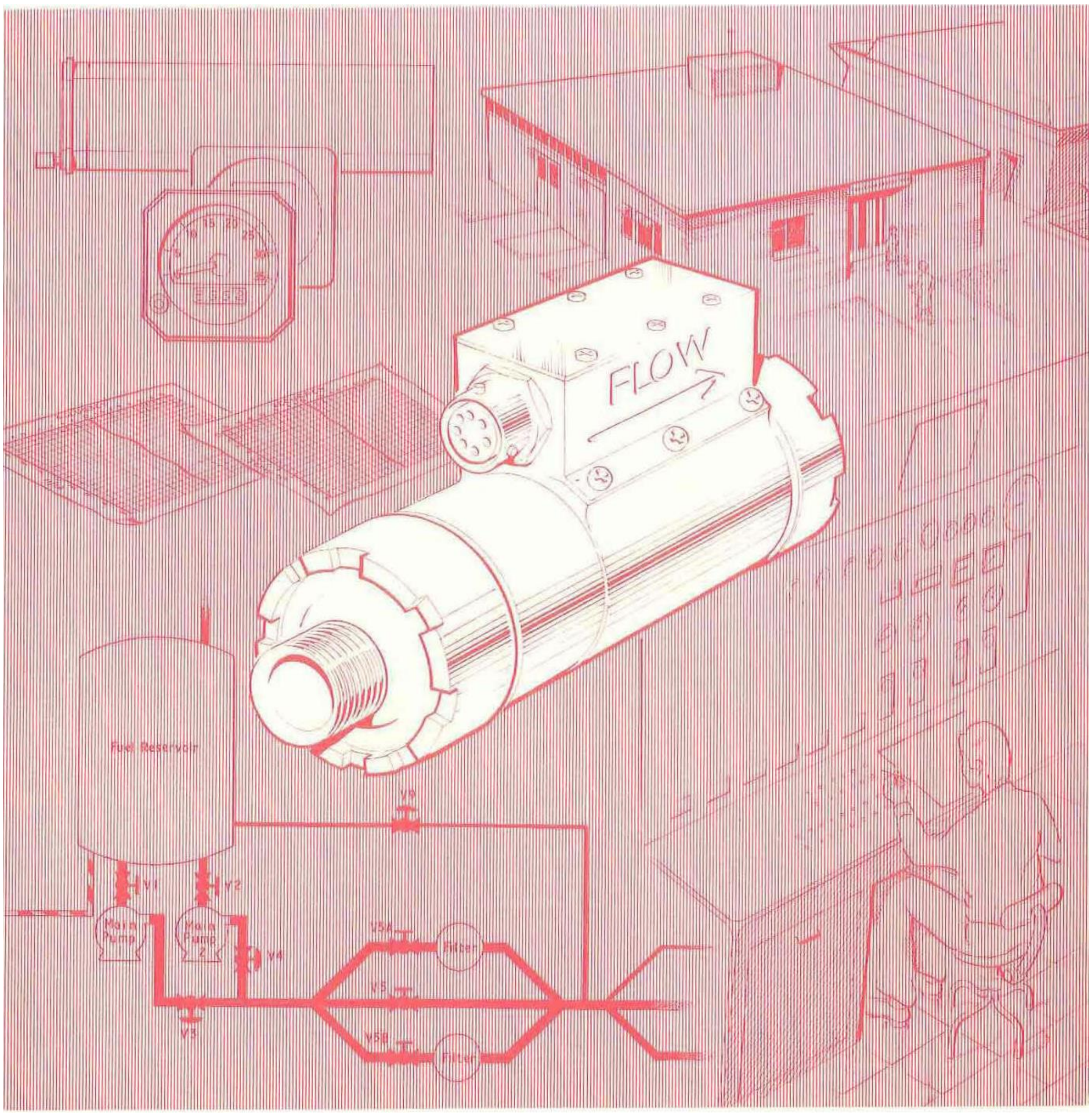
# The FUEL FLOW LABORATORY

by the Rochester Avionic Archives

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# CONTENTS:



# 1. Introduction

All aircraft fuel systems must have some form of fuel quantity indicator. These devices vary widely depending on the complexity of the fuel system and the aircraft on which they are installed. Simple indicators requiring no electrical power were the earliest type of quantity indicators and are still in use today on light aircraft. However, as aircraft grew larger it was necessary to have remote reading gauges. Another consequence of large aircraft was that fuel tanks may be distributed around the aircraft in the wings and fuselage and it is necessary to balance the quantity to maintain the aircraft trim. Yet another more sophisticated use of the fuel is to act as a heat sink to absorb kinetic heating from the structure and to dissipate heat generated by the air-conditioning and hydraulic systems.

The advent of the jet age and saw the need to know an engine’s fuel use in real time. This can be useful to the pilot for ascertaining engine performance and for flight planning calculations. With accurate fuel flow knowledge, numerous calculations can be performed to aid the pilot’s situational awareness and flight planning. Most high-performance aircraft have a fuel totalizer that electronically calculates and displays information, such as total fuel used, total fuel remaining onboard the aircraft, total range and flight time remaining at the present airspeed, rate of fuel consumption, etc.

Measuring fuel flow accurately is complicated by the fact that the fuel mass changes with temperature or with the type of fuel used in turbine engines. 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.

Additionally, every flow meter must be properly maintained and calibrated. All flow meters become inaccurate over time through regular use, meaning that regular re-calibrations must be completed based on specific calculations and general standards to ensure proper operation. Failure to calibrate the equipment means that the readings provided by the flow meters may be inaccurate and could result in system issues or even failures that could pose significant safety risks to those operating or travelling in the aircraft.

In consequence, for flowmeter development and calibration 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.

Fuel flow systems are not just used for aircraft fuel they also have applications in the hydraulic system and when filling the engines with lubricating oil. There are just as many applications in the world of transport from the basic petrol pump we are all familiar with.

## 2. Fuel Flow equipment

Instruments for the measurement of fuel tank capacity and flow seem to have been made by a number of companies such as Simmonds Aerocessories of London who advertised the product in 1952 and in that year they acquired Firth Cleveland Instruments and as that became the overall company name from 1953 onwards they are found under the Firth Cleveland Instruments name. Elliott Bros purchased Firth Cleveland Instruments in 1961 and continued the brand from the Treforest works where they also made Flowmeters and Test sets for these.

Elliotts established a substantial business in fuel systems and the aircraft supplied reads as a roll call of British civil and military aircraft for over 40 years. A snapshot of the platforms to which these were fitted can be gained from one of the Company databases:

AV8B, Argosy, BAC 1-11, Bristol Brittania, Buccaneer, Comet, Concorde, Dominie, EFA, Fiat Rig, Fokker F27 and F28, Hawk and Finnish Hawk, Herald, HS125, HS146 (BAe146), Javelin, Sea Venom, Sea Vixen, Typhoon, Valiant, Vickers Vanguard, Vickers Viscount, Scimitar, Trident, P1127, Phantom, Phoenix, Trident, Transall C160, MRCA (Tornado), G222, VC10, Wessex, RB211 and RJ500 engines.....

The Rochester Avionic Archives holds a number of items some of which are shown below:-

Fuel Flowmeter Amplifier from a Vulcan around 1958

Fuel Flow Transmitter from a Wessex Helicopter around

Fuel Level Tank Sensor Unit from a Vickers Viscount around 1967


Fuel Flow Rate Indicator supplied for the Trident around 1968

Fuel Flow system supplied for Concorde around 1970

Twin Fuel Flow Rate Indicator for the Tornado around 1973

Fuel Flow Transmitter supplied for the Harrier around 1981

Fuel Flow Transmitter supplied for the Eurofighter Typhoon around 1995

## 3. The Fuel Flow Laboratory

On November 20, 1963, Mr Neil Marten, M.P., Parliamentary Secretary to the Ministry of Aviation, officially declared open the new high-temperature fuel flow laboratory of Elliott-Automation Ltd. at Rochester in Kent.


Aerial View showing the location of the Fuel Flow Laboratory

### General Description

The Laboratory consists of two buildings, the Test House and the Control Building. These are situated within an area which was originally 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 contained 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 were observed. Because of the hazardous nature of aviation fuel, a separate Test House building was required and built such that in the event of an explosion, the blast would be directed toward the airfield and away from the Main Factory. It was designed to test fuel flow equipment for the new generation of supersonic aircraft where fuel temperature of 150°C or higher would be encountered, and units would be required to operate at rigid standards of accuracy under extreme conditions of temperature (up to 200°C ambient) and in areas of extreme vibration The building is of unique design.

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

The Laboratory could achieve gravimetric calibration accuracy within an error band of ±0.1% of flow rate under the following conditions:

1. Flow rates from 50 to 120,000 lb/hr through three different bores of pipe.

2. Fuel temperatures from -55°C to +180°C.

3. Ambient temperatures from -60°C to +200°C.

The facility was built entirely as a private venture and was used primarily for the testing of aircraft fuel flow meters and fuel system components under the range of environmental conditions likely to be encountered in supersonic flight.

## 3.1 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.

964


Interior view of the Test House in 1964

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

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

**Main Fuel Circuit** The flowmeter under test was fed with fuel, drawn from a reservoir holding 1,000 gallons, by means of two independently controlled centrifugal pumps operating in parallel. The fuel passed 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 passed to three pairs of metal tube Rotameters (which gave 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 was used to control a pneumatically operated valve in a bleed line between the inlet manifold and the reservoir. Flow rate was also held constant by maintaining a constant pressure drop across the orifice of the flow control valve. The stability of this automatic control was of a very high order.

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

On each weighing machine a set of four poise weights was provided any combination of which could 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, was 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 was used to circulate fuel from the reservoir through two of three heat exchangers. The high temperature heat exchanger used pressurized hot water from an oil-fired boiler, at a temperature of 204°C; the low temperature exchanger used Freon 22 from a refrigeration plant, at temperatures down to -40°C: the third heat exchanger was an intermediate one, using either warm or cool water, for fine control of fuel temperature.

The accuracy of control was 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 could be installed in any one of three test sections. These were enclosed within an insulated cylindrical cabinet which was internally 3 ft. 6 in. diameter by 6 ft. long. The nominal flow capacities of the sections were:

1 in. bore, 120 - 4800 Ib./hr.

2½ in. bore, 240 - 27000 Ib./hr.

4 in. bore, 3000 - 100.000 Ib./hr.

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

The cabinet could 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 was sprayed into the cabinet, the rate being manually controlled.

Beneath the cabinet a moving-coil vibrator was mounted giving a maximum thrust of 750 Ibf. 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 was sealed with a bellows of fluoro-carbon plastic where it passes through the wall of the cabinet.

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

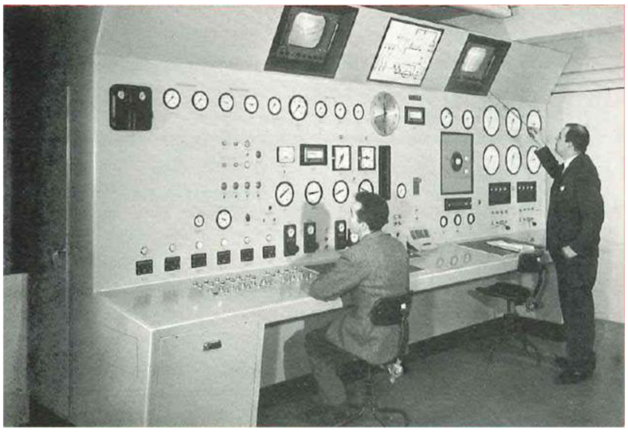
**Nitrogen System** Liquid nitrogen was stored in a vacuum-insulated enclosure situated between the Test House and the Control Building. It was used for a number of purposes in the

Test House, such as pressurizing, purging, fuel treatment, cabinet cooling and fire suppression. The liquid was evaporated to pressurize the free surfaces of fuel in the reservoir and weighing machine pressure vessels. The resulting gas served 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 have been severe at the higher temperatures of operation. A large bore balance pipe ensured that the pressure in all vessels was the same. Gaseous nitrogen was used for purging some electrical equipment which was neither flameproof nor intrinsically safe and it was 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 was 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 pipe work, while at high temperature.

## 3.2 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 were 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.

The Control Building about 1964



The Control Room in the Fuel Flow Laboratory

**Control Room** The Control Room housed two consoles and distribution panels for compressed air and nitrogen supplies. The main console was normally manned by two operators. The left-hand half was 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 was concerned with setting up of the flow rate, operation of the weighing machines, and display of the weighing period. The controls and instrumentation included 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. The timer was triggered when the weigher reached the balance condition by a pick off which senses the movement of the poise weight lever. The right-hand operator also had control of the amplitude and frequency of the vibration applied to the equipment under test. The subsidiary console was used for the display of the output signals from the equipment under test and was 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 could be operated and the overall errors measured.

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

The refrigerator room housed a multicylinder refrigerator compressor, capable of being operated in sections for different ranges of temperature. The heat extracted from the fuel was dissipated in an adjoining cooling tower using air as the cooling medium. This room also housed 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 contained all power supply equipment, including the power amplifier used to drive the moving coil vibrator.

**Safety Precautions**

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

The Test House and boiler room were equipped with automatic alarm and carbon dioxide fire extinguisher systems, which were 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 was electrically bonded to minimize the risk of build-up of electrostatic charges, and fuel velocities were kept low for the same reason.

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

**Conclusion** Considerable use was 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.

With the new Fuel Flow Test Lab in action the Company became a major supplier in fuel instrumentation.

## 4. Current status

In the 1980’s the building became surplus to requirements when the Company ceased manufacture of Fuel Flow instrumentation. The building was used in the 1990’s by the Phoenix project and has been used occasionally for the storage of equipment. However, no real long term use has been proposed for the building and it is currently under the care of BAE Systems Estates.

In 2014 a survey of the buildings was carried out to see if it might have any potential as a site for the Company Museum. The conclusion was that this would not be a practical future use.

## 4.1 The Test House

Due to the dilapidated condition of the sacrificial roof and South facing wall, the building is not totally weatherproof and therefore suffers from water ingress and pigeon infestation.

The grounds surrounding the Fuel Flow Laboratory and Test House are grassed and well maintained with flower beds and picnic benches. Weather permitting, it is one of the most pleasant areas on the site for employees to spend their lunchtime.


Inside the Test House
In 2014

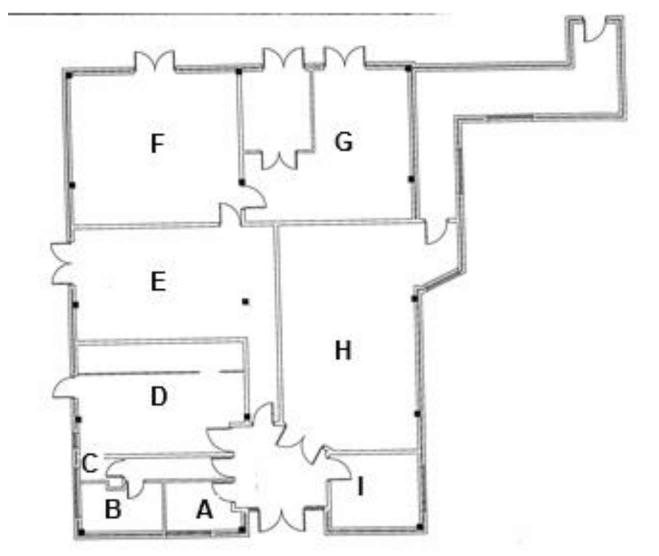
The Test House

## 4.2 The Control Building

A floor plan of the building as it was in use is shown on the right:

**Key**

Room A is a small office
Room B is a kitchen
Room C is a toilet
Room D is a workshop with an electrical storeroom enclosed within it.
Room E is a large workshop with work benches running the width of the room.
Room F is a plant room containing machinery to heat and pump fuel.
Room G is the Boiler Room
Room H is clear of equipment and furniture and includes a passage to the back of the building.
Room I is a small corner office.



Floor Plan

The Fuel Flow Laboratory Control Building today

The building is in good condition having been repurposed as a storage facility. The external walls are 9" brick with some evidence of weather erosion on the South facing wall. The internal walls appear to be cinder block or brick with plaster given their solid construction. Windows are Crittall metal frame, and the doors are all timber framed. The double wooden doors to the south of the building are in poor condition.

## 5. Associated Documents and Media

D0067 Brochure ‘The Fuel Flow Laboratory

M0571 Media  Elliott Laboratory Report 1964