SM1A MARINE GAS TURBINE EVALUATION AT PYESTOCK

BY

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ABSTRACT

The 3000 hours type test of the Spey SM1A marine gas turbine highlighted design shortcomings in the combustion system which have led to a series of early engine rejections in service. A subsequent 2000 hours endurance trial of the manufacturer's revised design has been completed at the Admiralty Test House, RAE Pyestock. This trial has shown that the major problem of carbon-induced erosion of turbine blading has been overcome. The extended length of this trial has also provided an ideal vehicle for a series of minor trials of engine components and evaluation of a variety of Engine Health Monitoring techniques.

Introduction

The Admiralty Test House (ATH), at the Royal Aerospace Establishment Pyestock (formerly the National Gas Turbine Establishment), was commissioned in 1952 and has provided a test bed for developing and evaluating marine propulsion and power generation gas turbines. Types of engine tested include the Gatric No. 38, Allens gas turbine alternator, G6, Proteus, Tyne, Olympus and now Spey[1].

Since April 1984 the ATH has been involved with type testing the Rolls-Royce Spey SM1A gas turbine change unit (GTCU) and module (FIG.1) rated at 12.75 MW, to assess its suitability as a main propulsion unit for R.N. warships. A 3000 hours endurance trial was carried out on GTCU 1903-003 between 24 April 1984 and 4 December 1985[2], and highlighted two major areas of weakness in the GTCU, which were:

(*a*) the combustion system;

(*b*) hot end corrosion and erosion.

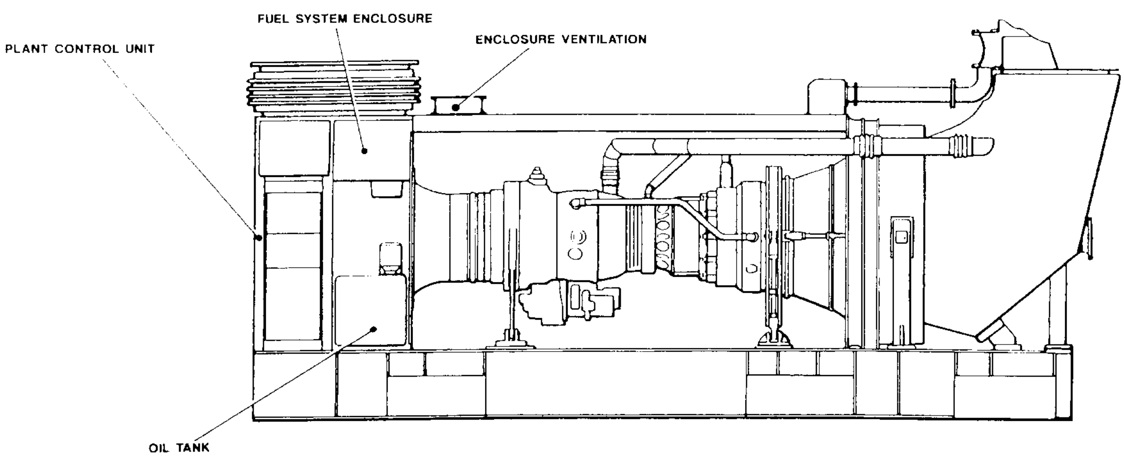

FIG. 1—SPEY SM1A GAS TURBINE CHANGE UNIT AND MODULE

Both the corrosion of the combustors (the Standard Reflex Airspray Burner (RAB) combustors were renewed after 1358 running hours) and the subsequent corrosion/erosion of the HP1 Nozzle Guide Vanes (NGV1) and the HP1 Turbine Rotor Blades (TRB1) were directly attributed to the unsatisfactory combustion characteristics of the Standard RAB. Therefore this area of the combustion system needed further improvement. The damage to the NGV1 and the leading edge and pressure face of the TRB1 necessitated the GTCU being removed at the 2440 hours point to have a number of the TRB1 blades replaced.

Following a redesign of the combustion system by Rolls-Royce it was decided to carry out a further 2000 hours Life Extension Trial on GTCU 1903-003 during the period June 1988 to August 1989. The primary objective of this trial was the evaluation of the new Improved RAB Combustion system (IRAB) (FIG. 2) in order to confirm the new combustors' integrity and ability to eliminate 'hot end' erosion. A secondary objective was also added: to evaluate and rank various protective coatings applied to the NGV1s and the TRB1s. In addition, the long-term life expectancy of various GTCU components could be evaluated, as 1903-003 would achieve 5000 total running hours on test.

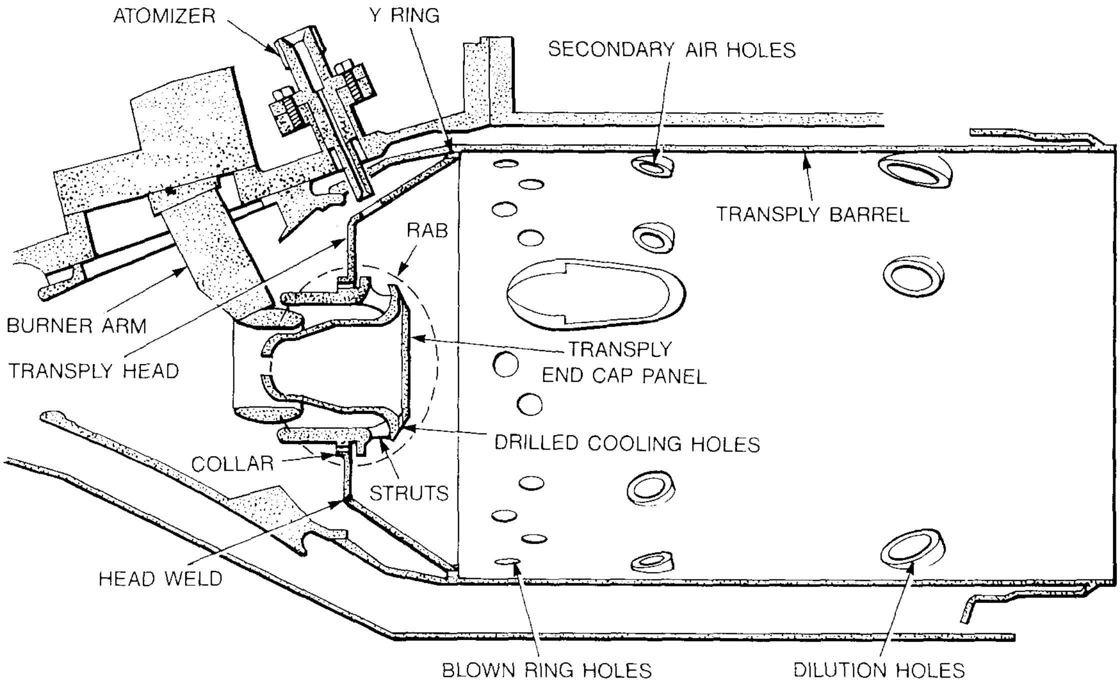

FIG. 2—IMPROVED REFLEX AIRSPRAY BURNER COMBUSTOR (IRAB)

The Combustion System Trial

For the purpose of this trial, the GTCU was supplied with combustors made from Nimonic 86 Transply material (FIG. 3). These were a set of nine new IRAB combustors together with one IRAB combustor (fitted in position 3) that had already been used for cyclic testing with salt water in the airflow. The GTCU was then run to a predetermined schedule for 200 hours before the combustors were removed for examination and detailed inspection by Rolls-Royce and RAE Pyestock Combustion Section personnel. At this point the nine combustors, excluding No. 3, were subject to some minor reworking to reposition the RAB end cap and body before being reinstalled in the GTCU. The trial then progressed as before up to the 650 hours point where a partial strip to examine combustors Nos. 7, 8, 9 & 10 was carried out. Throughout the trial the GTCU and specifically the combustors were examined by endoscope at weekly (approximately 100 running hours) intervals, using a novel video endoscopy technique. These inspections were recorded on video-tape and have proved invaluable in discussions between RAE, DGME and Rolls-Royce. During the trial salt water spray was introduced into the air intake from 561 hours onwards to simulate the marine aerosol. The maximum amount used was 0.01 ppm of sodium chloride in air.

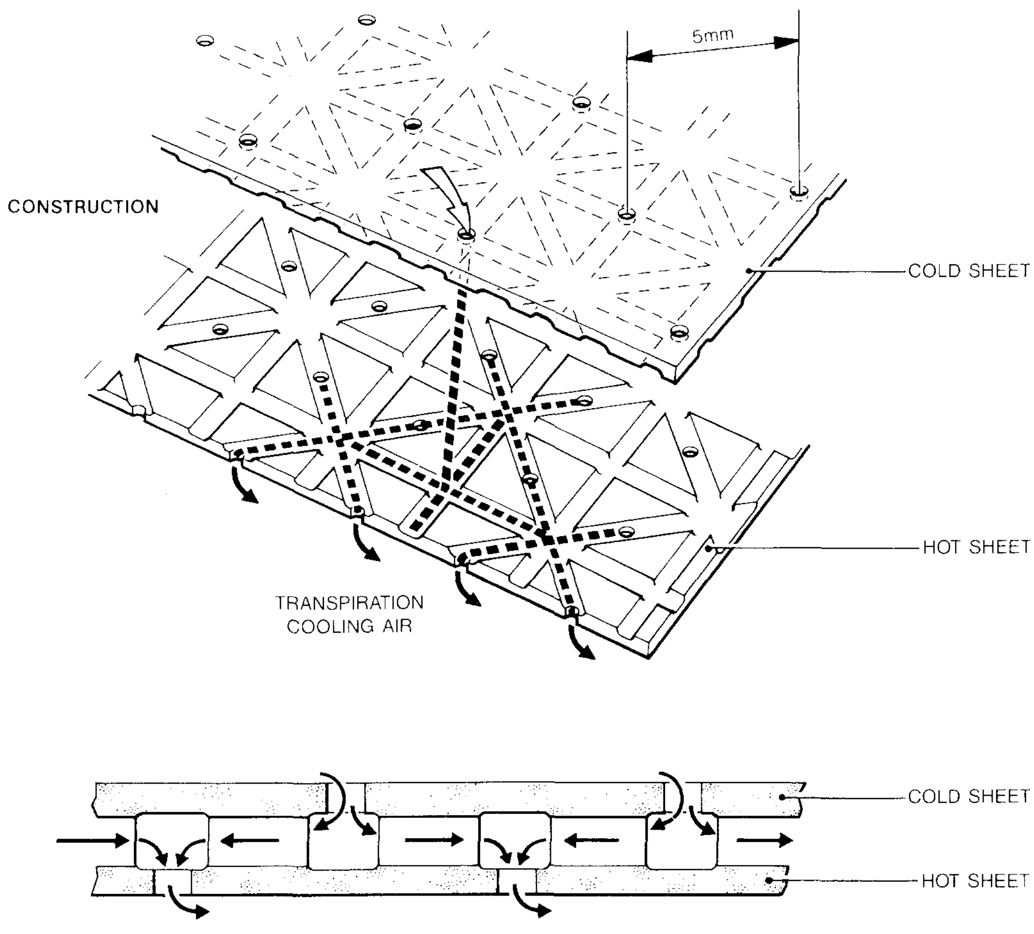

FIG. 3—NIMONIC 86 TRANSPLY SHEET MATERIAL

At the 712 hours point, as a result of the weekly endoscope inspection, concern arose over the integrity of the weld on one of the four RAB end cap support struts in combustor No. 8. It appeared to be cracked down both sides of the weld. The trial was halted, and the combustor removed and dispatched to Rolls-Royce at Ansty for investigation, comment and recommendations. Rolls-Royce concluded that the cracks presented no threat to the integrity of the combustor or the remainder of the trial, so the GTCU was rebuilt and the trial continued.

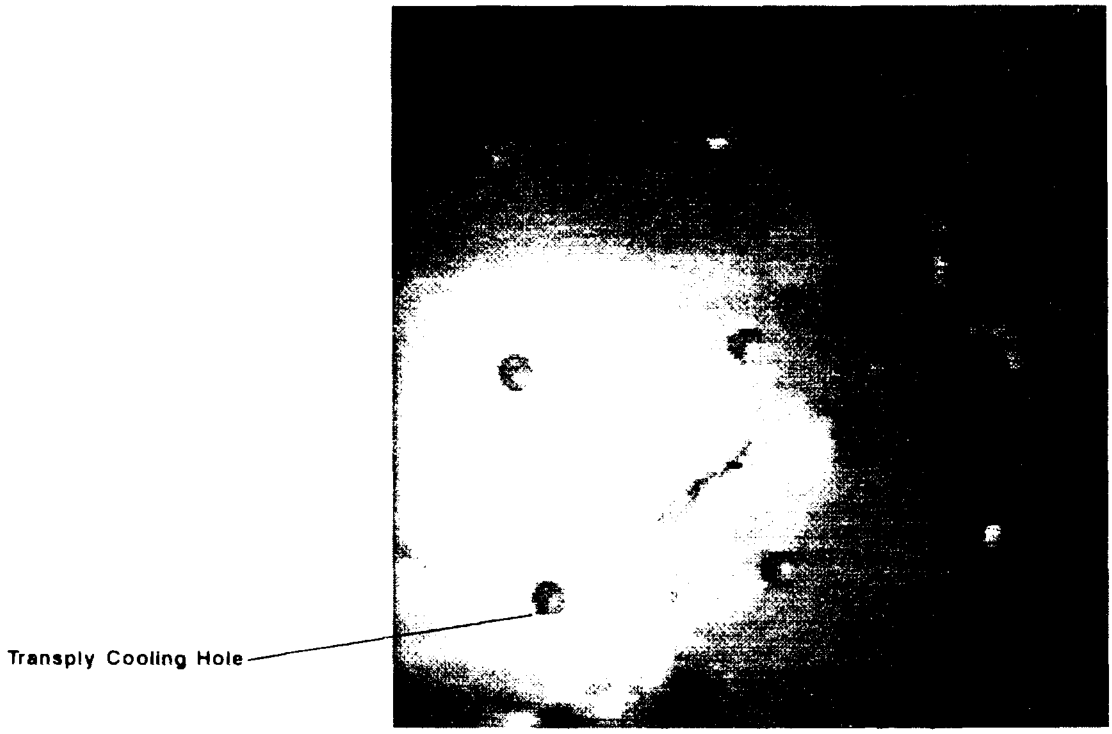

FIG. 4—COMBUSTOR NO.7 RAB END CAP AT 930 HOURS: COLD SIDE (A COMPUTER GRAPHICS PICTURE FROM A VIDEO ENDOSCOPE VIEW). THERE IS SOME SLIGHT MATERIAL DEFORMATION

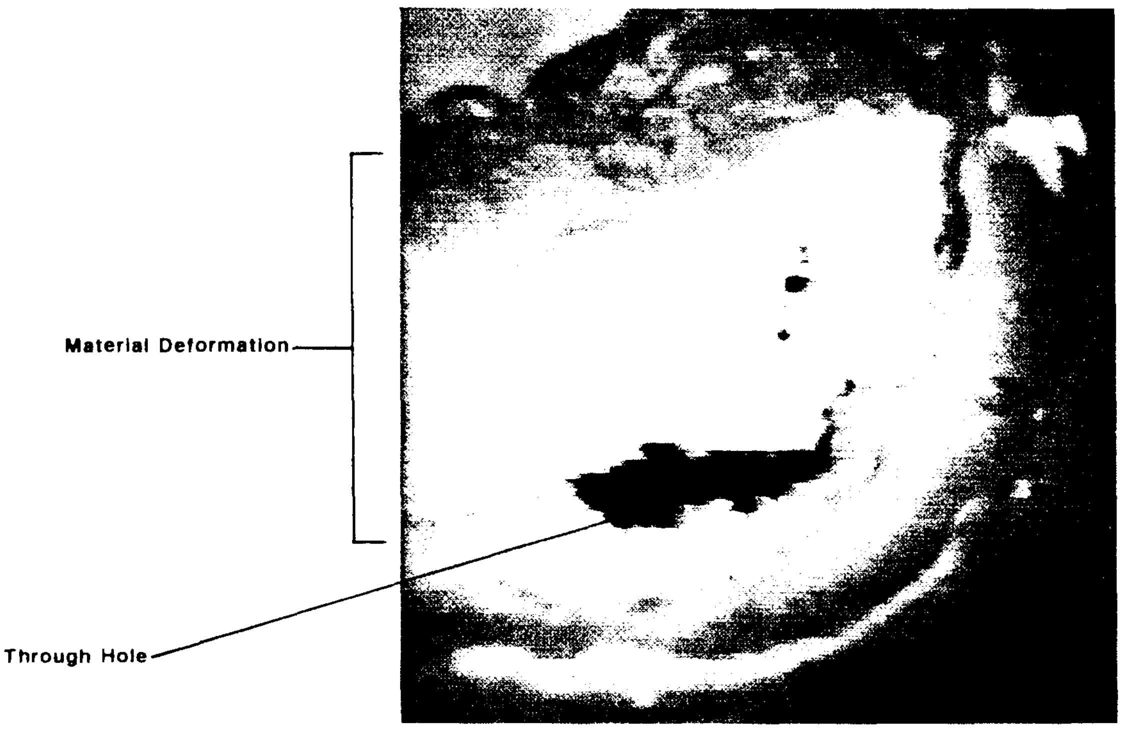

FIG. 5—CORROSION OF NO.7 RAB END CAP AT 960 HOURS: COLD SIDE. NOTE INCREASED MATERIAL DEFORMATION AND THROUGH HOLE

FIG. 6—CORROSION OF NO.7 RAB END CAP AT 960 HOURS: HOT SIDE. NOTE LOSS OF HOT LAYER SURFACE (MID GREY AREA) AND THROUGH HOLE

At the weekly inspection (924 hours), No. 7 combustor RAB end cap began to show signs of distress and metal distortion on both the 'hot' and 'cold' faces. After discussions with DGME and Rolls-Royce, the trial progressed with an agreement for ATH staff to repeat the inspection within another 50 running hours (approximately two days). This repeat inspection was duly done at 963 hours and the RAB end cap was found to be perforated. FIGS. 4, 5 and 6 compare appearance before and after perforation. (These pictures are computer graphic stills from the video endoscope inspection; some quality has necessarily been lost in reproduction.) The decision was taken to carry on with the trial until 1000 hours were completed. As an extra precaution the power turbine entry temperatures (T6) were monitored continuously by the watchkeeping personnel, but no significant changes were observed.

Enhancement at 1000 Hours

Once 1000 hours had been achieved, the combustors were again removed from the GTCU and subjected to detailed inspection and examination. Considerable carburization and sulphidation had taken place in the combustors and the characteristic 'green rot' corrosion was plainly visible in all the combustors, the cooling ring in No. 3 combustor having been particularly severely attacked. At this point the opportunity was taken to examine the NGV1s in some detail and they were found to be in a comparatively good condition. On completion of the examination, a design review meeting took place at Rolls-Royce, Ansty, resulting in a proposal to enhance some of the IRAB combustors into Enhanced RAB (ERAB) combustors (FIG. 7).

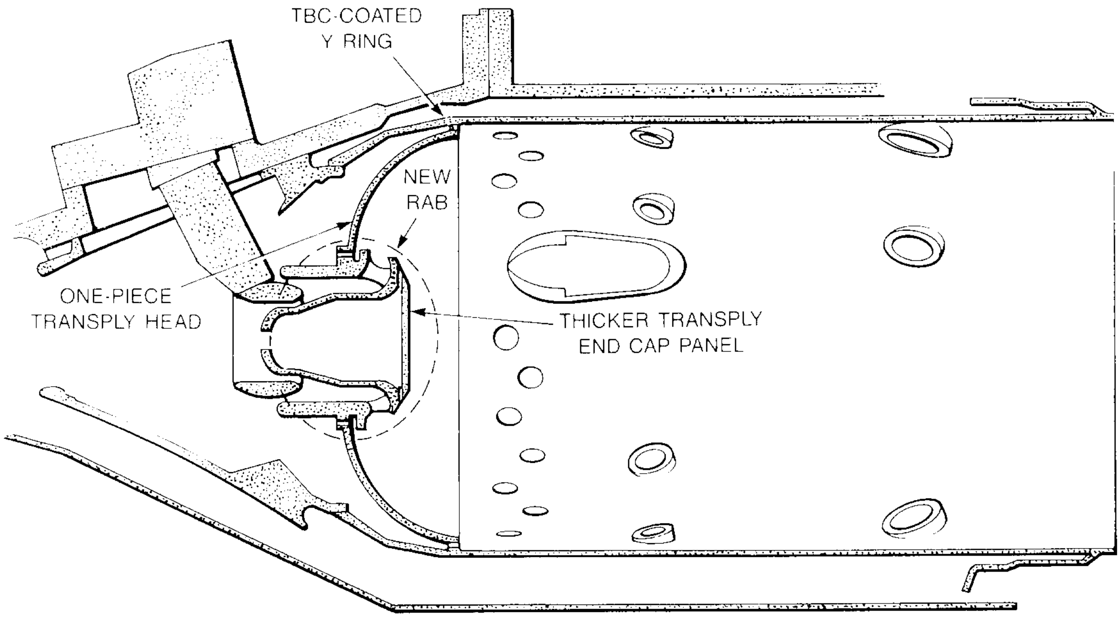

FIG. 7—ENHANCED REFLEX AIRSPRAY BURNER (ERAB)

The enhancements were:

(*a*) To use a single piece pressed flare combustor head instead of the welded two-piece head.

(*b*) To coat the whole of the interior of the combustor with Thermal Barrier Coating (TBC).

(*c*) To use '1-2/5 Thick/Thin' Nimonic 86 transply in the RAB end cap, thus increasing the flow of cooling air to the cold face of the RAB end cap.

(*d*) To increase the cooling air flow in the vicinity of the Y ring.

The final outcome of the design review exercise was that combustors 1, 2, 7 & 10 were fully enhanced, combustors 3, 4, 5 & 8 RAB bodies and end caps were replaced with existing design Nimonic 86 Transply material, and combustors 6 & 9 were left unaltered as a datum (TABLE I).

The remaining 1000 hours of the trial was then used to evaluate the effectiveness of the enhancements in comparison with the unaltered combustors. The second 1000 hours was to be a direct repeat of the first, using the same schedules, endoscope inspection intervals and strip inspections, with salt water spray not being reintroduced into the air intake until a further 561 hours had been completed.

This 'Rainbow' set of IRAB combustors was then run until the 1200 hours strip and inspection when, due to the worsening condition of Nos. 3, 4, 5, 6, 8 & 9, it was decided that an additional strip and inspection should be carried out at the 1450 hours point. No. 3 combustor was the worst, but it must be emphasized that it had seen earlier usage and had experienced salt water injection prior to fitting in 1903-003.

At the 1450 hours strip inspection, further evidence of severe green rot corrosion was recorded and the holing of some of the RAB heads was becoming more pronounced. As the overall deterioration of the combustors appeared to have slowed down somewhat, the complete set was reinstalled and the trial progressed. No. 3's condition was approaching a critical state, but as it had not reached the manufacturer's criteria for replacement it was decided to retain it in the trial.

TABLE I—*Status of the combustor set at 1000 hours—number of hours run for each component*

Combustor			*RAB*	
No.	*Barrel*	*Head*	*Body*	*Endcap*
1	1000[a]	new[b]	1000[a]	new[c]
2	1000[a]	new[b]	1000[a]	new[c]
3	1000[a]*	1000[a]*	new[d]	new[e]
4	1000[a]	1000[a]	new[d]	new[e]
5	1000[a]	1000[a]	new[d]	new[e]
6	1000[a]	1000[a]	1000[a]	1000[a]
7	1000[a]	new[b]	1000[a]	new[c]
8	1000[a]	1000[a]	new[d]	new[e]
9	1000[a]	1000[a]	1000[a]	1000[a]
10	1000[a]	new[b]	1000[a]	new[c]

a Component from first 1000 hours of trial.
b ERAB combustor, with new single piece head, increased cooling flow, full coverage thermal barrier coat.
c 'Thick/thin' transply with increased cooling flow (new design)
d New body, original design.
e 'Thin/thin' transply (existing design).
* Plus a previous 20 hours which included 1000 cycles from idle to full power.

Effect of the Corrosion on Performance

It should be noted that up until this point in the trial, the running performance of the GTCU had not been affected by the degradation and holing of the combustor heads. The transient response of spool speeds and T6s to a normal start cycle is shown in FIGS. 8 and 9. However, at approximately 1600 hours the starting characteristics began to be affected by the significant through-holing in the primary zone of No. 3 combustor head. The effect was that the flame in combustor No. 3 was blown out during the start, and did not relight for about 5 seconds. This is shown in FIGS. 10 and 11. This not only extended the time to achieve idle but, more significantly, increased the average value of T6 steadily. The GTCU control system has a T6 trip which terminates the start if the average T6 temperature exceeds 500°C. By this point in the trial the average T6 had risen by some 40°C and was within 1° of the trip level. Hence it can be seen that the limiting factor on combustor life may be its effect on GTCU starting temperature rather than structural integrity.

The condition of No. 3 combustor at the 1650 hours strip inspection was such that it had exceeded the criteria for removal and was replaced by a spare IRAB held at RAE Pyestock.

For the last two hundred hours of the trial, endoscope inspections were carried out at approximately 60 hourly intervals in order to monitor the steady deterioration of the remaining combustors as Nos. 4, 5, 6 & 8 were approaching the condition of the replaced No. 3.

During the routine endoscope inspection carried out at 1845 hours, evidence of the beginning of corrosion could be seen on the 'cold face' of No. 7 RAB end cap. The 'hot face' was very badly corroded in the vicinity of the weld and the majority of the hot layer of transply was suffering severe corrosion. Combustor No. 6 was by now the worst of the set when judged on overall condition.

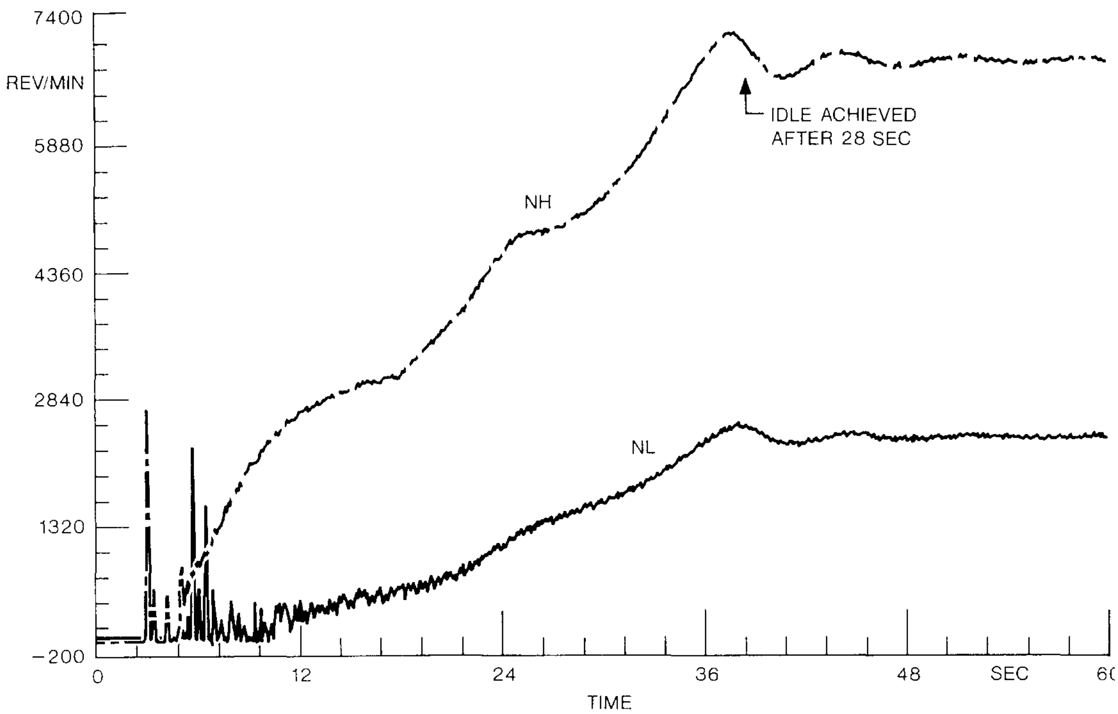

FIG. 8—HP AND LP SPOOL SPEEDS (NH AND NL) DURING START SEQUENCE AFTER 1361 COMBUSTOR HOURS—A GOOD START

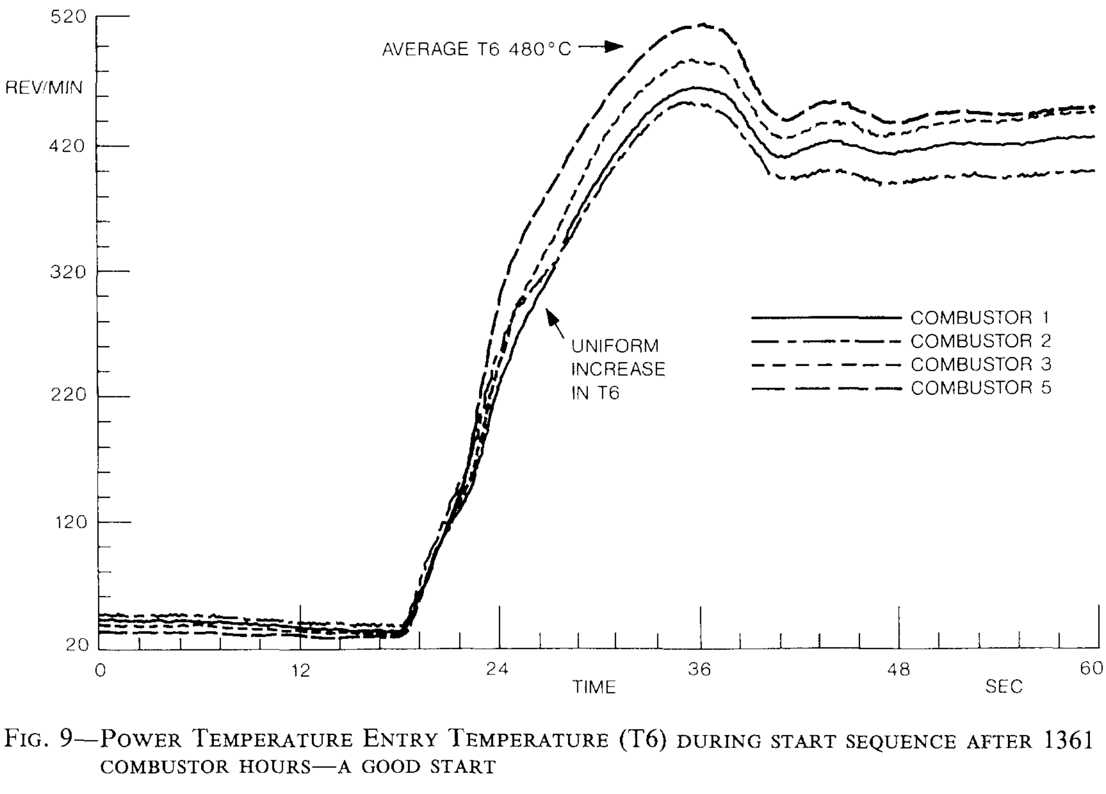

FIG. 9—POWER TEMPERATURE ENTRY TEMPERATURE (T6) DURING START SEQUENCE AFTER 1361 COMBUSTOR HOURS—A GOOD START

The endoscope inspection at 1909 hours revealed little change in the condition of the combustors except that the green rot corrosion was progressing steadily and many of the holes in the combustor heads were becoming more defined.

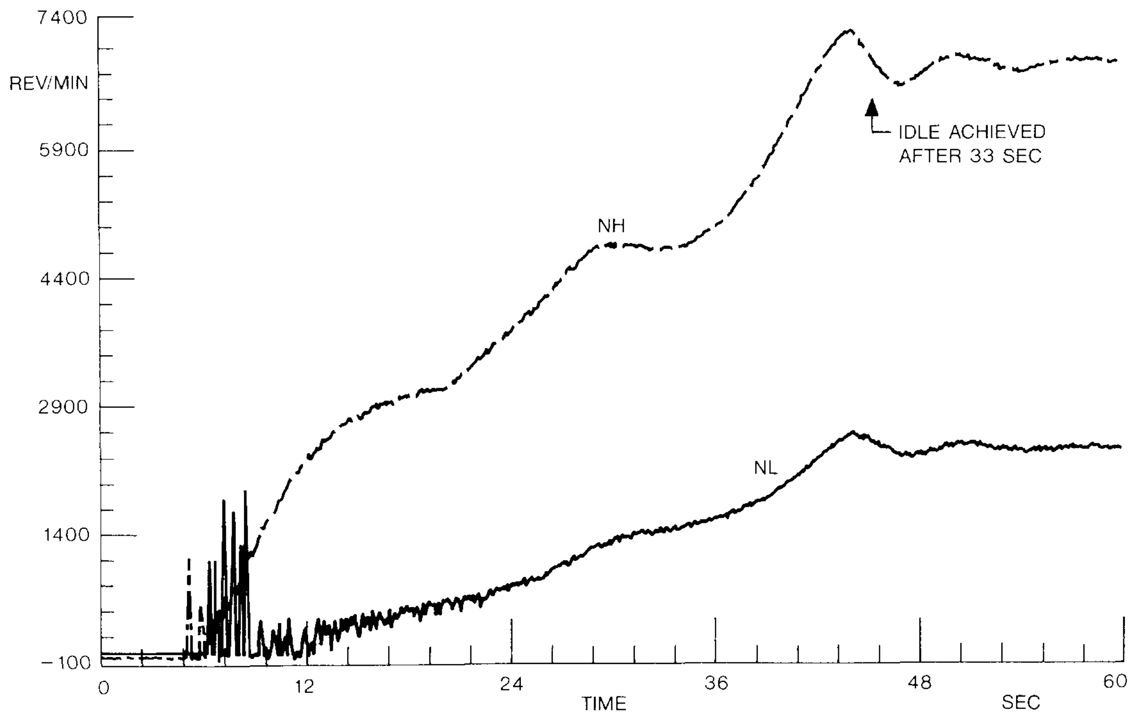

FIG. 10—HP AND LP SPOOL SPEEDS DURING START SEQUENCE AFTER 1625 COMBUSTOR HOURS—A POOR START

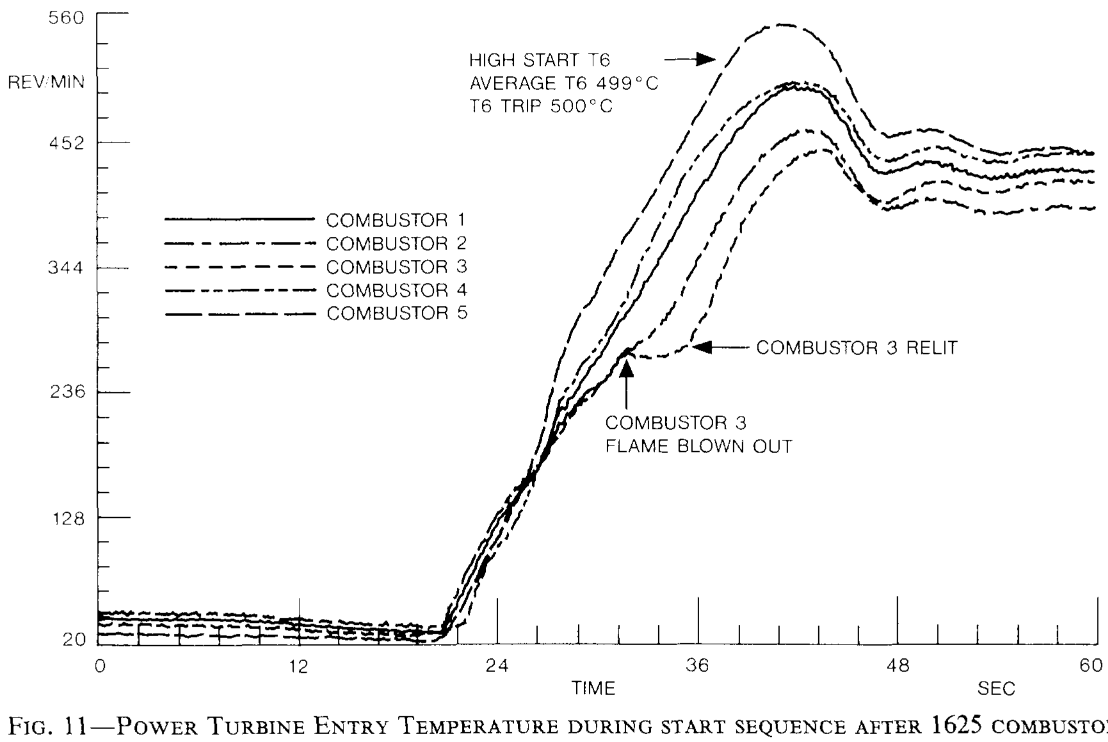

FIG. 11—POWER TURBINE ENTRY TEMPERATURE DURING START SEQUENCE AFTER 1625 COMBUSTOR HOURS—A POOR START

At the 1970 hours inspection No. 7 RAB end cap was viewed from both faces and was found to be holed in two places. The weld on the end cap 'penny piece' was cracked over 50% of its length, the 'hot layer' of end cap transply was corroded over 75% and rampant corrosion of the end cap was evident. There was little evidence to show that the poor condition of this RAB end cap had any detrimental effect to the running of the GTCU. It is however a known fact that a combustor with an open ended RAB will generate more carbon during combustion.

The trial was progressed and the 2000 hours target achieved ahead of schedule. The final strip and detailed examination of the combustors was carried out at RAE Pyestock before their return to Ansty. At the same time, the GTCU was subjected to an extensive endoscope examination. A summary of the status of the combustor set is in TABLE II.

TABLE II—*Status of the combustor set at 2000 hours—number of hours run for each component*

Combustor			*RAB*	
No.	*Barrel*	*Head*	*Body*	*Endcap*
1	2000[a]	1000[b]	2000[a]	1000[c]
2	2000[a]	1000[b]	2000[a]	1000[c]
3	1650[a]*	1650[a]*	650[d]	650[c]
The above N°3 was withdrawn from trial at 1650 hrs. and replaced with:				
3	350[f]	350[f]	350[f]	350[f]
4	2000[a]	2000[a]	1000[d]	1000[e]
5	2000[a]	2000[a]	1000[d]	1000[e]
6	2000[a]	2000[a]	2000[a]	2000[a]
7	2000[a]	1000[b]	2000[a]	1000[c]
8	2000[a]	2000[a]	1000[d]	1000[e]
9	2000[a]	2000[a]	2000[a]	2000[a]
10	2000[a]	1000[b]	2000[a]	1000[c]

a Component from first 1000 hours of trial.
b ERAB combustor, with new single piece head, increased cooling flow, full coverage thermal barrier coat.
c 'Thick/thin' transply with increased cooling flow (new design).
d New body, original design.
e 'Thin/thin' transply (existing design).
f New IRAB combustor from production engine set.
* Plus a previous 20 hours which included 1000 cycles from idle to full power.

The Effect of Combustor Improvements on GTCU Life

Design improvements to the combustors appear to have reduced the level of carbon and smoke produced, particularly at part load, and extended the life of the GTCU, although whether the two-piece or pressed head design is better is open to discussion and may ultimately depend on cost or ease of manufacture.

Both the Improved RAB and the Enhanced RAB combustors appear to have eliminated 'hot end' erosion. The NGV1s and TRB1s are in a very good condition after 2000 running hours when compared with the original trial after 2440 hours. The overall good condition of the LP and HP compressors indicates that an expected life of 5000 hours for the major components of the engine is well within reach.

The degradation of the enhanced combustor No. 1 with engine use over 800 hours may be contrasted to that of the original IRAB version of the same combustor by comparing the conditions in FIGS. 12 and 13 with those in FIGS. 14 and 15. It can be seen that corrosion at the Y ring has become firmly established at the 1000 hours point in each case. The steady progress of this sulphidation corrosion to eventual penetration of both hot and cold layers of the transply, may be observed in FIGS. 16 to 19. This shows the IRAB head of combustor 8 (which was not enhanced to the single piece pressed head construction at 1000 hours) developing to a near critical state by 2000 hours.

The repeated failure of No. 7 RAB end cap on approximately the same time scale appears to be a coincidence, but it remains possible that some unidentified factors have increased the severity of operation associated with the position of No. 7 combustor.

The effective life of the combustors, when subjected to the relatively rigorous utilization of this trial, appeared to be in the order of 1500 hours. This may well extend, however, towards 2000 hours or more in service. A more realistic figure should become established following the proposed sea trials of the IRAB combustor.

It was not possible using endoscope techniques to rank the series of different turbine blade coating materials visually. Detailed metallurgical examination will be required to determine the relative effectiveness of these coatings, following the strip of the GTCU at Rolls-Royce, Ansty.

Minor Trials

The availability of an engine undergoing extended testing on a comprehensively instrumented installation, operated by an independent group which can respond rapidly and flexibly to a customer's requests, has allowed a number of problems affecting Fleet operation of the SM1A to be investigated effectively. In addition, several engine health monitoring techniques have been installed for assessment under a realistic operating environment. While detailed discussion of these techniques is beyond the scope of this paper, brief examples are given below.

Fleet problems investigated include: premature failures of the bleed valve bellows, which affect engine availability; erratic operation of the bleed valve, leading to surge; and the occurrence of rotating stall following rapid deceleration to idle. Staff are currently investigating the effect of engine type, installation and ship operating modes on specific fuel consumption.

Engine health monitoring techniques under investigation include:

(*a*) Electrostatic gas path debris monitors at inlet and exhaust, which indicate that the Spey is no more susceptible to foreign object damage than any other marine gas turbine.

(*b*) Advanced Vibration Analysis. This uses computer-based analysis of data from a necklace of accelerometers to diagnose vibration sources down to component level.

(*c*) On-line lubricant monitors to sample GTCU lub oil continuously for debris content. This technique provides a real time alternative to magnetic chip detection.

(*d*) Analysis of engine transient data using Very High Speed (VHS) computer scanning and plotting packages to detect changes in engine condition and performance. VHS plots have been instrumental in the diagnosis of a number of engine defects throughout the trial.

Conclusions

The revised design of the SM1A combustion system was comprehensively evaluated in the Admiralty Test House during the 2000 hours Life Extension Trial. The primary objective of the combustor improvement package has been achieved: both the Improved RAB and Enhanced RAB combustors produced a significantly lower amount of carbon than the Standard RAB units presently in service. This has resulted in a marked increase in the life expectancy of the turbine blading and therefore the GTCU as a whole.

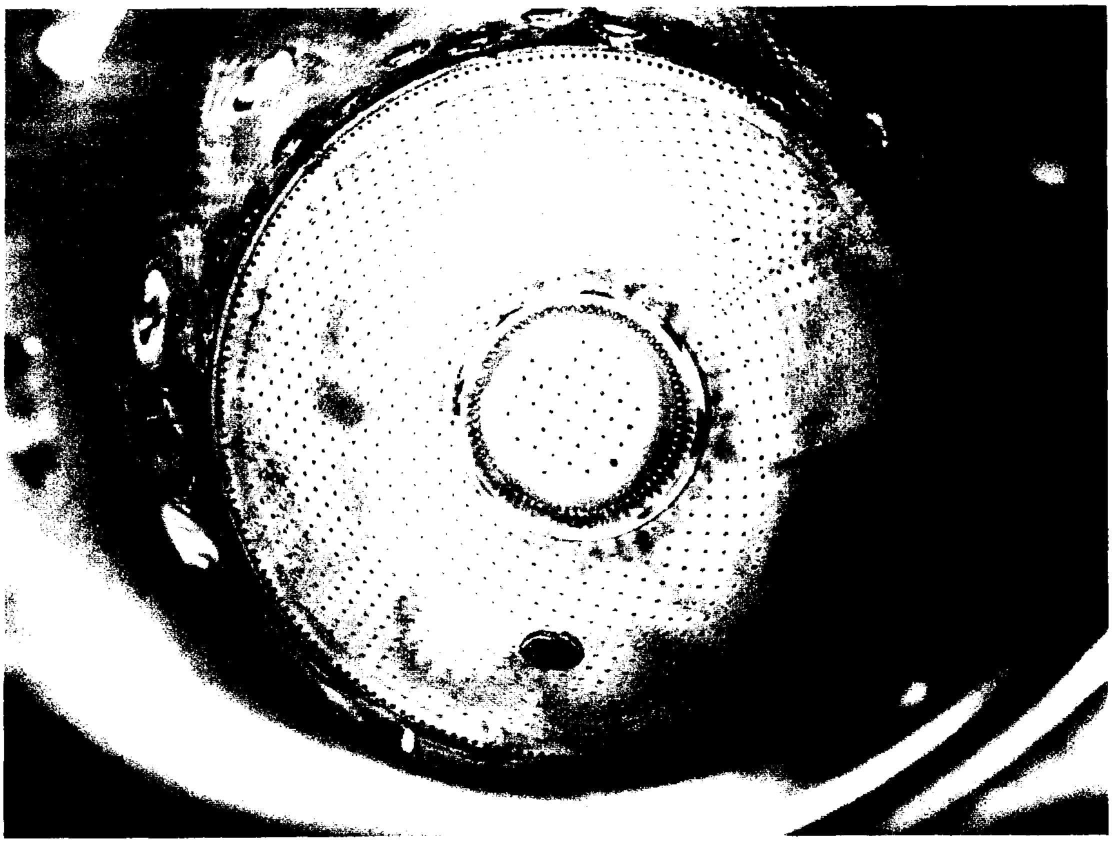

Fig. 12—Combustor No.1 at 1200 hours (1000 hours as IRAB, 200 hours as ERAB)

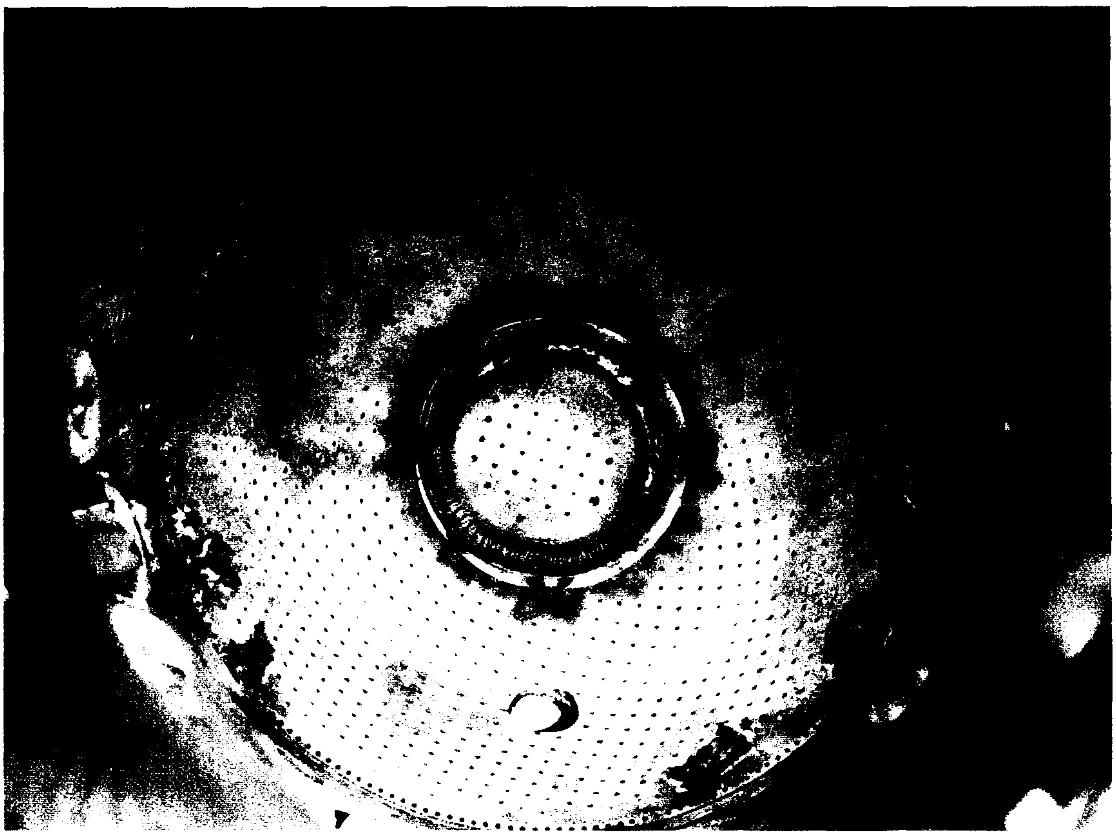

Fig. 13—Combustor No.1 at 2000 hours (1000 hours as IRAB, 1000 hours as ERAB)

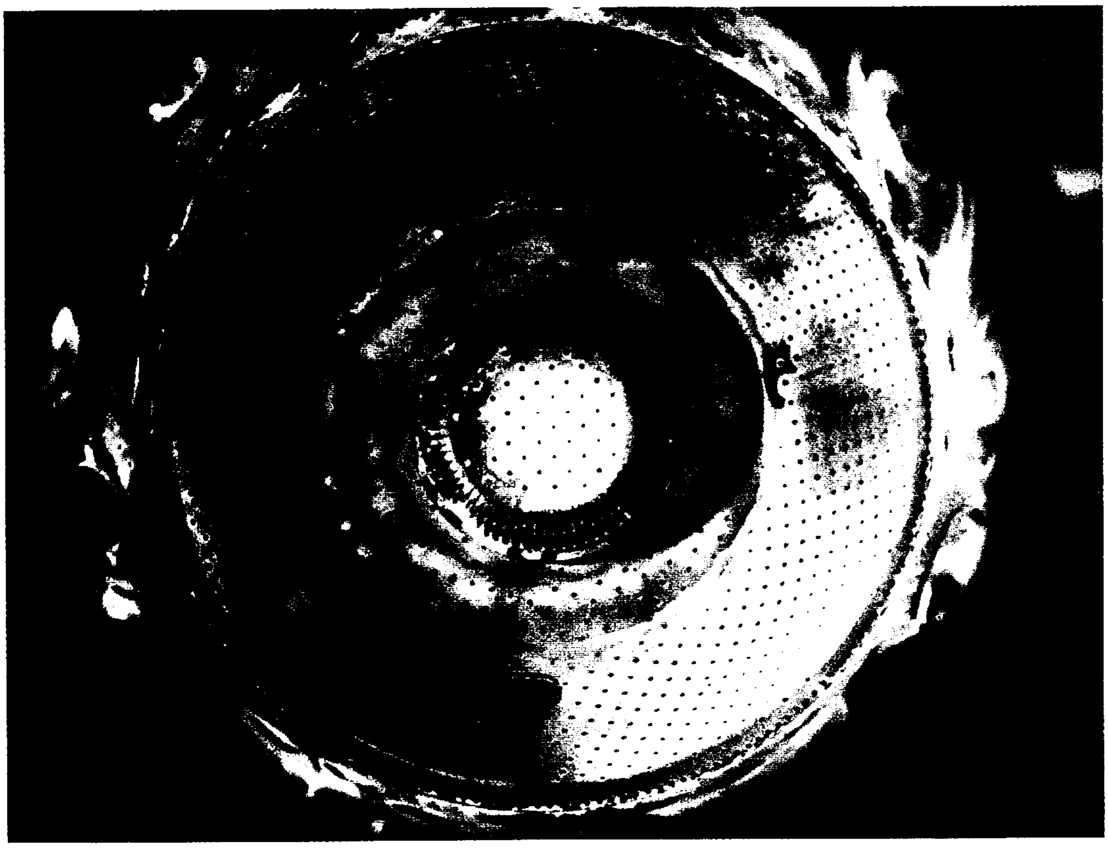

FIG. 14—COMBUSTOR NO.1 AT 200 HOURS (IRAB)

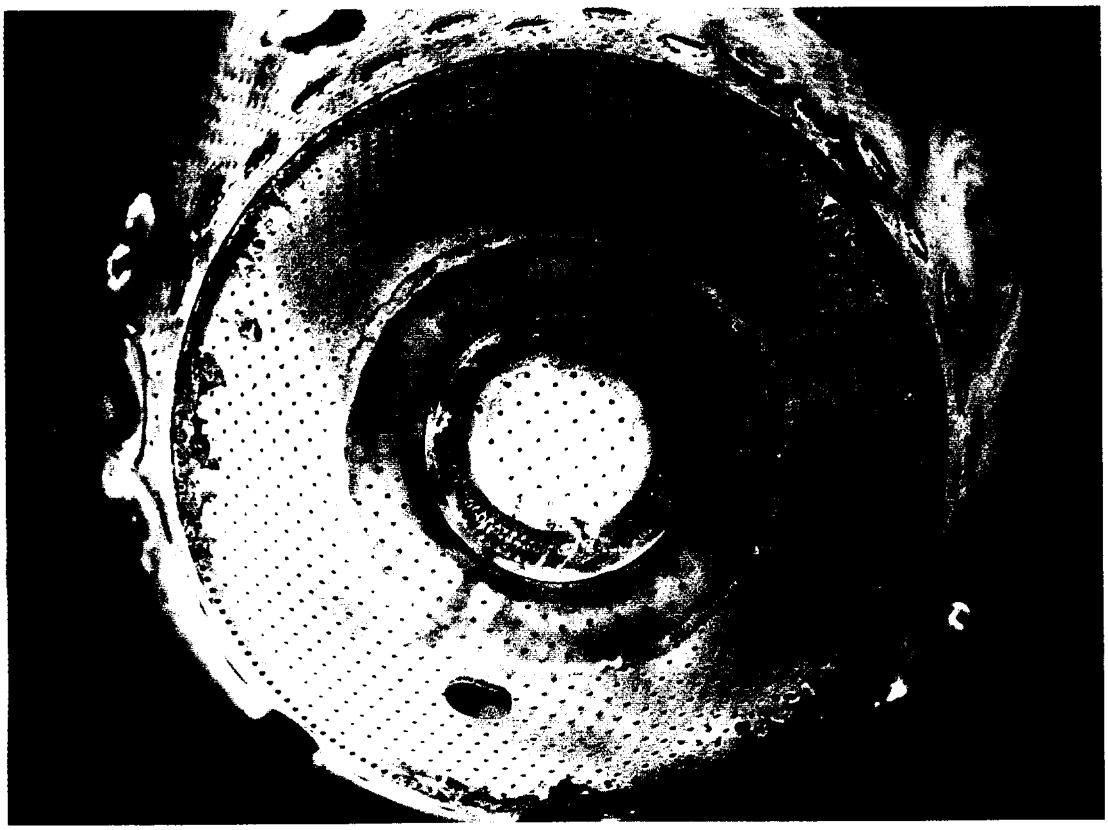

FIG. 15—COMBUSTOR NO.1 AT 1000 HOURS (IRAB)

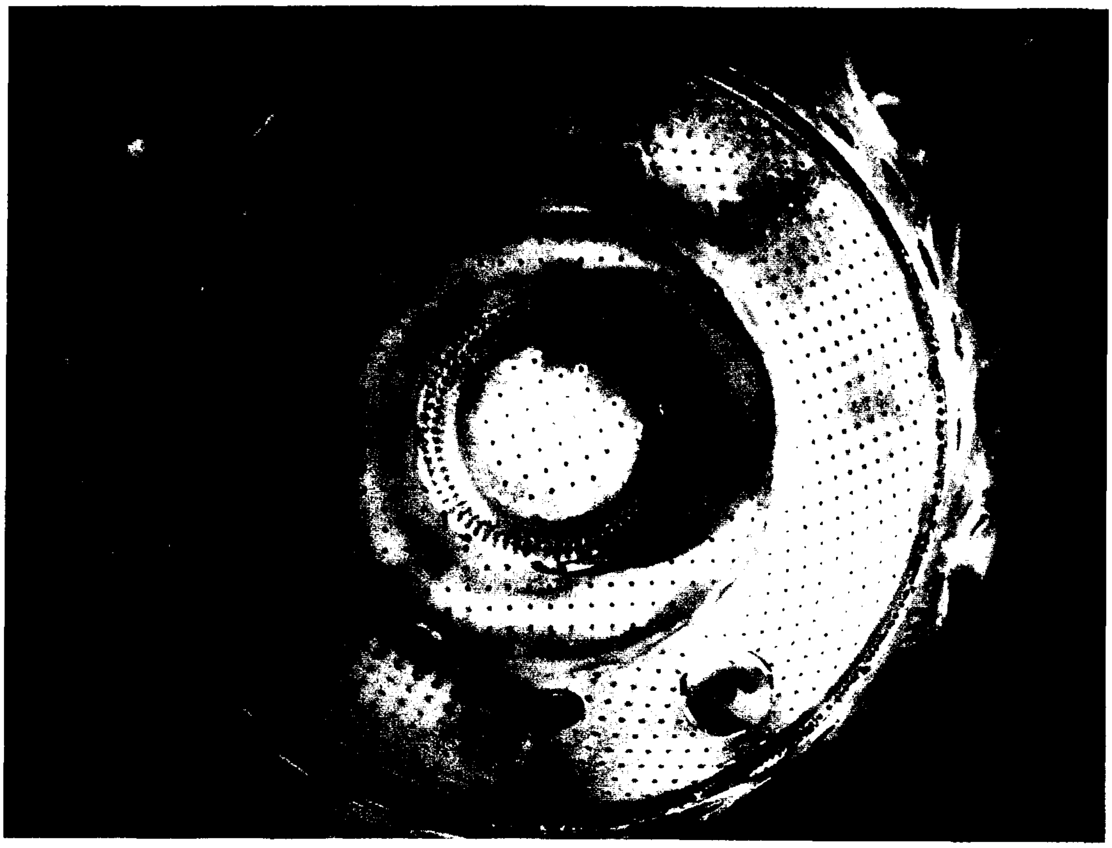

Fig. 16—Combustor No.8 at 200 hours (IRAB)

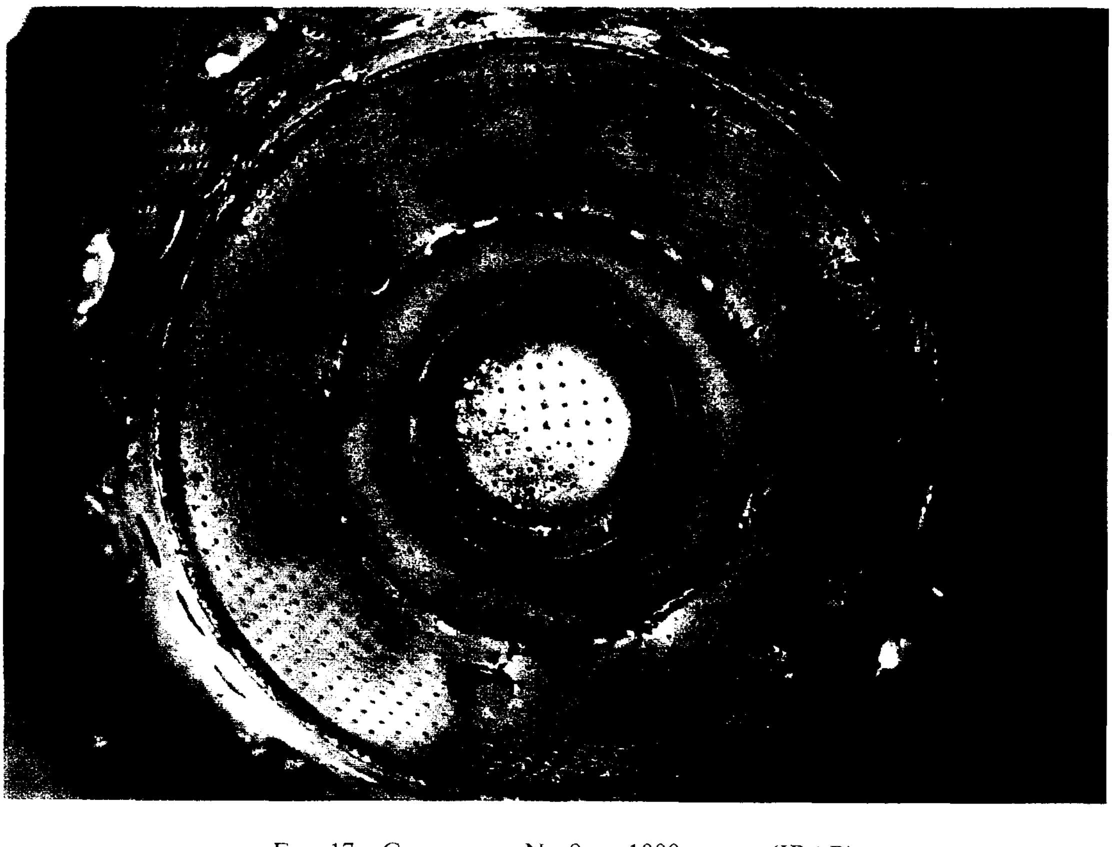

Fig. 17—Combustor No.8 at 1000 hours (IRAB)

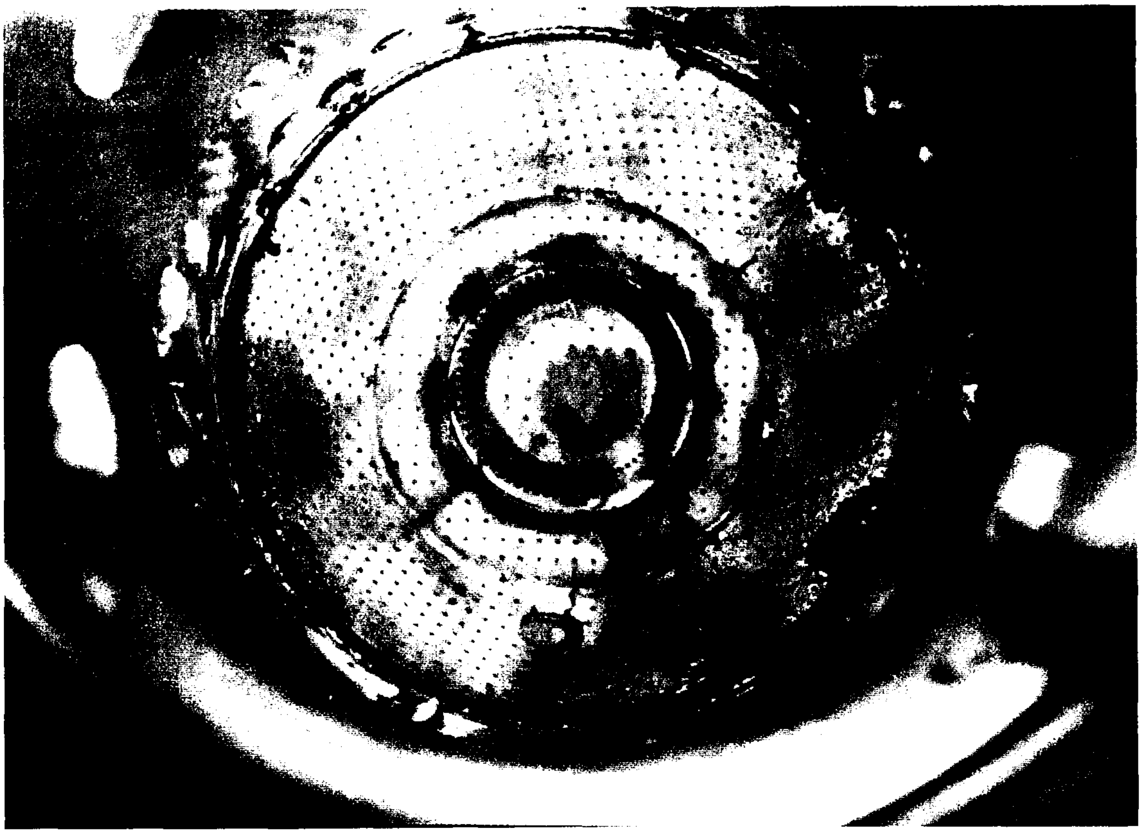

FIG. 18—COMBUSTOR NO.8 AT 1200 HOURS (IRAB)

FIG. 19—COMBUSTOR NO.8 AT 2000 HOURS (IRAB)

The availability of an engine undergoing extended testing on a comprehensively instrumented installation, has allowed a number of problems affecting Fleet operation of the SM1A to be investigated effectively. In addition, several engine health monitoring techniques have been installed and evaluated under a realistic operating environment.

The Marine Engine Section's effectiveness is enhanced significantly by the inclusion of naval officers whose combination of seagoing experience and engineering ability complements the civilian staff expertise to offer a unique breadth of support to DGME. This also provides the naval officer with a valuable opportunity to experience the latest developments of marine engine technology in a research environment.

References

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2. Harry, N. J. F. V.: Marine Spey '86 update; *Journal of Naval Engineering*, vol. 30, no. 1, December 1986, pp. 173–177.