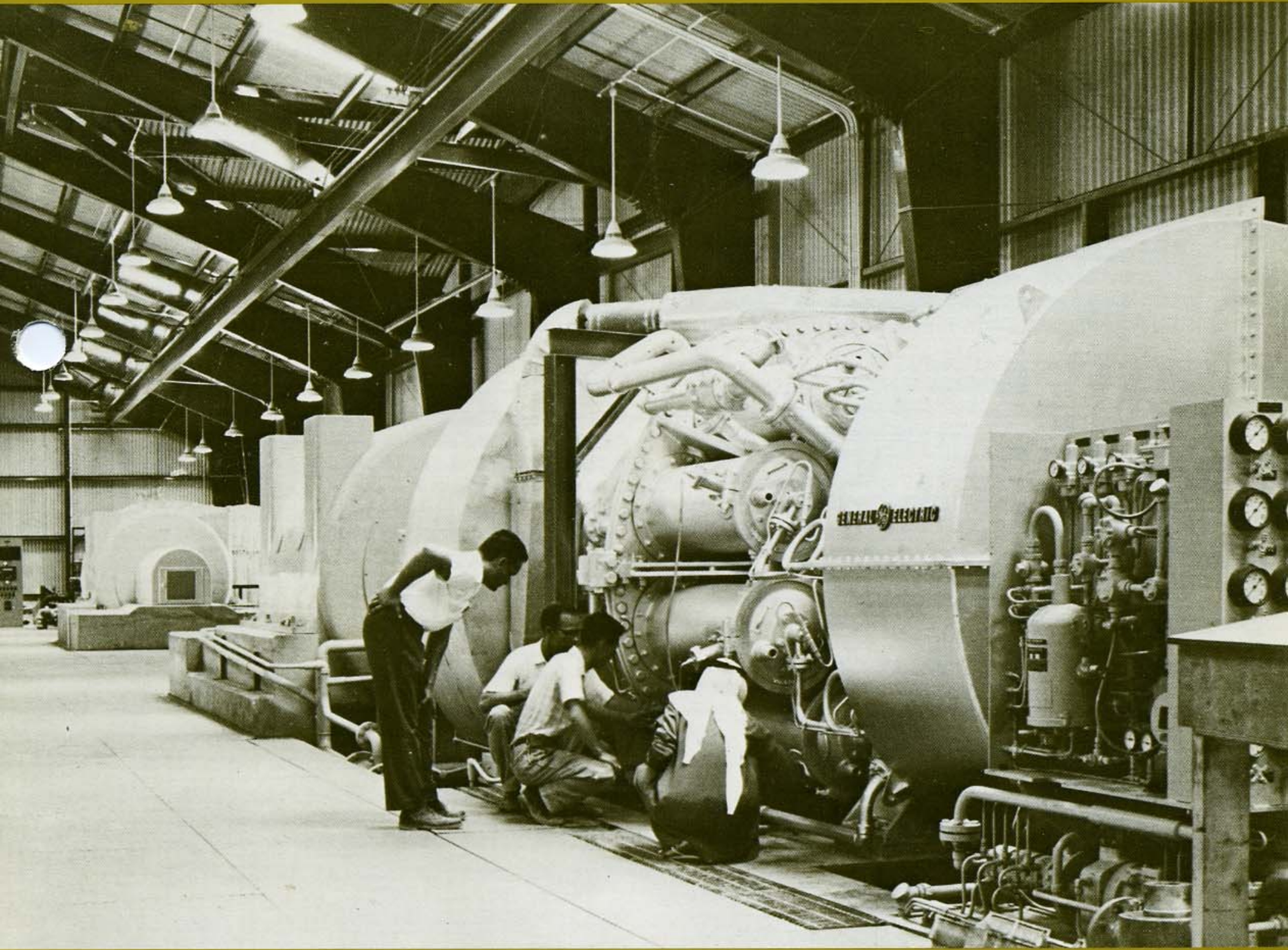
Computer speeds gas turbine combustor testing

A Solution to a Measurement Problem for:

GENERAL ELECTRIC
Gas Turbine Operations
Schenectady, New York



The General Electric Series 5000 Gas Turbine Power Plant, shown here in a non-packaged configuration. (It is also very commonly configured as a Package Power Plant complete with gas turbine, controls, switching, and accessories.) Note the three combustion chambers in front of the viewers.

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The General Electric Company Gas Turbine Operations in Schenectady, New York, is engaged in the full range of engineering and manufacturing activities involved in producing heavy-duty gas turbine systems. GE has pioneered in the development of modern gas turbines, which represent a composite of technological advances from its own unique expertise in both jet engine and steam turbine design. GE produces a broad line of gas turbines designed to meet virtually any need. A highly successful product of GE's capability is exemplified by the GE Model Series 5000 heavy-duty gas turbine. It is widely used for industrial and utility power generation as well as mechanical drive applications, performing service ranging from continuous duty to standby operation.

INSIDE THE GAS TURBINE

Gas turbines are available in a variety of designs: simple cycle, regenerative cycle, single- or dual-shaft, etc. Perhaps the most commonly used is the simple-cycle, single-shaft design; most gas turbine power plants are of this design.

A somewhat simplified diagram of the major components comprising a single-shaft gas turbine is shown in Figure 1. The main elements are an axial-flow compressor, fuel and combustion system, and power turbine. The axial compressor (centrifugal-type compressors are usually used only in smaller gas turbines in the range of 500 hp and less) provides a continuous stream of high pressure air into the combustion chamber (10 such chambers are used on a Series 5000 unit) where fuel is added and burned. The resultant high-pressure gases expand in the power turbine to produce useful shaft output power for electrical or mechanical applications.

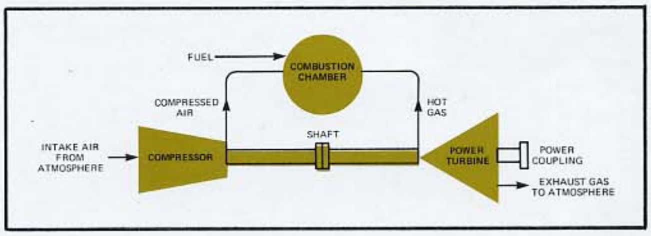

Figure 1. Major components of a simple-cycle, single-shaft gas turbine power plant.

A CLOSER LOOK

While all elements of a gas turbine require a good deal of research, development, testing, and other necessary engineering efforts, the combustion chamber presents some rather unique challenges to designers and engineers. A closer look at the combustion chamber will point out some of these factors and at the same time *provide insight on the need to accurately measure a large number of performance characteristics.*

A typical combustion chamber (commonly referred to as a combustor) is shown in Figure 2. Its function is to supply heat energy to the cycle. This is done, as mentioned earlier, by mixing fuel with compressed air and burning the fuel inside the combustor. Air flow patterns in a combustor are shown in Figure 3. Each combustor is equipped with a fuel nozzle which atomizes and injects the fuel into the "reaction zone" where combustion takes place. Only a fraction of the air is used in the reaction zone (the length of which is approximately 1½ times the combustor diameter). The hot combustion products are then mixed with the remaining (excess) air in a "tempering zone" where the hot gas is cooled to the allowable turbine inlet design temperature. This hot gas from the combustor is delivered to the turbine nozzle by means of a transition piece. Crossfire tubes are used to interconnect the reaction zones of a multiple combustor system so that only one ignition source need be used for lightoff. GE design incorporates pressure-retracted spark plugs for ignition, with a minimum of two plugs for added reliability. When the turbine speed increases, the combustor pressure causes the spark plugs to retract, thus removing the electrodes from the flame zone.

Designing successful combustion systems involves a number of factors which are so interrelated that an improvement in one area may be detrimental in another. GE combustion systems are the result of a balanced design concept with particular emphasis on the following, which are the very same parameters involved in combustor testing, as described later:

- Proper ignition timing and fuel injection
- Holding internal pressure drops to reasonable limits
- Maintaining stable combustion with no loss of flame from full fuel flow to a no-load value
- Metal temperatures (low enough to ensure long life)
- Proper temperature distribution at the turbine inlet (the turbine nozzle is the hottest part of the gas turbine)
- Reduction of carbon which can deposit inside the combustors and also show up as smoke in the stack
- Minimize the production of exhaust pollutants

Placing each factor in its proper relation to every other factor involves a number of different technologies to produce this balanced design. GE has determined that, after theoretical design, a successful combustion system is best arrived at by empirical means. For this reason, the Gas Turbine Operations has conducted many thousands of tests on combustors through the years.

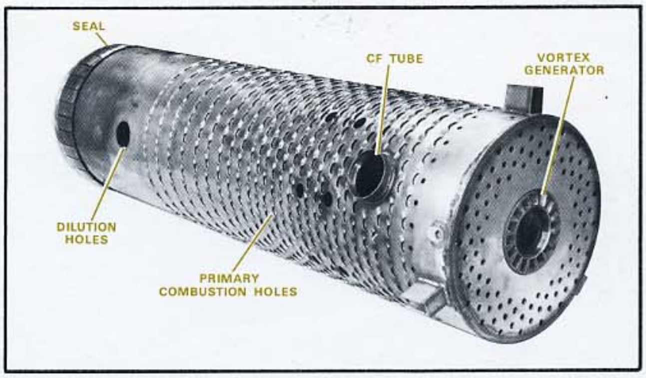

Figure 2. Gas turbine combustor, typically 10", 12", and 16" diameter. Heat energy is supplied to the cycle by burning fuel in pressurized air inside the combustor.

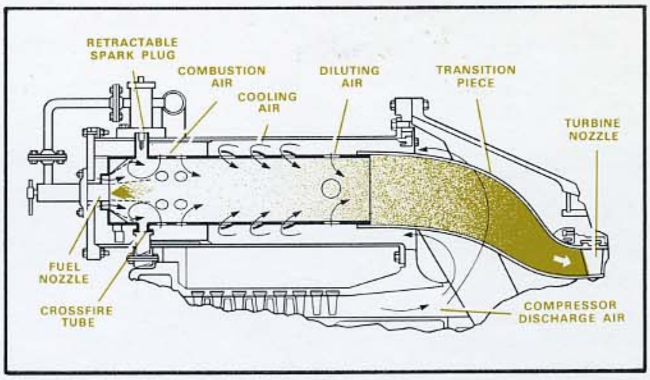

Figure 3. Air flow patterns in a combustor. Proper air flow is a critical factor in preventing blowout whenever fuel flow must be very quickly reduced to no-load value.

SOLUTION: COMPUTERIZED DATA ACQUISITION

The Combustion Development Laboratory of the Gas Turbine Operations has prime responsibility for developing combustion systems for all GE heavy-duty gas turbines. Here, too, is the responsibility for conducting extensive testing of combustors to assure that the combustion system will perform as required when installed in a complete gas turbine system, and also to develop the technology necessary for combustion systems for advanced machines.

Traditionally, the acquisition of combustor test data has been done by means of analog meters and chart recorders. While these techniques provide acceptable data, the combustion engineers have long been aware of inherent inadequacies associated with using straight analog methods. The most obvious of these are the requirements to manually read meters and manually record the readings for subsequent analysis. These, of course, are time-consuming tasks and subject to human interpretation error. Combustor designers need results as soon as possible after test completion because preparation for succeeding tests is quite often dictated by results of previous tests. Also, to speed up the process, the data must be available directly in engineering units. Analog methods fall short of satisfying these basic requirements.

Approximately two years ago, the Operation studied the various data acquisition techniques and equipment available. Particular emphasis was placed on a system design which would meet present needs and at the same time offer flexibility for future expansion. The study very clearly showed that a computer-controlled digital data acquisition system would give GE the flexibility and power to handle the combustor testing requirements. Ultimately, a Hewlett-Packard computerized digital data acquisition system, as shown in the block diagram (Figure 4), was selected as the best solution to the Operation's overall requirements.

At the heart of the system is a general-purpose, stored-program digital computer with 8K (16-bit words) memory. The computer is equipped to interface with a wide variety of data logging and display peripherals and data input devices, in addition to those specifically used in the combustor test system. The system presently uses a comprehensive software package including drivers for all the computer interfaces, diagnostic and verification software, an analog scan routine which simplifies data acquisition operations under interrupt control and allows random or sequential scanning of the analog inputs, plus a data acquisition and control executive (DACE) which schedules and coordinates all data acquisition activities in real-time. When operating with the DACE software system, programming is done in FORTRAN or Assembly languages. The system may also be programmed in BASIC language, using the BASIC interpreter, for non-real-time applications.

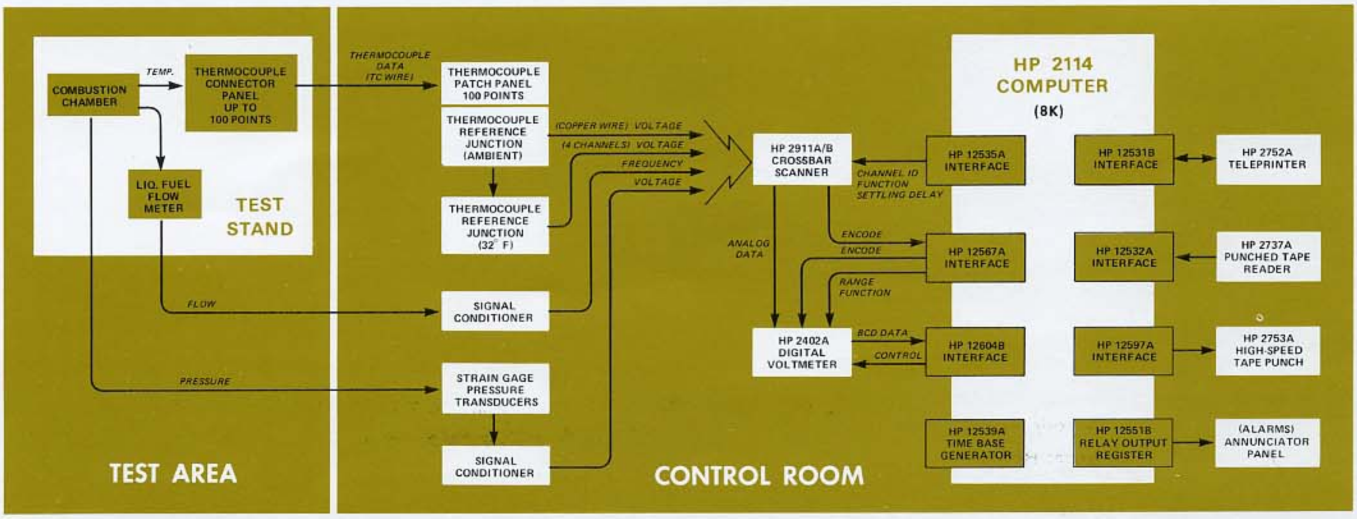

Figure 4. Computerized data acquisition system for combustion system testing at General Electric.

Analog inputs to the system are through the 200-channel crossbar scanner, and then through the voltmeter where they are digitized for input to the computer. The hardware time base generator provides a precise time reference for scheduling the execution of "tasks" (measurements, calculations, etc.) when operating under DACE control. The teleprinter is the system command terminal providing communications between the operator and the computer. The punched tape reader handles program inputs to the computer at the rate of 500 characters per second. The high-speed tape punch allows measurement data to be punched on tape for later in-depth analysis at a large central computer facility. The relay output register provides 16 programmable contact closures to an annunciator panel in the control room.

INSIDE THE TEST LAB

All testing is made using full-size combustors in a test arrangement which simulates one machine combustor and associated hot gas path of a multi-combustor system. (Extensive experimentation with scaled-down combustors has produced results which have proved to be invalid, thus requiring that tests be conducted on full-size combustors.) Figure 5 shows a combustor system mounted on one of several test stands in the lab. Fuel and air are supplied from a central source and are made available to one test stand at a time. It is interesting to note that the largest single cost in combustor testing is a supply of compressed air, which can be as high as $90 to $100 per hour. (The casual observer probably thinks of air as something which is free – it is, at one atmosphere level as provided by nature. Compressed air, though, is very expensive to produce since its cost is directly related to pressure levels and the length of time needed.) Combustor performance is evaluated over the range of flow and temperature conditions that will be encountered in actual system operation. Virtually any size combustor can be tested in addition to the commonly used 10", 12", and 16" sizes. The lab is fully equipped to test regenerative-type systems as well as special air extraction systems.

The computerized data acquisition system is in a centrally-located control room, averaging about 30 feet from the test stands. Thermocouple (TC) connector panels, mounted at each test stand, are permanently wired with TC wire to corresponding TC patch panels (100 points each) in the control room. Figure 6 shows TC input connections being made on the patch panels. A TC reference junction, actually a large copper block capable of accommodating 100 TC inputs, is mounted on each patch panel. The transition from TC wire to copper wire (the actual reference junction) is made within the copper block whose temperature floats with ambient temperature. The temperature of the copper block is measured by four calibrated TCs which are connected to an electrical ice-point reference. A reference TC output, representing the copper block temperature, is added by the computer to each TC output from the test stand. Thus, each test stand temperature point is corrected by the computer system to appear as though it truly had an actual ice-point reference junction. By this technique, as opposed to purchasing multi-reference junctions, GE has reduced initial costs by approximately $2,500 per test stand with additional savings to be realized if it is desired to change TC materials.

Figure 5. In the test lab, preparations are being made for testing a non-regenerative combustion system. Pressurized air enters the test stand through the large pipe in the foreground.

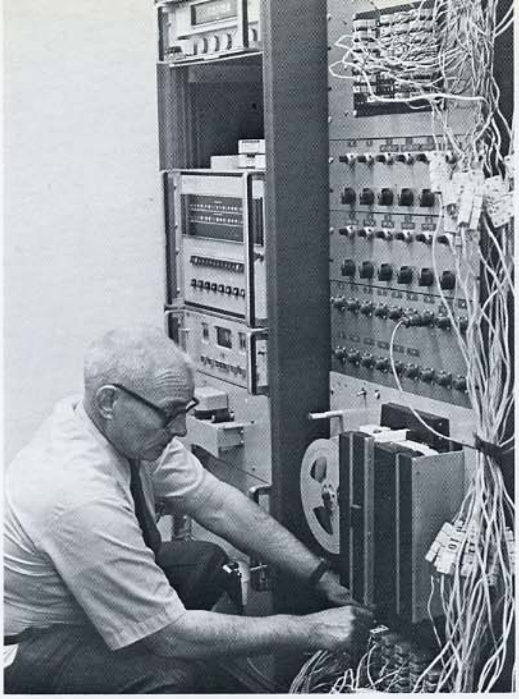

Figure 6. The computerized data acquisition system inside the control room (teleprinter is not shown). Here, Mr. W.E. Hill, Combustion Systems Development Engineer, is making a final check of thermocouple inputs prior to beginning a new test.

Pressures are measured by transducers housed in a cabinet inside the control room. All are temperature-compensated, bonded strain gage transducers with four arms active. Differential-type pressure transducers are used for all differential pressure measurements. Other pressure transducers are gage type rather than absolute. Since the gage type is referenced to one atmosphere (14.7 psi) it is less likely to leak and cause erroneous readings as compared with the absolute type which is referenced to vacuum. The system can also provide pressure readouts in absolute units by obtaining barometric pressure from a barometer, and adding barometric to gage pressure in the computer. When operating in BASIC, the barometer readings are input to the computer through the teleprinter keyboard. Under DACE, the barometer readings are handled as accessible constants, that is, they are called through a software program written for the purpose. Each pressure transducer is electrically connected to a signal conditioner, and input to the measurement system is through the crossbar scanner.

SOLUTION (continued):

A turbine-type flow meter is mounted at each test stand to meter liquid fuel flow at the fuel nozzle; the electronic portion of the meters is installed in the cabinet with the pressure transducers inside the control room. These are rf-type meters which produce a constant amplitude square wave output whose frequency is proportional to flow rate. The actual physical measurements of air flow and gas fuel flow are obtained from an orifice by means of pressure transducers, and detected as analog voltages at the crossbar scanner input.

The physical arrangement of the test lab, with essential measurement instrumentation available in the centrally-located control room, simplifies the operation and maintenance of the system; also, it is a relatively easy task to change from test stand to test stand. The latter has been achieved, in part, by planning the system so that common measurements, such as pressures and flows, are made on the same input channels regardless of which test stand originates the data. This also eases system programming efforts. Moreover, the computerized data acquisition system has proved to be a one man operation, as projected in the original system study, thus releasing other previously-needed technicians into more productive areas of combustor development.

RUNNING THE TESTS

Once a test stand is set up and all the test data points connected, the entire data acquisition process then operates under program control in real-time, through the DACE software system. DACE control accounts for about 90% of total computer usage, while BASIC language programming is used the remainder of the time. Combustor tests needs can, to some extent, be handled by programming in BASIC, however, as an interpretive language it does not provide the real-time capability nor other features offered by DACE.

Typically, a combustor test requires about 100 measurements, consisting of 80 to 90 air temperatures in the range of 500 to 1850°F, 10 to 15 pressures in the range of 15 to 100 psi for air and 50 to over 1000 psi for fuel, and 4 or 5 air and fuel flows. Some tests may also specify metal temperature surveys which can require an additional 20 to 30 temperature measurements in the range of 500 to 1400°F. (The significance of metal temperatures lies in the fact that the length of life of hot gas parts is dependent upon their operating temperatures.)

Most testing is done after the combustor reaches steady-state conditions, i.e., test points are allowed to stabilize before measurement begins. The only testing of a varying nature is of parameters related to combustion stability and ignition.

GE conducts comprehensive combustor testing with a six-task procedure using the DACE operating system. *Under DACE scheduling, the computer automatically executes the tasks in real-time and at specified intervals in the order of priority set up by the operator for the combustor test requirements.* The six tasks comprising the combustor test sequence are:

- Task #1. Prior to beginning the actual data acquisition process, 34 channels are measured to check out the test stand and verify that it can be safely operated. This task: (1) measures and prints only liquid flow rate, (2) measures and prints only air flow rate, and (3) prints out test identification, test requisition number, data, and engineer's name, as entered from the teleprinter keyboard. Data are recorded on the high-speed tape punch, as desired, and printed out in engineering units on the teleprinter.

- Task #2. This task measures the complete temperature distribution at a simulated turbine nozzle. The task is written in a general manner to handle tests on any test stand in the lab. Data are recorded on the high-speed tape punch, as desired, and printed out in engineering units on the teleprinter.

- Task #3. This task measures a block of adjacent temperature input channels, and outputs channel number and temperature for all channels. Each block begins with one of the four ice-point reference junction channels. Data are recorded on the high-speed tape punch or printed out in °F on the teleprinter. Black body and color temperature of the flame are measured. Color temperature is assumed to be the actual flame temperature, and flame emittance is computed.

- Task #4. This task permits checking any selected input channel for calibration, troubleshooting, or balancing pressure transducer bridges. The selected channel number is input from the teleprinter keyboard. Switch register options permit either a single measurement or repetitive measurements each half second.

- Task #5. This task measures bunker C fuel flow rate by relating data obtained from load cells on a weigh tank to elapsed time from the time base generator. Successive weight and time measurements are made. The computer subtracts each succeeding weight measurement from the initial weight, and divides by elapsed time to obtain an integrated flow rate. The output is printed out in lb/hr on the teleprinter.

- Task #6. This task measures main chamber air flow rate (by means of pressure transducers) plus water flow rate. In addition, the ratio of water to air is calculated (in percent). Measurements and calculations are printed on the teleprinter.

Certain critical temperature and air flow measurements are monitored by an alarm system (annunciator panel) in the control room. Out-of-limit conditions are signalled by blinking lights to enable the operator to cut back fuel flow or stop the test, if necessary.

BENEFITS OF MODERN TECHNIQUES

The computerized data acquisition system has sharply increased the testing capabilities of the Combustion Development Laboratory. Now, the design engineers have test data and computed performance parameters available immediately after a test is completed. Immediate results, printed directly in engineering units, help designers to early recognize any unusual operating conditions. Also, decisions pertaining to a test can be made and preparations begun immediately for the next test without waiting for results, which previously required about four hours.

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