regard to engine usage patterns and the reasons why we should suddenly be hit with such a high failure rate at this time. These debates have however been inconclusive, and are likely to remain so.

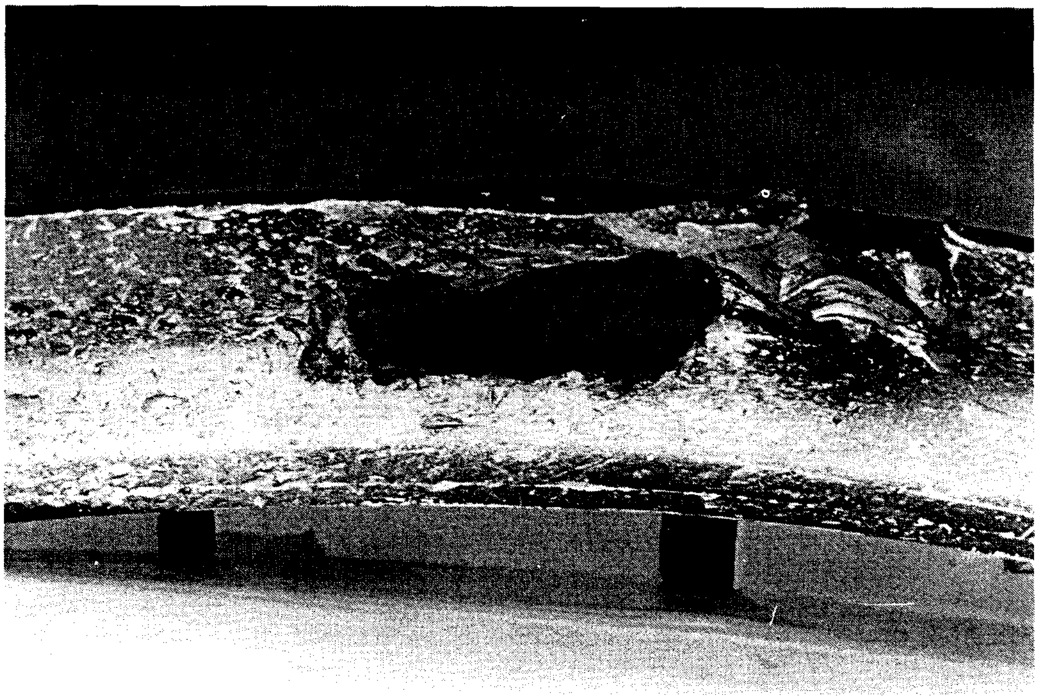

FIG. 6—PUNCTURED HP TURBINE CASING

The series of photographs (Figs. 4 to 10) show the cause and effect of an HP turbine blade failure. In this case (H.M.S. *Boxer* engine no. 2017158 at 711 hours) the failure was caused by a detached segment of combustion chamber splash cooling ring lodged against the HPNGVs and subsequent fatigue failure of one HP turbine blade.

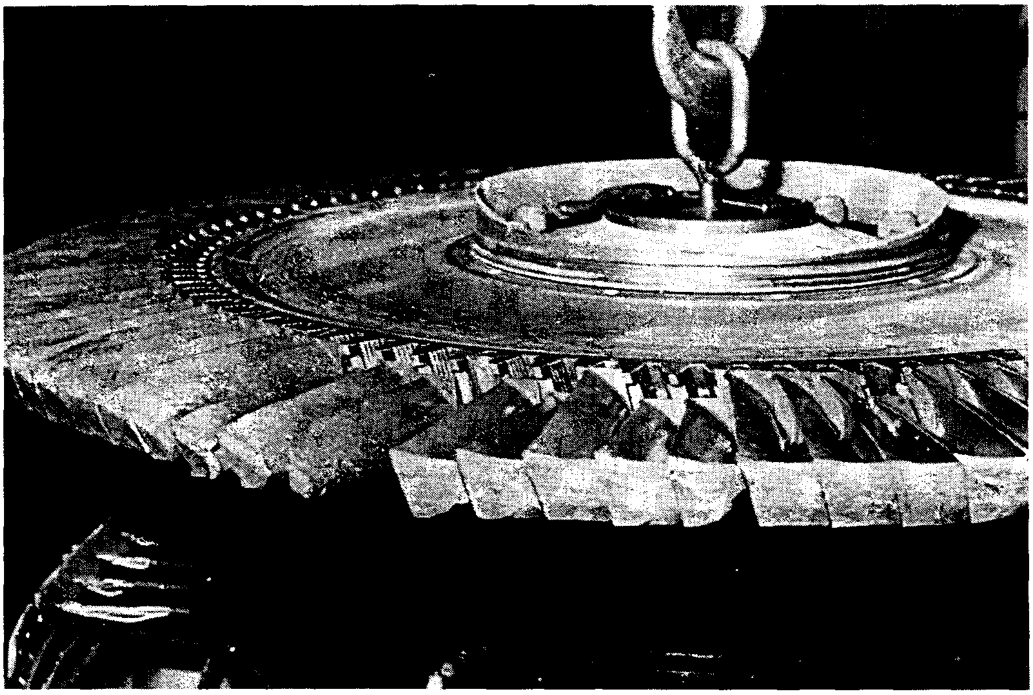

Fig. 7—Damaged HP nozzle guide vanes

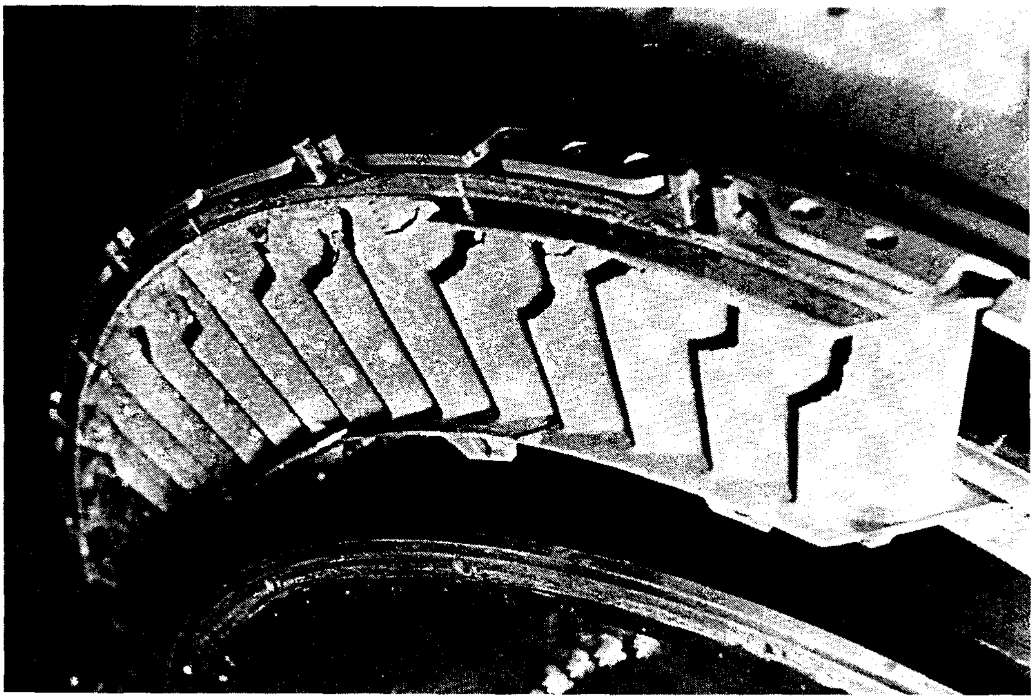

Fig. 8—HP turbine disc blade assembly, with failed root in position

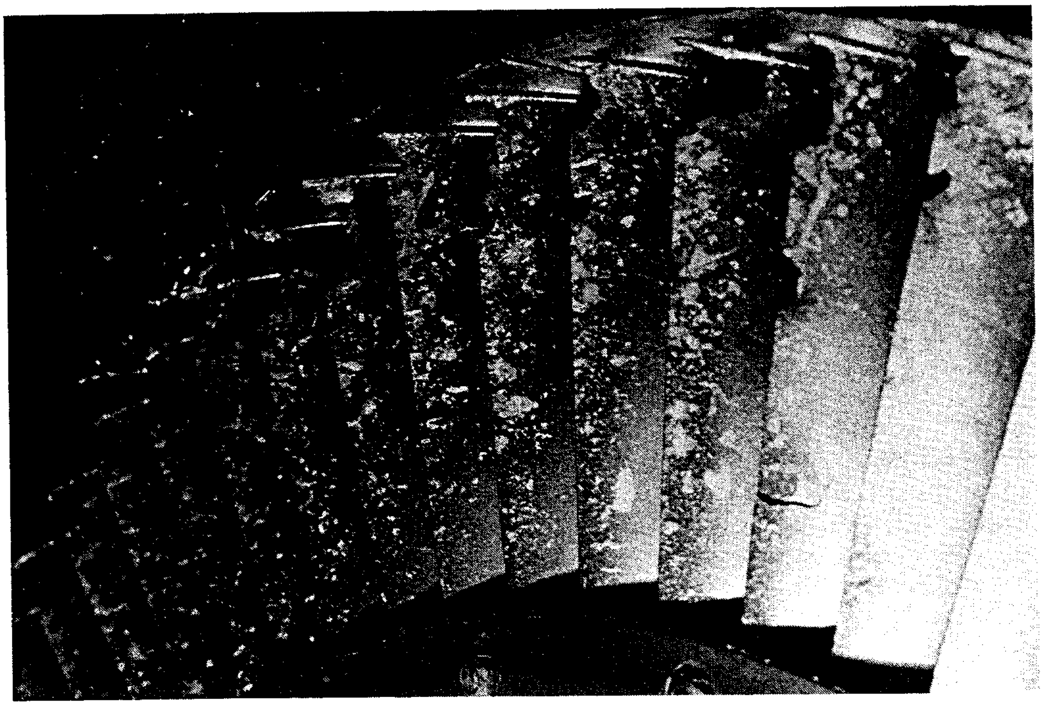

FIG. 9—DAMAGED LP NOZZLE GUIDE VANES

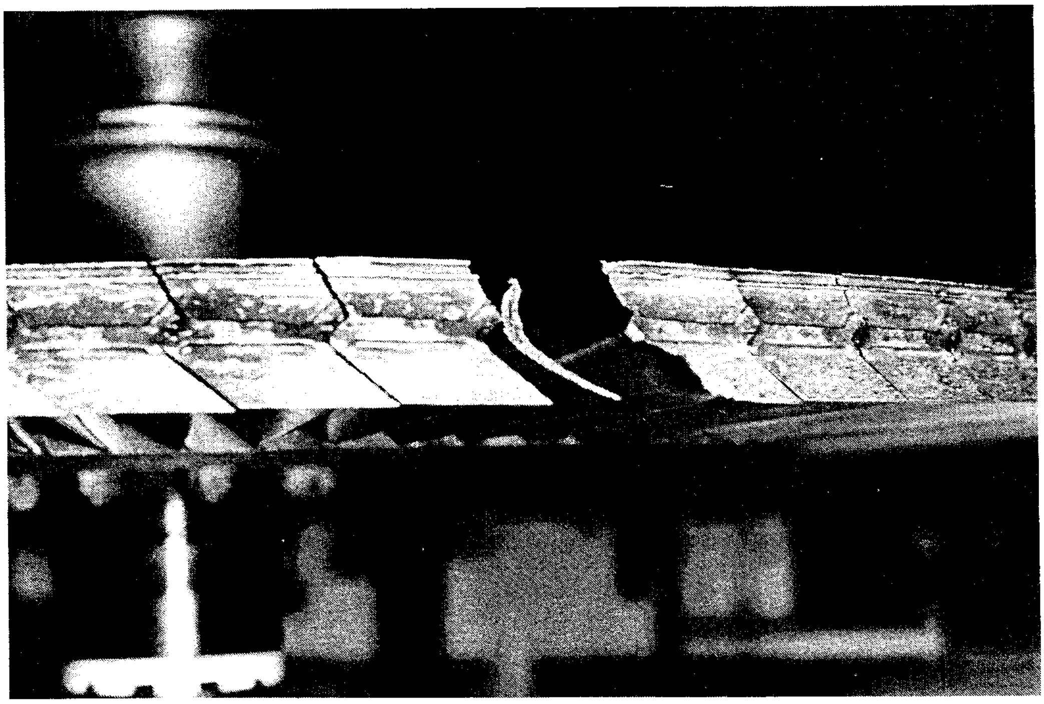

FIG. 10—LP TURBINE BLADE WITH OUTER PLATFORM MISSING