

Combustion Efficiency in Gas Turbine Engines

STUDY OF TEMPERATURE DISTRIBUTION WITH RHODIUM-PLATINUM THERMOCOUPLE PROBES

By P. J. Stewart

Aero Engine Division, Rolls-Royce Limited, Derby

One of the many critical test-bed procedures carried out at the development stage on new or improved designs of gas turbine engines is the investigation of temperature distribution to ensure that the expansion rate of the gas flow through the flame tubes is evenly balanced throughout the engine, thus ensuring a good combustion efficiency. It is also important to ensure that the best temperature distribution is achieved for balanced power output.

In the test, use is made of specially designed thermocouple probes, constructed of 40 per cent rhodium-platinum alloy, which house fine gauge platinum: 13 per cent rhodium-platinum thermocouples. An extensive series of temperature determinations across the combustion discharge nozzle provides information from which the temperature distributions may be ascertained and vital information on the gas flow deduced.

A diagram of a gas turbine engine is shown on the opposite page.

In the simplest of terms its operation is as follows: air taken into the engine is compressed and passes through guide vanes into a series of flame tubes positioned round the annulus of the engine and enclosed by a combustion chamber. Fuel burners in the flame tubes burn kerosene at approximately 2000°C. The gas expands rapidly and forces its way through the combustion chamber where nozzle guide vanes guide the gas to the turbine blades. Here a proportion of it is converted into mechanical energy to drive the compressor (in the case of a turbo-prop engine

Improvement in design of a gas turbine engine depends to a great extent upon achieving the optimum temperature distribution across the combustion chamber. In order to study this and so to be able to modify design a comprehensive series of temperature readings must be made across the combustion discharge nozzle. This article describes the test-bed procedure adopted by Rolls-Royce to provide the information required, the measurements being made with platinum thermocouples housed in specially designed probes. To withstand the high temperatures and pressures involved these probes are constructed in 40 per cent rhodium-platinum.

a large percentage of the gas energy is absorbed by the turbine to drive a propellor) while the rest of the gas exhausts to provide propulsion.

There are two main types of combustion systems which may be loosely described as cannular and annular. In the first case a series of cans or flame tubes is arranged around the engine with one fuel burner in each flame tube, in the latter case there is a single continuous flame tube around the engine which has a ring of burners round it.

These different systems do not affect the basic principles involved in the combustion efficiency test. The flame tubes may be constructed of high temperature Nimonic alloy,

but the temperature of the flame is so high that to avoid burn-out of the tubes it is imperative that the flame envelope should not impinge on the tube walls.

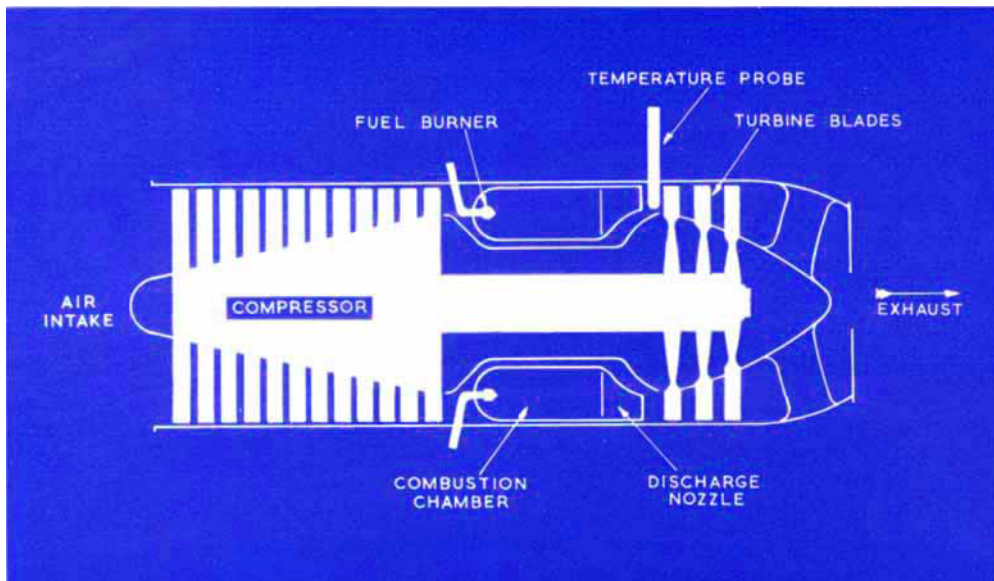
Combustion Traverse Test

The temperature measurements are not carried out in the immediate flame area: no normal material ductile enough to be formed into a thermocouple probe could withstand such temperatures without involving considerable expense. The determinations are made at some distance from the flame, the usual position of immersion into the engine being around the nozzle guide vanes situated at the exit from the combustion chamber, as shown in the diagram below.

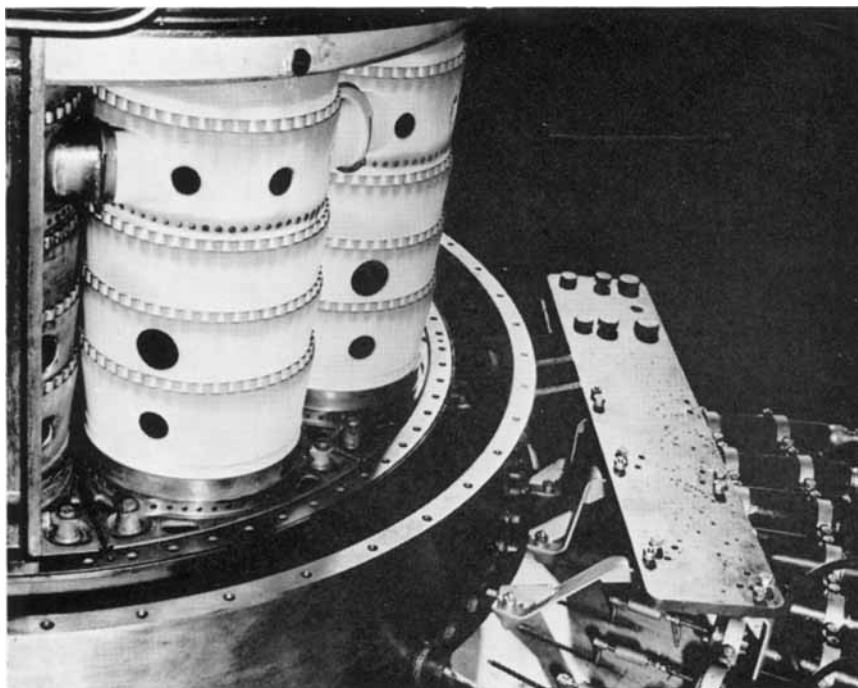
This position ensures that the temperature (1200°K to 1400°K) is not too high for the probe to withstand, bearing in mind the considerable pressure (approximately 200 p.s.i.g.) to which it is subjected, and that it is accessible through the wall of a modified casing that is used during development testing. The measurements gained in this position are used to calculate accurately temperature distribu-

tion and flame deflection. Such combustion test measurements are not carried out in flight, for once the shape of the flame is set this feature is incorporated in the basic design and is standard in all production engines.

To give sufficiently accurate cover of the selected test area and to gain a comprehensive appreciation of the temperature gradients as many as fourteen probes are used, the cross-sectional area in which readings are taken being approximately 18×3 inches. The probes are traversed across this area, movement in and out being by means of an electric actuator. The distance travelled into the engine by the probes is measured by a Desynn indicator and the temperature at the particular immersion is recorded on a multipoint recorder. As in each position several seconds are allowed to ensure that the sheathed thermocouple truly attains the temperature to be measured, a complete combustion traverse test can be of several days' duration. The test is normally applied simultaneously to two of whatever number of combustion chambers are present, a total of fourteen probes in all being used.



Simplified diagram of a gas turbine engine showing the main engine construction and the position at which the probes are inserted



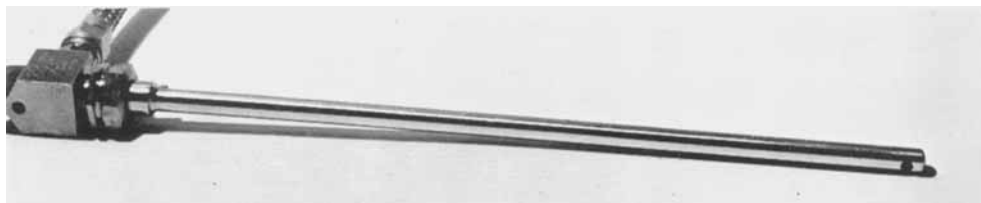
Part of an engine with outer covers removed to show the flame tubes that are to be subject to the combustion traverse test. The positions of entry of the probes can be seen on the outer casing of the engine, the probes being hidden behind the fan plate

The location within the engine of the selected chambers is not critical but two sets of readings are taken and correlated so that findings and possible design amendments are not based merely on the results from a single chamber. These results may be further correlated with those from instruments situated in the exhaust area of the engine.

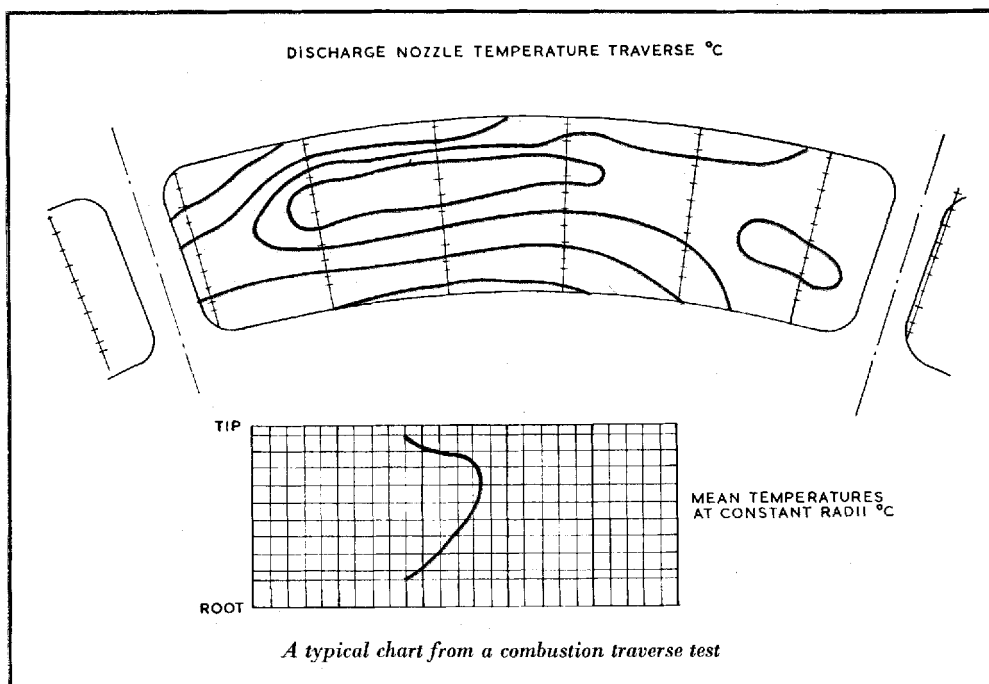
From the recorded temperature measurements a chart is produced showing flame distribution and temperature gradients across the combustion chamber, an illustrative chart being shown below. The actual flame temperature can then be deduced and this is

considered in relation to the original design features. Should the flame shape be such that it impinges on the flame tube wall or is likely to result in an unbalanced power output from the engine, alternative courses of action are considered. The flame shape may be altered by adjusting the volume of cooling air that is fed into the flame tube for stabilisation, while modification of burner design, a change to a different type of burner, modification of flame tube design or a change in the type of fuel are alternatives that may be considered.

The course of action that is taken depends entirely on the type of engine involved and on



A typical 40 per cent rhodium-platinum probe manufactured for Rolls-Royce Limited by Johnson, Matthey & Co., Limited



the expense incurred in carrying out such a modification, and therefore no generalisations are possible in this article.

Probe Design

The outer sheath of probes employed in the combustion traverse tests carried out on the earliest jet engines, which operated at much lower temperatures than the engines of today, were made of a special grade of stainless steel or of Inconel. Subsequently 20 per cent rhodium-platinum alloy was used, but with the increasing tendency towards higher flame temperatures and higher pressures in gas turbine engine design, recourse has had to be made to 40 per cent rhodium-platinum.

This high melting point alloy (1950°C) has a good tensile strength (31 tons per square inch) a relatively high Vickers hardness (150 in the annealed state) and excellent resistance to creep above 1000°C, this last property generally determining its use in high temperature applications.

Under test conditions the probe has to withstand exposure for a number of hours to

a temperature of approximately 1200°C and to pressures approaching 200 pounds per square inch. The sheath therefore has to have a wall thickness great enough to ensure that it can withstand the force exerted but not so thick that the response time of the thermocouple is sacrificed.

Many types and sizes of probe are employed, the actual dimensions and design being dependent to a degree on the engine design, but basic features are common to all probes. A double sheath is employed, both the inner and outer tubes being of 40 per cent rhodium-platinum and maintained parallel to each other by means of a guide washer of the same alloy. To maintain sensitivity of response a 0.078 inch diameter hole is situated close to the sealed end of the outer tube, while the shorter inner tube has an open end. The hot gas from the flame tube is thus able to circulate within the probe and flows over the junction of the platinum: 13 per cent rhodium-platinum thermocouple, the rest of the thermocouple wires being contained in a twin-bore alumina sheath.