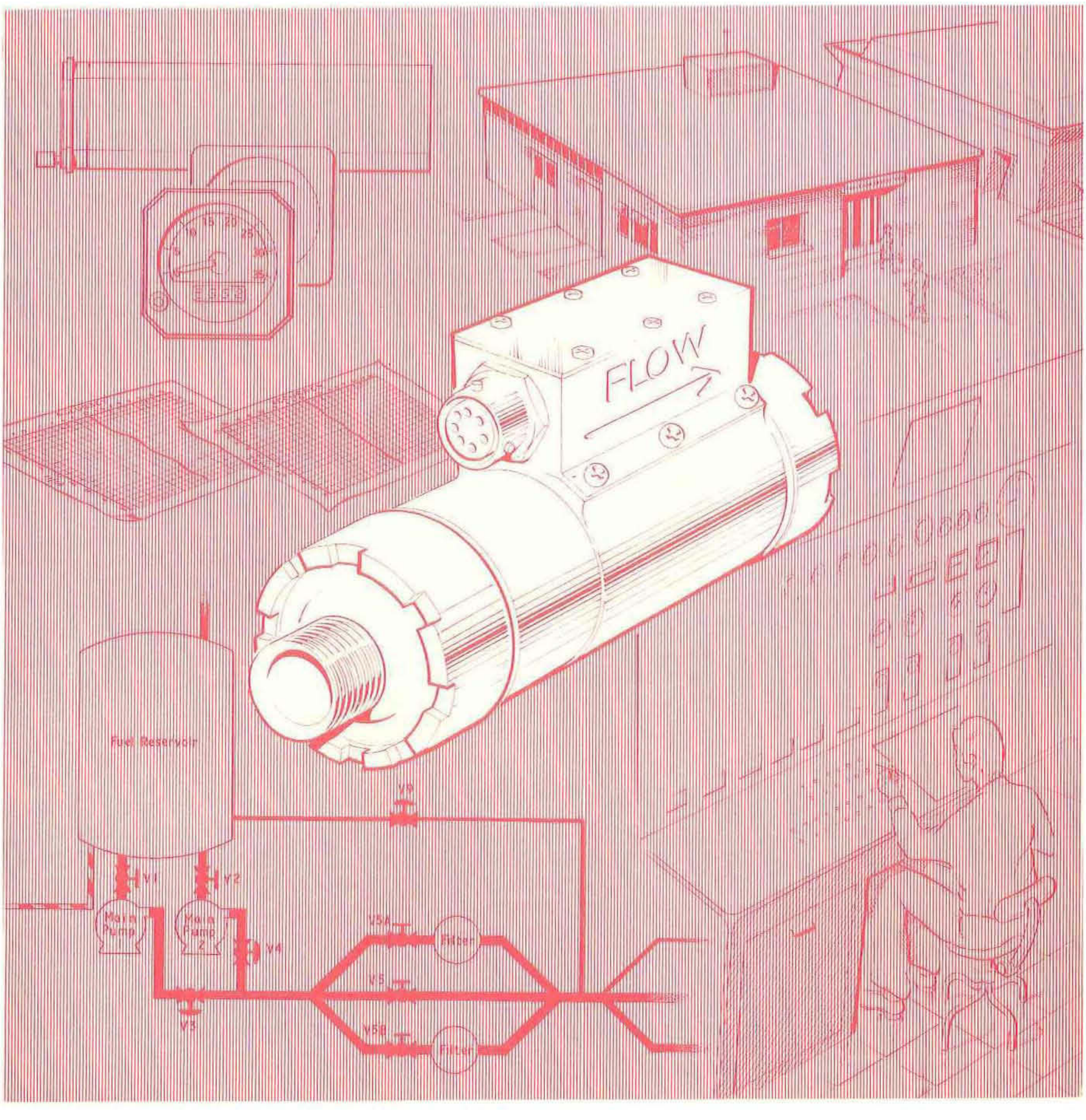
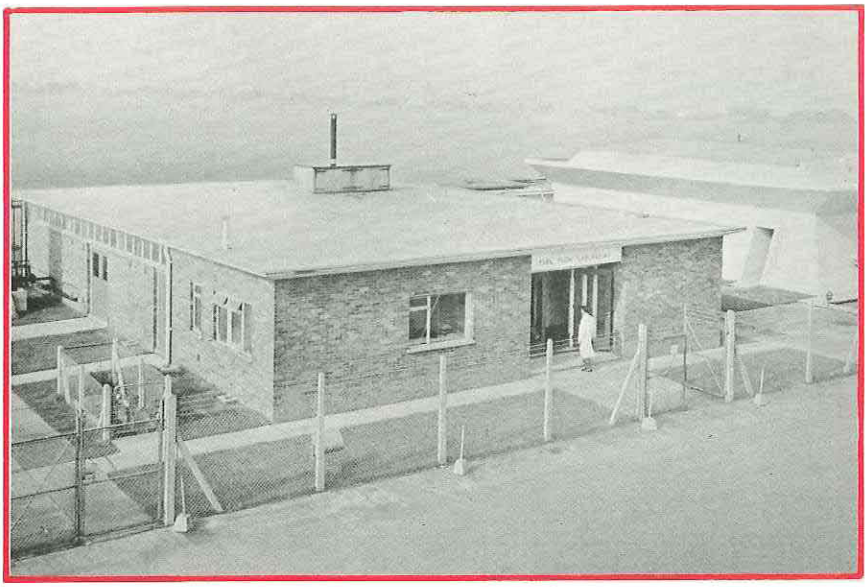
MARCONI
ELLIOTT
AVIONICS

Fuel Flow Laboratory



Marconi-Elliott Avionics Fuel Flow Laboratory



Introduction Fuel flowmeters are used in high speed aircraft to indicate the rate of fuel consumption and, by integration, the amount consumed. The indications are required in mass units with errors not exceeding 0.5% of reading over the greater part of the flow range. Where the flow transducer is engine-mounted it is usually downstream of a heat exchanger in which lubricating oil is cooled by the fuel, with the result that the fuel temperature in supersonic flight may reach 180°C. However on take-off under arctic conditions the initial temperature may be well below zero. In consequence, for flowmeter development there is need for a test facility of high accuracy, capable of circulating fuels at any temperature within a wide range, while the transducer itself is subjected to vibration and ambient temperature conditions similar to those experienced in flight. The MEA Fuel Flow Laboratory has been designed to fulfil this need.

The Laboratory precisely measures flow rate by timing the period during which a predetermined mass of liquid is collected in a weighing tank. A stable flow rate is maintained by means of an automatic controller. The average flow rate during the timed period may then be calculated. For a group of three readings at any given flow rate, the true value is expected to lie within 0.1% of their mean, with better than 95% confidence.

Operating Conditions Flow rates are controllable over the range from 120 to 100,000 lb./hr, at fuel temperatures from −40° to +180°C and ambient temperatures from −60° to +200°C. Under any combination of these conditions it is possible to apply controlled vibration to the flowmeter under test, corresponding to accepted levels for engine mounting.

Alternative types of aviation fuel are available for test.

General Description The Laboratory consists of two buildings, the Test House and the Control Building. These are situated within a fenced compound which also contains a number of underground storage tanks for test fuels, and other tanks for boiler fuel and liquid nitrogen supplies.

The Test House contains the whole of the fuel circulating equipment; a reservoir for the fuel in use, pumps, pipework, control valves, filters, the unit under test, weighing systems, and heat exchangers for heating or cooling the fuel. Within this building stringent safety precautions are observed.

The Control Building contains the Control Room from which all operations in the Test House are remotely controlled, a small laboratory for fuel assay, a workshop, and three rooms housing electrical, boiler, refrigeration plant, air compressor and ancillary equipment.

The Test House

Structure The Test House consists of a floor approximately 45 feet square, surrounded on three sides by reinforced concrete walls. Each of these is approximately seven feet thick at the base, and weighs over 200 tons. The fourth wall and roof consist of very light frameworks covered with translucent plastic corrugated sheeting. The concrete walls are not securely founded in the ground, but rest on copper sheets laid on wedge-shaped footings. Should a high-energy explosion occur, some of the energy would be absorbed in moving the concrete walls outwards up their ramps, and the remainder dissipated as blast either upwards or outwards over open country. The control room and factory premises which are adjacent to the concrete walls are thus protected.

Next to the fourth wall there is an open pit containing the fuel reservoir and circulating pumps, together with the auxiliary system for fuel flow through the heat exchangers.

Beneath the Test Section Cabinet, which houses the flowmeter under test, there is an underground chamber with an inert atmosphere, into which fuel may be dumped in emergency.

Main Fuel Circuit The flowmeter under test is fed with fuel, drawn from a reservoir holding 1,000 gallons, by means of two independently controlled centrifugal pumps operating in parallel. The fuel passes through 10 micron filters to an inlet manifold supplying three alternative test sections of 1 in., 2½ in. and 4 in. bore respectively.

From the test sections the fuel passes to three pairs of metal tube Rotameters (which give an approximate indication of flow rate in the Control Room by a pneumatic remote transmission), and thence to three variable-orifice control valves which were designed specifically for this application.

The differential pressure across the flow control valves is used to control a pneumatically-operated valve in a bleed line between the inlet manifold and the reservoir. Flow rate is also held constant by maintaining a constant pressure drop across the orifice of the flow control valve. The stability of this automatic control is of a very high order.

Downstream of the control valves the three sections converge to a single discharge pipe, which may be directed to deliver to either of two tanks, each mounted on the platform of a steel-yard-type platform weighing machine. The tanks are of annular form, the fuel entering through a central vertical stand pipe from which it is sprayed radially. Each tank may be drained, through large bore remotely-controlled dump valves, back to the reservoir.

On each weighing machine a set of four poise weights is provided any combination of which may be applied to the steelyard by pneumatic actuators, representing up to 2,000 lb. of fuel for the larger machine and 250 lb. for the smaller. Each machine, together with its tank and discharge pipework, is mounted within a steel pressure vessel, to permit control of the atmosphere at the free fuel surfaces in the tanks.

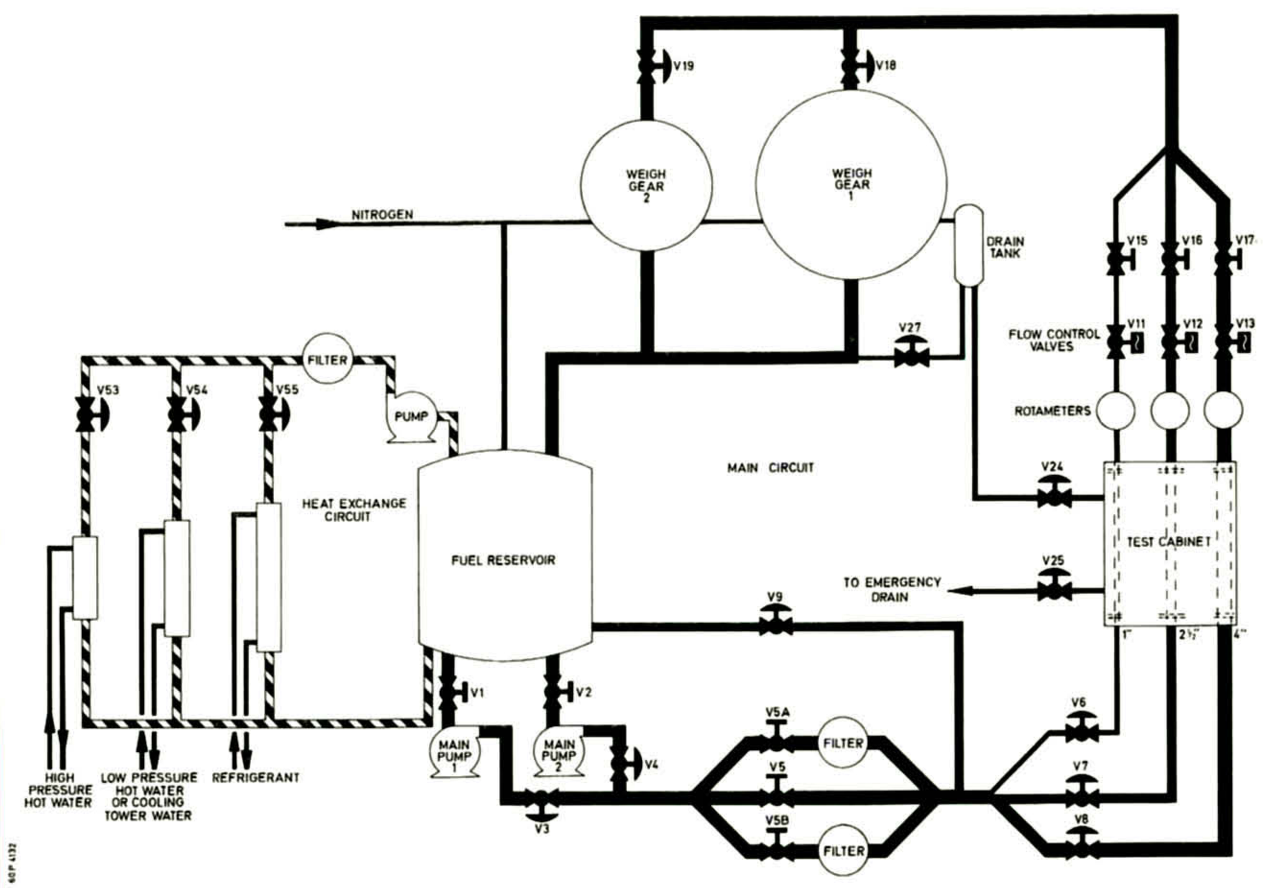
Auxiliary Fuel Circuit. A separate centrifugal pump is used to circulate fuel from the reservoir through two of three heat exchangers. The high temperature heat exchanger uses pressurized hot water from an oil-fired boiler, at a temperature of 204°C; the low temperature exchanger uses Freon 22 from a refrigeration plant, at temperatures down to −40°C: the third heat exchanger is an intermediate one, using either warm or cool water, for fine control of fuel temperature.

The accuracy of control is within ±½°C of the set value at temperatures between 5°C and 40°C, and within ±2°C at the extremes of the temperature range.

Test Section Cabinet The flowmeter under test can be installed in any one of three test sections. These are enclosed within an insulated cylindrical cabinet which is internally 3 ft. 6 in. diameter by 6 ft. long. The nominal flow capacities of the sections are:

1 in. bore,	120 – 4800 lb./hr.
2½ in. bore,	240 – 27000 lb./hr.
4 in. bore,	3000 – 100,000 lb./hr.

The test section bores are such as to limit the fuel velocity to values which are unlikely to result in the accumulation of a significant static electrical charge.



Main Circuit and Heat Exchange Circuit

The cabinet can be filled with nitrogen at a low positive pressure, and the atmosphere circulated by a fan, over a bank of electrical heater elements, to give temperatures up to 200°C, controllable to within ±5°C. For low ambient temperatures, liquid nitrogen is sprayed into the cabinet, the rate being manually controlled.

Beneath the cabinet is mounted a moving-coil vibrator giving a maximum thrust of 750 lbf. at frequencies up to 3,000 Hz, permitting vibration to be applied to the flowmeter under test whilst simultaneously subjecting the unit to specified flow rates, fuel temperatures and ambient temperatures. The vibrator drive is sealed with a bellows of fluoro-carbon plastic where it passes through the wall of the cabinet.

Some fifty electrical leads are brought from a terminal board in the cabinet to a display console in the Control Room. Low-capacitance coaxial cables are used to enable a wide range of supply and signal connections to be made with the equipment under test.

Nitrogen System Liquid nitrogen is stored in a vacuum-insulated enclosure situated between the Test House and the Control Building. It is used for a number of purposes in the Test House, namely pressurizing, purging, fuel treatment, cabinet cooling and fire suppression. The liquid is evaporated to pressurize the free surfaces of fuel in the reservoir and weighing machine pressure vessels. The resulting gas serves the dual purpose of preserving an inert atmosphere above the fuel, and also maintains an elevated pressure up to 30 p.s.i.g. which reduces evaporation losses. These would otherwise be severe at the higher temperatures of operation. A large-bore balance pipe ensures that the pressure in all vessels is the same. Gaseous nitrogen is used for purging some electrical equipment which is neither flameproof nor intrinsically safe, and is also bubbled through the fuel in the reservoir to remove entrained oxygen. Cooling of the test section cabinet was described in the previous section. All waste nitrogen is discharged into the underground chamber used for emergency dumping of hot fuel in case of accident, such as a failure of the equipment under test, or associated pipework, while at high temperature.

The Control Building

Structure The Control Building is a single storey industrial structure of conventional construction, apart from the use of an unusually strong flat roof of reinforced concrete. Precautions have been taken in the pipe and cable ducts connecting the building to the Test House to reduce hazard due to the possible accumulation of flammable vapour.

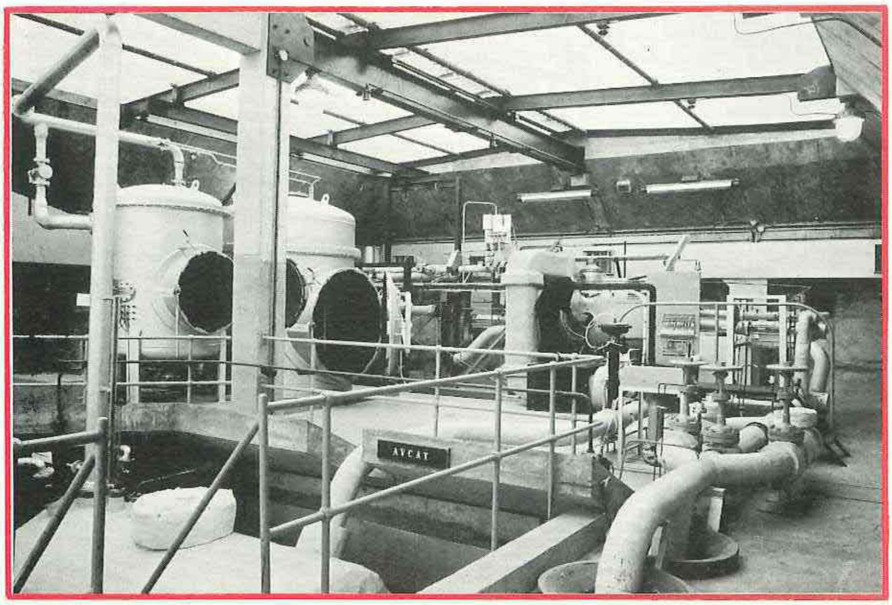
Control Room The Control Room houses two consoles and distribution panels for compressed air and nitrogen supplies. The main console is normally manned by two operators. The left-hand half is concerned with pumping and environmental conditions, nitrogen pressurizing, purging and fuel conditioning, and ancillary functions such as bleeding air from the main fuel circuit after start-up, and monitoring of filter pressure drop, pump seal coolant temperature, etc. The right-hand half is concerned with setting up of the flow rate, operation of the weighing machines, and display of the weighing period. The controls and instrumentation include inching switches to set flow rate, Rotameter gauges to give an approximate indication of the flow rate set, poise weight levers to select the amount of fuel to be weighed and a timer counter to measure the weighing period. NB The timer is triggered when the weigher reaches the balance condition by a pick off which senses the movement of the poise weight lever. The right-hand operator also has control of the amplitude and frequency of the vibration applied to the equipment under test. The subsidiary console is used for the display of the output signals from the equipment under test, and is arranged to be adaptable for mounting a variety of instruments, from laboratory measuring instruments to those actually used in the aircraft. If necessary, a complete aircraft flowmeter system can be operated and the overall errors measured.

Equipment Rooms The boiler room houses an oil-fired packaged boiler giving a normal hot water supply and a pressurized supply for the high temperature heat exchanger.

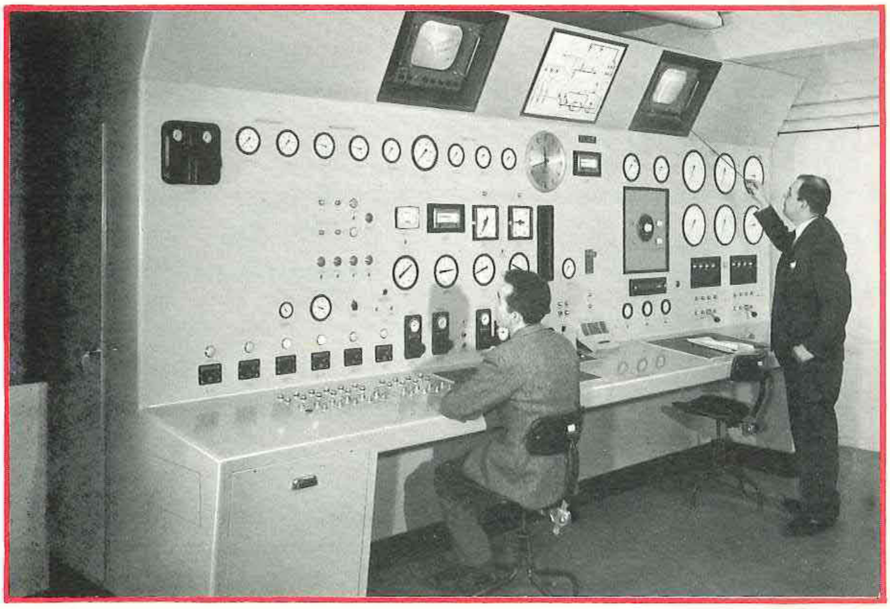
The refrigerator room houses a multi-cylinder refrigerator compressor, capable of being operated in sections for different ranges of temperature. The heat extracted from the fuel is dissipated in an adjoining cooling tower using air as the cooling medium. This room also houses the air compressor, reservoir, and drying equipment, for the supply of compressed air used for actuation of the weighing machine poise weights, control valves and various pneumatic instruments.

The electrical equipment room contains all power supply equipment, including the power amplifier used to drive the moving coil vibrator.

Interior of Test House



Control Console



Safety Precautions The main safety precaution which has been taken is that of maintaining a flameproof area within 30 feet of any fuel tanks or pipework. Within this area, which of course includes the whole of the Test House and external storage tank installation, use has been made of certified flameproof electrical equipment wherever possible. Where this is impossible as in the case of many indicator lamp circuits, use has been made of circuits operating at energy levels which are intrinsically safe, with appropriate limiting resistors in the control room. Alternatively, purging of the equipment with gaseous nitrogen has been employed, as in the case of flow control valve actuators.

The Test House and boiler room are equipped with automatic alarm and carbon dioxide fire extinguisher systems, which are arranged to cut off all power supplies apart from emergency lighting.

The arrangement for dumping burning fuel from the test section cabinet has already been described.

All pipe work is electrically bonded to minimize the risk of build-up of electrostatic charges, and fuel velocities are kept low for the same reason.

With the exception of the weighing tanks, which are of aluminium alloy with a low copper content, all metal in contact with fuel is of stainless steel to minimize catalytic degradation at high temperature. Reduction of entrained oxygen by bubbling nitrogen through the fuel is for the same purpose, and counters any tendency to form unstable oxidation products when the fuel is maintained at high temperature for protracted periods.

Conclusion Considerable use has been made of the Laboratory for the testing and development of angular-momentum type true mass flowmeters for aircraft and for testing of industrial turbine-type flowmeters at elevated temperatures. It is thought that in the future the Laboratory will also prove valuable in developing and type testing other components of aircraft and industrial fuel systems for which equally arduous operating conditions are becoming common, and to this end the facilities are being offered to organizations outside the GEC-Marconi Group.

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