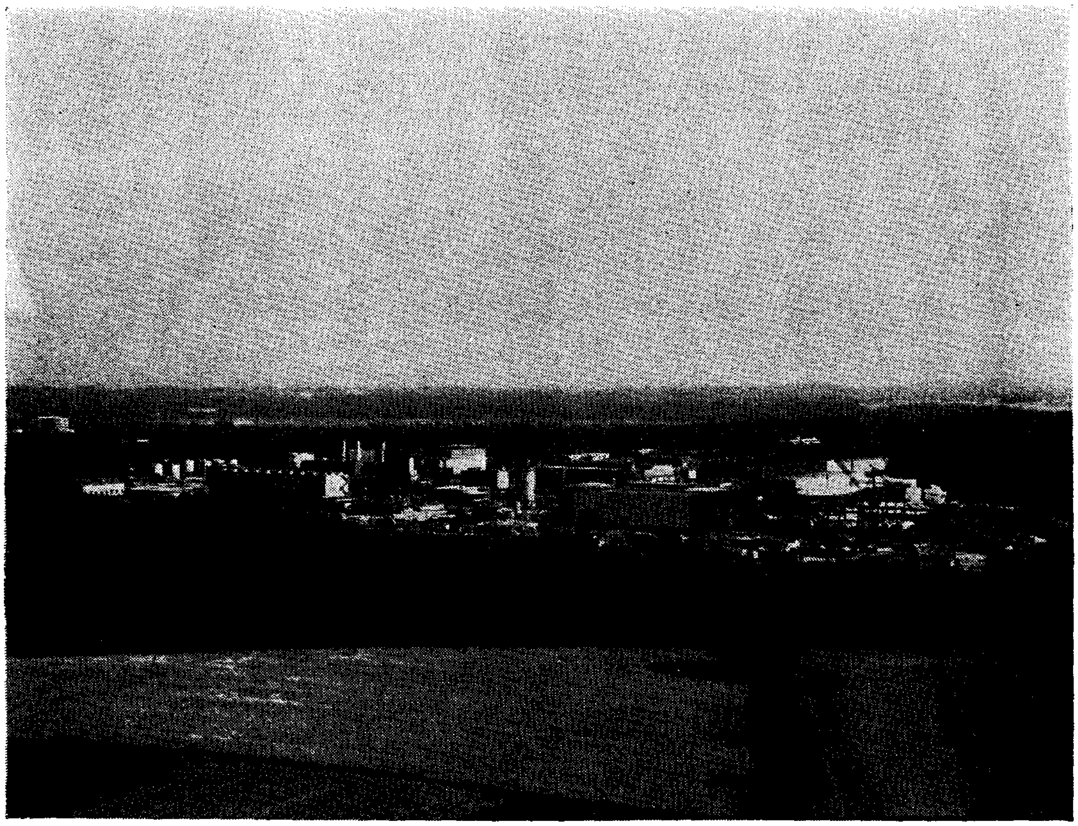

FIG. 1—GENERAL VIEW OF TEST FACILITY

THE NATIONAL GAS TURBINE ESTABLISHMENT

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Introduction

The National Gas Turbine Establishment at Pyestock in Hampshire is the Government centre in the United Kingdom for research into the problems of gas turbine engines and related systems.

In 1949, there were two branches of the Establishment, one at Pyestock, and the other at Whetstone in Leicestershire, but it was envisaged that they would be brought together on a centralized site at some future date. The site selected was Pyestock and the movement of equipment and personnel from Whetstone was finally completed in 1955. In the intervening years since 1949 the Pyestock site has been expanded and developed, particularly during the last decade or so with the installation of large-scale plant for full-scale environmental testing of aircraft powerplants.

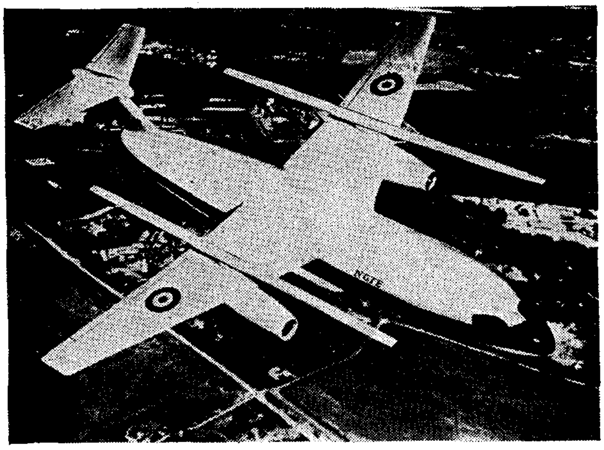

FIG. 2—A GLIMPSE OF THE FUTURE(?)—LOW NOISE LEVEL VERTICAL TAKE-OFF AND DESCENT COMBINED WITH HIGH SPEED CRUISE USING N.G.T.E. CIRCULATION-CONTROLLED STOPPABLE ROTORS

Because of its original mandate for research and development of gas turbines for land, sea and air uses and its contact with a wide range of industry, the N.G.T.E. today is well-placed to make a major contribution to the technological progress necessary for national survival. Advance evidence of this exists in the contribution already made by the Naval Marine Wing, coupled with the increased use of aircraft-type gas turbines for the propulsion of Navy ships and other purposes.

In the following sections, some facets of the Establishment are presented, to provide as complete a picture as possible in the space available.

The Aero-Engine Research Programme

Some two-thirds of the professional staff currently in post are engaged on the Establishment's research programme, with additional responsibilities, delegated from headquarters, for the management and monitoring of the bulk of Government-sponsored research in the aero-engine industry.

The major part of the Establishment's 'in-house' programme (and for that matter the extra-mural programme), is directed towards applications which are clearly defined and expected to be in operational service in the short term, the remainder being work of general value. A small amount of effort is, naturally, devoted to longer term considerations. Although most of the programme is self-contained, there are various inter-faces with other interests where the work concerns, for example, air intakes, propelling nozzles, general installation matters and, of course, materials; close liaison on these aspects is maintained with other Government establishments and companies concerned.

The programme is organized by Research Fields as follows:

(*a*) *Assessment of Powerplant Performance and Application*

This research constitutes a small, highly directed, continuous quest for ways of improving gas turbines and jet propulsion systems in respect of overall performance and cost effectiveness. The bulk of the work is on engine design studies, mission studies and engine selection, undertaken largely in conjunction with the airframe specialists and concerned almost exclusively with investigation of proposals to meet user requirements.

(*b*) *The Interaction of Propulsive and Lifting Flow Systems*

Here the work covers various aspects of the hot gas re-circulation, ground erosion and débris ingestion problems in V/STOL systems such as the Hawker Siddeley 'Kestrel'. The main effort is engaged on the N.G.T.E. technique for the exploitation of aerodynamic circulation control, with particular reference to helicopters, for which the circulation-controlled rigid rotor offers operational and performance advantages, together with a prospect of reduced maintenance and improved reliability. There is also a lively interest in an earlier N.G.T.E. proposal for high speed, stoppable rotor, V/STOL aircraft conforming to such low noise standards that the same basic aircraft could be conceived in a civil as well as a military rôle (see FIG. 2).

(*c*) *Powerplant Operation and Control*

Work on powerplant items such as air intakes, propelling nozzles, control systems and general installation and operational problems, forms an important section of the programme. The increases in versatility and in the variety of operations required of modern aircraft have accentuated the problems of optimizing powerplant performance and minimizing drag. The successful application of high by-pass ratio engines is critically dependent upon solving the resulting installation problems. Increased powerplant complexity and the continuing drive to improve engine handling have maintained emphasis on control systems research. Attention is currently focused on the possibility of applying digital computers to engine control, and on the use of fluidic logic in supporting sub-systems.

(*d*) *Engine Rotor Systems—Fans, Compressors, Turbines*

The high proportion of expenditure in this field, about one-quarter of the total, reflects the continuing effort which is necessary to uprate the performance of turbo-machinery. The work is aimed at reduction of component size, weight and cost, improved efficiency, and flow stability in conjunction with aircraft intakes, and makes full use of advanced digital computers. Research is also in progress on a single-stage centrifugal compressor of some $6\frac{1}{2}:1$ pressure ratio for small gas turbines, as a contribution to good part load fuel consumption is to be obtained by its use in association with a rotary regenerative heat exchanger and a variable geometry free power turbine. Such engines have considerable potential for helicopters, light aircraft, marine craft and surface vehicles.

(*e*) *Combustion Systems and Associated Chemical and Physical Phenomena*

The combustion programme contains a base load of work on fuel injection, ignition, mixing processes, film cooling and heat transfer, under conditions closely simulating those obtaining in practical combustion chambers. The increasing range of duties for the aero-engine has re-emphasized the fact that combustion chamber design is a compromise between the conflicting requirements of various operational conditions. Experiments are aimed at a burning zone operating near stoicheiometric fuel/air ratio coupled with variable geometry to control the division of airflow within the chamber over a wide range of overall fuel/air ratio. Because of the method of their construction, combustion chambers are more amenable to change during development than, say, a compressor; in consequence the results of the research can not only be absorbed rapidly into engine development projects, but can, in some instances, be fitted retrospectively to service engines during overhaul.

(*f*) *Mechanical Engineering and the Use of Materials*

The bulk of the work in this field is extra-mural, the N.G.T.E. contribution being usually model scale, in contrast to the full-scale work undertaken by the firms. A good example of this is the N.G.T.E. small-scale disc research, which forms an essential and relatively inexpensive adjunct to the full-scale work done in industry. The N.G.T.E. materials research programme is concerned mainly with high temperature applications and it includes the evaluation of possible new turbine materials, such as niobium, together with the development of protective coatings for easily oxidized alloys. Research is also proceeding on the wire reinforcement of nickel based alloys and on the impregnation of carbon fibres with aluminium. Another class of study concerns the erosion of gas turbine blading during the operation of helicopter engines in desert regions, and the resistance of high temperature materials to sea-salt corrosion is under investigation in the laboratory as well as in the Naval Marine Wing. Considerable interest attaches to the use of reinforced plastics for engine components, in particular for the fan blades of high by-pass ratio engines and for the low temperature components of lift engines.

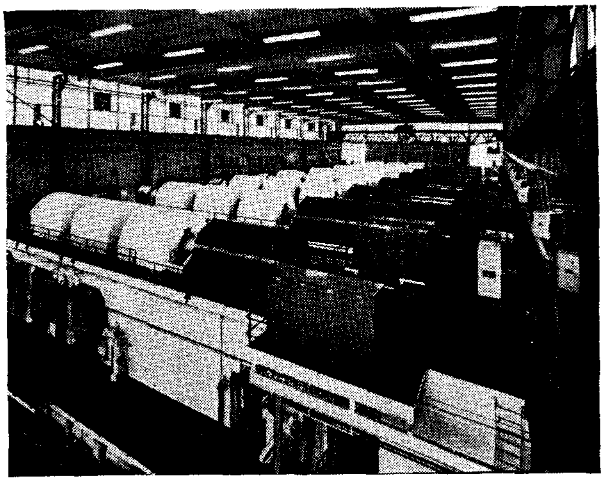
FIG. 3—COMPRESSOR/EXHAUSTER SETS IN THE AIR HOUSE

(*g*) *Noise*

The Government-sponsored engine noise research programme is closely co-ordinated by N.G.T.E., which itself undertakes about one-quarter of the work. For some years now much of the programme has been concerned with turbo-machinery noise, including helicopter rotors—in preparation for the coming breed of big fan engines. However, the problems of jet noise are still far from complete understanding and there are also significant items in the subjects of noise propagation and perception. To make possible the free-field environmental testing of full-scale fans and compressors, a national turbo-machinery noise laboratory is now under construction at Ansty near Coventry for use by the various organizations as appropriate.

Full-Scale Engine Environmental Testing

The Engine Test Facility

The Engine Test Facility at Pyestock enables a complete simulation to be made of the flight conditions encountered by an engine in an aircraft. Steady-state and transient operating conditions can be represented and special tests can be undertaken, for example trials under altitude icing conditions to examine the effectiveness of measures to prevent the build-up of ice on the intake or engine. The Facility (see FIG. 1) consists of a centralized pressure air supply/exhaust extraction plant, four cylindrical test cells with their control rooms and a data acquisition and processing centre. There is in addition a normally aspirated test bed (Glen Test House) used primarily for research and development tests and for calibrating engines before installation in the altitude cells.

Two main types of test arrangement, 'free-jet' and 'connected', are employed. In a free-jet test, a stream of air moving at the aircraft flight speed is produced in a manner analogous to that of a conventional wind tunnel; the engine and its intake can thus be tested together under conditions encountered in free flight. In a connected test, air is piped directly to the engine compressor at the same pressure and temperature conditions as would be provided at the compressor face by the intake in flight.

Both types of test require compressors to provide large quantities of compressed air and exhausters to pump even larger quantities of exhaust gases away from the altitude pressure level simulated in the test cell. These require-

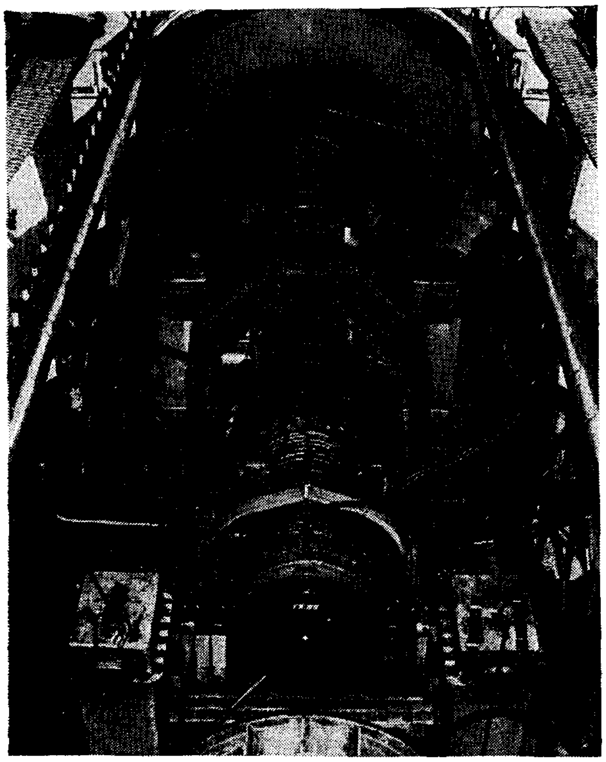

FIG. 4—AN OLYMPUS ENGINE BEING INSTALLED FOR TEST IN CELL 3

ments are met by machinery located in the Air House (see FIG. 3). There are eight large compressor/exhauster units, each of which can be run either as a compressor or as an exhauster and the total installed electrical power is about 350,000 h.p.

Air is taken from atmosphere through driers before being compressed by the compressor/exhauster units to either three or nine atmospheres pressure depending on the test requirements. It is then further processed to adjust its temperature before being fed into the test cell. For example, in Cell 3 some of the pressure air can be expanded in a turbine and its temperature reduced to – 80 degrees C. This cold air can then be mixed with dry atmospheric air or with air which has passed through other of the compressor/exhauster units to achieve a wide range of temperature control at inlet to the engine.

Having passed through the engine the exhaust is cooled and pumped from the cell to atmosphere. In Cells 1 and 2 this extraction is by means of air-driven ejectors, but in Cells 3 and 4 it is obtained by using the compressor/exhauster units. The air supply system is thus capable of simulating both the true flight conditions corresponding to the pressure and temperature at the compressor face, as well as the lower pressure conditions around the exhaust system corresponding to the altitude at which the aircraft is flying.

Cells 1 and 2 are 12 ft diameter and they have been in use for eight years. Cell 3 is a 20 ft diameter cell which has been in operation for five years and FIG. 4 shows an Olympus engine being prepared for test in this cell; the lid of the cell has been removed to allow the engine to be lowered in from above. Cell 4, shown in FIG. 5, is a large free-jet cell which first came into routine operation during 1966.

Cell 1 is used for free-jet testing of ramjets and for model intake research work at full scale Reynolds number. Normally the free-stream approach Mach number is fixed during a test but incidence can be varied while running. A range of supersonic nozzles enables tests to be undertaken between Mach 2·0 and 3·0, and using a variable Mach number slotted nozzle a ramjet launch can be simulated.

Cell 2 is used for connected tests. The original test capability has been extended and the cell can now cope with high density tests of engines requiring a sea-level static air mass flow in the region of 300 lb/sec.

Cell 3 is a connected cell which can deal with the full range of engine and flight transients; the simulated flight environment can be maintained no matter how quickly the engine conditions are changed. Icing trials are done in this cell.

Cell 4 is a large free-jet cell with a variable Mach number working section and variation of incidence and/or yaw while running. It has a working section

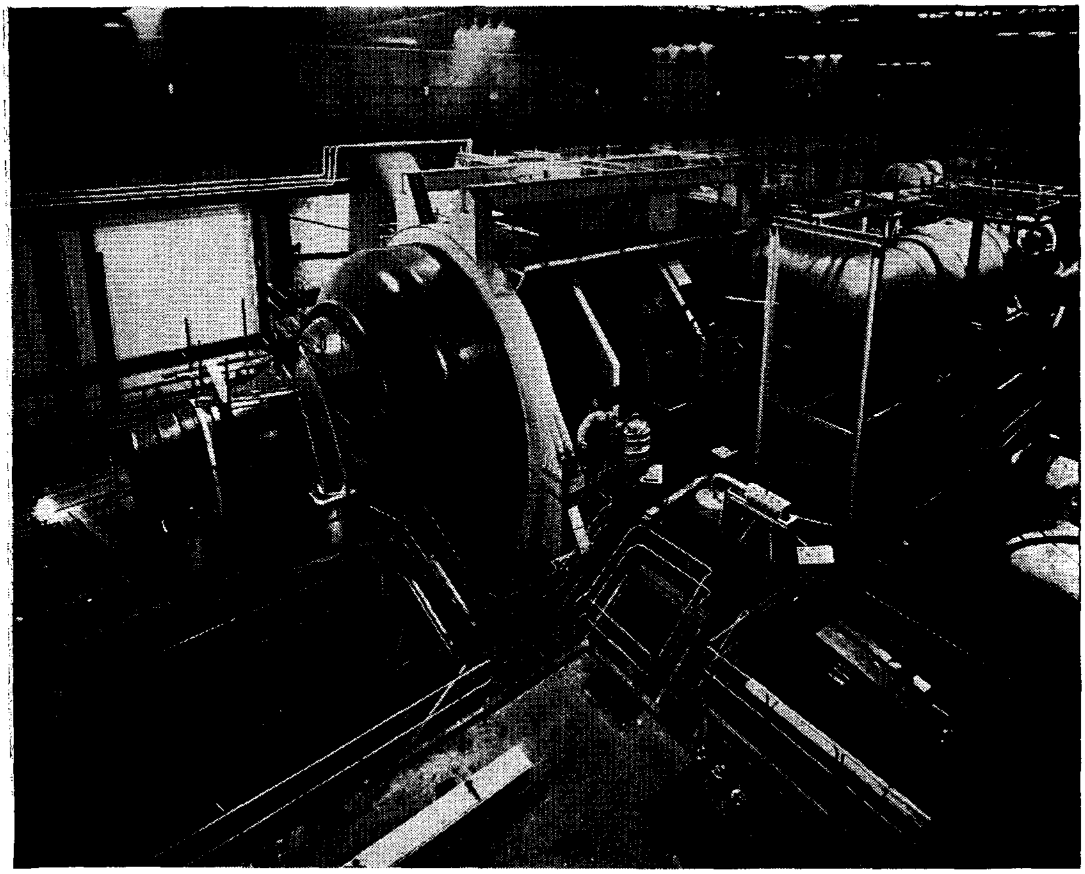

FIG. 5—GENERAL VIEW OF CELL 4—PLENUM CHAMBER IN CENTRE, EXHAUST SYSTEM ON RIGHT

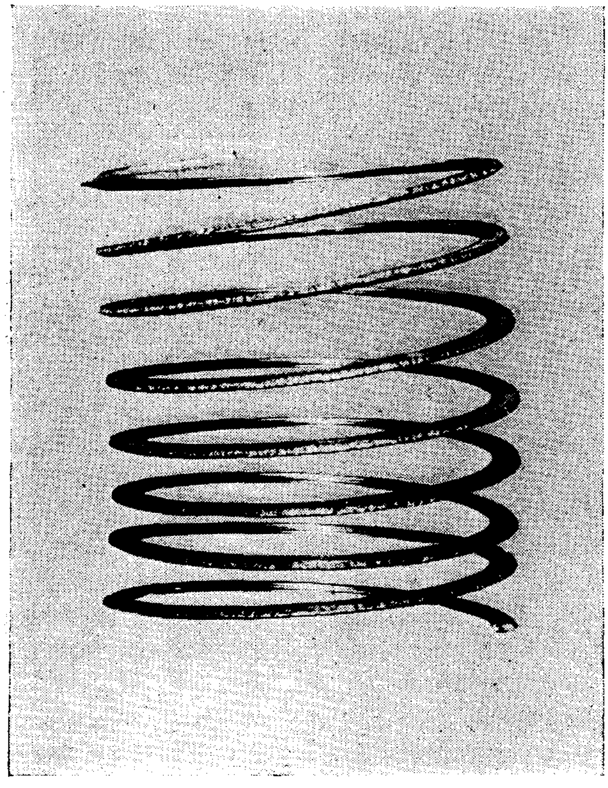

FIG. 6—THREAD FAILURE IN NUT OF 6 FT DIAMETER GATE VALVE

of 25 sq ft which enables tests of the combination of Concord intake and Olympus engine to be made over a Mach number range from about 1·7 to 2·3.

Each control room houses a large part of the instrumentation pertaining to the test in hand. In addition to some 700 engine driving and plant instruments there is a comprehensive system of measuring instrumentation which records engine performance data such as temperatures, pressures, flows, speeds, frequencies, thrust, etc. Part of this data is fed in digitized form to an 'on-line' computer which evaluates the engine performance as the test proceeds. Other information is passed to a central recording system with 'quick look' facilities in each control room. An idea of the complexity of this data-gathering system may be gained from the fact that Cells 1 and 2 each have about 400 channels

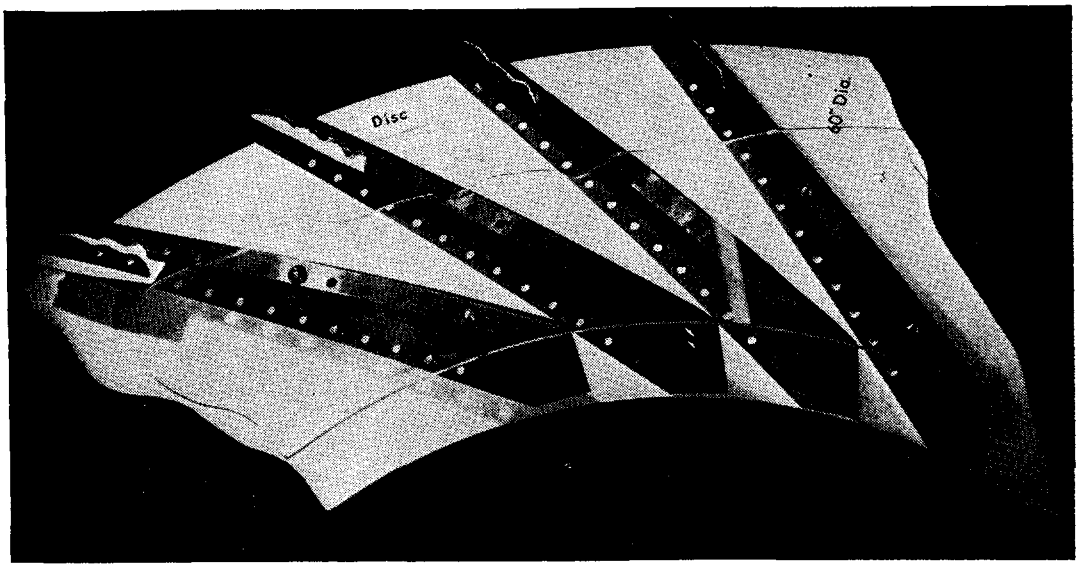

FIG. 7—FAILURE OF IMPELLER VANES IN COMPRESSOR/EXHAUSTER

feeding information to the data centre, Cell 3 about 600 and Cell 4, 700. There are in addition in the Photographic Instrument Room some 400 manometers and 100 dial gauges, shared between Cells 3 and 4, which can be recorded automatically by camera on demand from the cell control rooms.

Operation and Maintenance of Facilities

Some idea of the size and complexity of the E.T.F. will have been gleaned from the above. Add to this other plant for component testing in aerodynamic and combustion research, plus laboratories for small scale investigations, and the result is a very considerable array of plant of many different kinds. The operation and maintenance of this plant is an expensive and exacting task.

Steam and electricity are required in large quantities. The steam installation, which includes two ex-naval Battle Class boilers, provides 750,000 lb/hr at 400 lb/sq in. and 650 degrees F. This steam is used for three main purposes: to drive the E.T.F. compressors in conjunction with synchronous electric motors on the same shaft; in the testing of engine compressors, where the compressor on test is driven directly by a 14,000 h.p. steam turbine; for peak load lopping to the extent of 13 MW. The steam power is complementary to the National Grid supply which is taken in at 132 kV and 33 kV to a total capacity of 160 MW. This supply, together with the steam power and a gas turbine alternator recently being installed, totals over 200 MW.

The four test cells of the E.T.F. are fed through pipes ranging up to 10 ft diameter (there are over 4½ miles of pipes over 2 ft in diameter on the site) with control valves of all types and of size up to 15 ft diameter. Ancillary plant includes cooling tower installations, water and electricity distribution networks, communication systems, computer installations and the like.

The power costs to mount a test are very high and there is therefore a large premium warranted to ensure reliability, demanding a scheduled maintenance system which deploys a labour force of several hundreds and contains upwards of 20,000 items on card index. This work load is constantly growing as more equipment comes into service and the schedules are under constant review as to times and frequency.

Some interesting failures have been recorded, two of which are described and illustrated. It would seem that FIG. 6 is a photograph of a helical spring; in actual fact it is the thread from the nut of a 6 ft diameter gate valve and it is one of many similar failures. Large gate valves of this type are not able to withstand the frequent operation which test work demands. They must of necessity be opened and closed without equalization of pressure, so that gate loads are high, and instead of being operated a few times a year, as in normal service, they are operated many times a day. Wear rapidly takes place so that eventually shear occurs and the thread of the nut is left on the shaft in the form shown. The answer has been to fit recirculating ball screws.

FIG. 7 shows a failure of impeller vanes from a 60 in. diameter high pressure compressor attributed to thermal cycling. Normally a machine of this nature, when it is used for blast furnace blowing, would go on load for many months at a time and the pressure ratio would be low. At Pyestock the machines are started and stopped two or three times a day and compressors are operated in series so that the pressure ratio and temperatures are correspondingly high. An interesting feature is the great similarity between the pieces which have cracked and in some cases detached themselves. They are almost like identical jig-saw pieces. The cure has been to use different material and restrict as far as possible the severity of the temperature cycling.

The Naval Marine Wing

The Naval Marine Wing was set up in 1948 as a joint venture with the (then) Admiralty and became operational in 1952. Its principal objectives are:

(*a*) To undertake full-scale testing, including endurance trials of gas turbines proposed for naval use, simulating as far as possible the marine installation and environment.

(*b*) To investigate any fundamentally maritime problems relating to the naval use of gas turbines.

(*c*) To investigate problems concerning the operating and maintenance of naval gas turbines and ancillary equipment.

A secondary but important objective is to provide a link between naval marine engineering and the gas turbine field generally.

Today, the Wing consists of a small naval staff with supporting civilian professional and industrial staff. Facilities, housed in the Admiralty Test House consist in the main of one large (100 ft × 40 ft) test bay, which can be subdivided as required, and one smaller bay. Electrical load tanks up to 1,250 kW, and water cooling plant capable of dissipating something over 25,000 h.p. are available and cooling tower arrangements are such that the provision of additional cooling capacity would be a relatively simple matter. Space for rig work on ancillary equipment, a small workshop, and a small laboratory, used at present mainly for atmospheric salt analysis, are also incorporated in the building.

Since its opening in 1952, the Wing has worked on many different projects. These have included proving and performance trials on the Metro-Vick Gatric (2,500 h.p.) and G.4 (5,000 h.p.) and the A.E.I. G.6 (7,500 h.p.) propulsion engines; and on the Allen 1,000 kW and 500 kW and the Ruston and Hornsby TA (900 kW) and TF (750 kW) turbo-alternators. The G.6 engine was endurance tested to establish component lives, including an investigation into turbine disc overheating (the cause of the failure in H.M.S. *Ashanti*) which successfully established both the basic reason and a satisfactory remedy. The Ruston TA was used for an extensive investigation, in collaboration with the Chemistry, Physics and Combustion Department, into the problems of burning residual fuel. The Ruston TF also underwent endurance trials, and modifications were developed to improve the engine ignition system. The Allen 500 kW alternator has been used for endurance trials and for trials of a number of modifications, including an improved combustion can and a 'zero-staged' LP compressor, which have enabled the engine to be uprated by some 20 per cent.

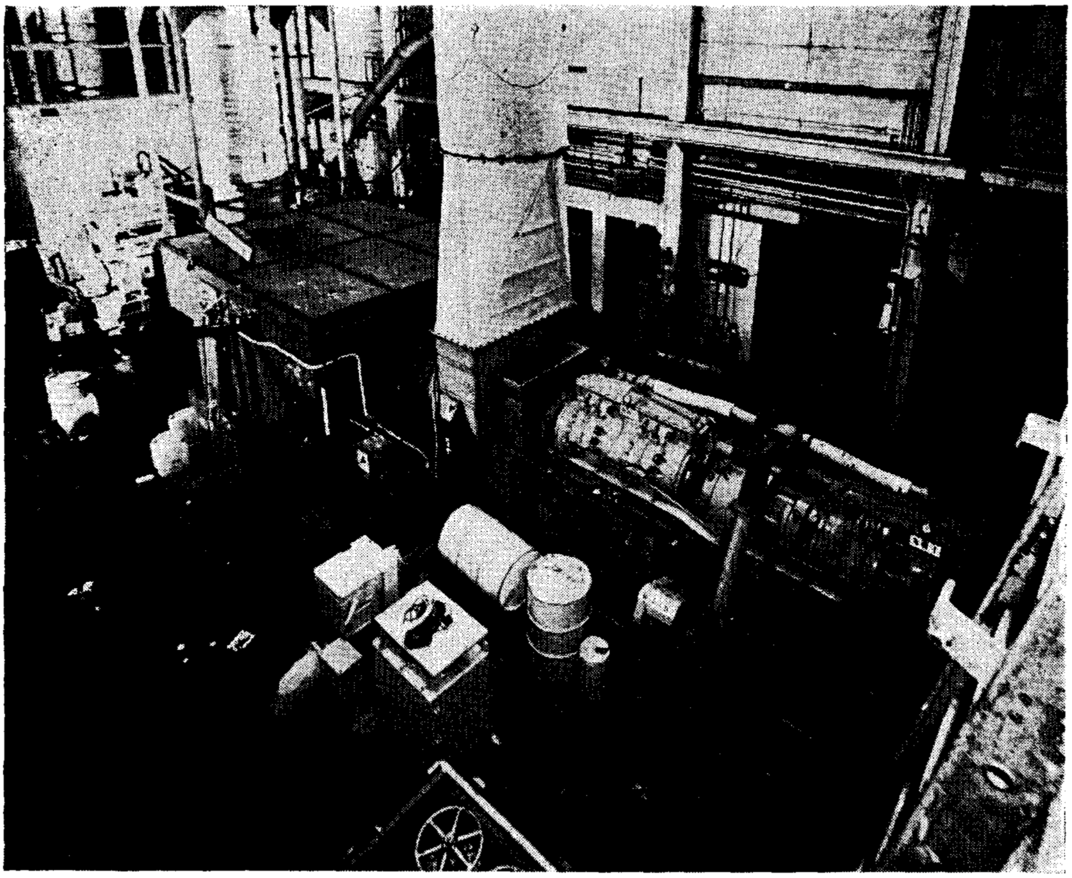

FIG. 8—ROLLS-ROYCE TYNE ENGINE ON TEST IN MAIN TEST BED AREA OF THE NAVAL MARINE WING

The recently adopted M.O.D. policy of using wherever possible fully developed aircraft engines, with the minimum of modification (thereby taking advantage of the extensive development effort applied to such engines) has brought about a very considerable change in the Wing's work (and in the physical appearance of the test beds!). Whereas in the past effort has been mainly concentrated on mechanical development of the engine as such, this is now neither practicable nor desirable, and it is therefore possible to concentrate much more on efforts to define and to simulate the 'marine environment'.

Engines currently under test are the Bristol Siddeley Marine Proteus, a marinized version of the Rolls-Royce Tyne (see FIG. 8) and, in the generator field, a Centrax CS 600-2 engine with a 500 kW alternator and (later) a waste-heat boiler. The Proteus is being used in a dual rôle, to assess its long-term endurance and for investigations into engine intake layouts. The Tyne is being examined for its suitability (after some engine alterations) as a propulsion and generator engine for the future. The Centrax engine is at present being evaluated for H.M.S. *Exmouth*, and also, when the waste-heat boiler is fitted early in 1967, as an example of a 'total heat' plant (in which the high part-load fuel consumption characteristic of the simple robust industrial engine is compensated for by the use made of its exhaust heat).

Evaluation and simulation of the marine environment can be subdivided into three components. Ship movement and shock is the most obvious, but as simulation of this is not deemed economically practicable, no work has been done on this in the Wing. The second component is the operating cycle, which imposes thermal stresses on the engine and loads on the governing and control system. Simulation of this is relatively simple, given sufficient 'user-data' from ships, and engines are run at Pyestock on cycles designed to be rather more severe than the worst which can be foreseen for operation at sea.

The most difficult component of the marine environment to simulate is salt. After several years of work, and many sea trials, it is believed that the capability to assess with reasonable accuracy the total salt burden likely to be found in the atmosphere, in any but the very worst of weather, is almost within reach. Simulation of this, however, depends on knowledge of particle size, and in this respect the work is much further behind.

Arising directly from the above, a great deal of effort has been directed to means of removing salt from the air, either by suitable intake design or by filtering devices. So far, most of the work has necessarily been empirical, but it has recently become possible with the success of the specific empirical work, to make a start on the general problem.

Evaluation of the problems caused by salt in the fuel will be the subject of future work.

Conclusion

The spectacular development of the gas turbine, and particularly its use for jet propulsion, has affected the design and performance of every type of aircraft, enabling the boundary of manned flight to be pushed well into the supersonic regime and bringing the concept of direct engine-produced lift into the realm of practicability. Future progress in engine technology will be more difficult, requiring greater skill and understanding, but there can be no question that great opportunities still exist to secure improvements in overall economy on conventional aircraft and to invent new modes of operation and flight systems which will expand the scope of air transport. In parallel, there are equal opportunities to develop the potential of the gas turbine and associated technology over a wide front, making maximum use of the ideas explored and the hardware evolved for aircraft propulsion.