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COMPRESSOR RESEARCH FACILITY
RIG 4 PROJECT ANALYSIS REPORT

VOLUME II. TEST AND OPERATING PHILOSOPHY

THE GENERAL ELECTRIC COMPANY

TECHNICAL REPORT AFAPL-TR-70-28, VOLUME II

OCTOBER 19, 1970

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COMPRESSOR RESEARCH FACILITY

RIG 4 PROJECT ANALYSIS REPORT

VOLUME II. TEST AND OPERATING PHILOSOPHY

THE GENERAL ELECTRIC COMPANY

CRF Rig 4 Project Analysis Report
Volume II
19 October 1970

FOREWORD

The study described in this project was performed as part of Contract No. F33615-69-C-1704 in support of Project No. 3066 'Gas Turbine Technology," by the Management and Technical Services Department, General Electric Company in Bay St. Louis, Mississippi. This contract calls for the analysis, design, development, construction and checkout of a Compressor Research Test Facility at Wright-Patterson Air Force Base.

The work was directed by the Air Force Aero Propulsion Laboratory and was managed by the Civil Engineering Directorate of the Aeronautical Systems Division. Key personnel associated with the Program include Mr. B. Koziej, Program Manager, Civil Engineering Directorate; Mr. J. Gutman, Project Manager, Aero Propulsion Laboratory, Technical Facilities Division; and Mr. W. Nabors, Project Engineer, Aero Propulsion Laboratory, Turbine Engine Division.

The report was submitted by General Electric in March 1970. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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LIST of ABBREVIATIONS

ACCEL	acceleration
A-D	analog-to-digital
AUTO	automatic
BCD	binary coded decimal
CAL	calibration
CFE	contractor-furnished equipment
CHAN'S	channels
CPU	Central Processing Unit
CRF	Compressor Research Facility
CRT	Cathode Ray Tube
dc	direct current
DECEL	deceleration
DIFF	differential
^{o}F	degrees Fahrenheit
Ft.	foot, feet
FS	full scale
hp	horsepower
GEN	generator
GFE	government-furnished equipment
GPM	gallons per minute
HRS	hours
Hz	Hertz
Imp. Rout.	improvement routine
in	inch
I/O	input/output
IRIG	International Range Instrumentation Group
kHz	kilo-Hertz
lb-ft	pound-feet
lbs	pounds
MAX	maximum
MG	motor generator
MIN	minimum
MIN	minute
No.	number
O'GRAPH	oscillograph

LIST of ABBREVIATIONS (cont'd)

pps	pulses per second
PRESS	pressure
psia	pounds per square inch absolute
PWR	power
Rdg.	reading
REF	reference
REQ'D	required
RMS	root mean square
RPM	revolutions per minute
SEC	seconds
TEMP	temperature
TM	torquemeter
TYP	typical
X-Y	abcissa-ordinate (graph axis)

SECTION 1
INTRODUCTION

INTRODUCTION TO VOLUME

The purpose of Volume II of the Rig 4 Preliminary Project Analysis Report is to outline the Compressor Research Facility (CRF) test and operating philosophy which has been defined as a result of the studies conducted during Phase I of the CRF program. Much of this operating philosophy is directly associated with the initial CRF configuration (System I); however, with very few modifications, it can be applied to the more advanced configurations under consideration (System II and System III as described in paragraph 2.2).

This information is presented as follows:

- Section 2 - General (CRF purpose, capabilities, and modes of operation)
- Section 3 - Facility Operating Philosophy (description of all aspects of the recommended facility operating philosophy including control console layout, personnel requirements, test planning and documentation, calibration and maintenance, operation of facility controls, operation of computer and measurements systems, and pretest preparation).
- Section 4 - Compressor Testing Philosophy (discussions of how the facility can be used for accomplishing several typical compressor tests)

INTRODUCTION TO TEST AND OPERATING PHILOSOPHY

Compressor testing is necessary because of the intrinsic interdependence of variables which inhibit development of satisfactory analytical techniques for prediction of compressor performance. Compressor testing involves a number of complex, interrelated activities, equipment, data systems, and goals balanced against time and cost to accomplish meaningful results. Under present testing techniques, time becomes a limiting factor when delays are required for converting and digesting previous test data to enable prediction of the next step in the test procedure. The overall philosophy used to generate test and operating concepts for the Compressor Research Facility will be directed as much as possible to cutting the time and expense required to test an axial flow compressor in a safe, pollution-free environment. The goal will be to provide a facility capable of operation at maximum efficiency with a minimum number of people. This, in general, will be accomplished through automatic control and decision making with the digital computer when possible. It should be realized that the minimum number of personnel required to operate the CRF will be increased to more than those personnel at other existing compressor test facilities because of the test time speedup and massive quantities of information that will be available in near real time for the test participants. Many duties now performed by human operators can be performed better and more accurately by computer control, thereby leaving personnel free for duties for which there are no adequate substitutes. The duties which can be performed by the computer include some of the functions of control, data acquisition, computation, parameter adjustment, monitoring, test logic, and certain decision making. Delegation of many of these responsibilities to the computer is possible and can minimize test time, increase the amount of data for a given test time, reduce the cost per data point, provide data not now practical to obtain, minimize human error, and provide additional safety for the test vehicle.

The overall operating philosophy for the CRF, therefore, will be to direct all functions possible to automatic control. The digital computer will be used to provide high speed data acquisition, high speed performance computations, and rapid and efficient display of compressor test data. As an option, the computer may also be used to provide setpoint control for several of the major compressor parameters during a test and, therefore, make further reduction of the test time possible. Flexible closed loop automatic control systems will be provided to control compressor parameters during a test. These control systems will be designed to interface with computer setpoint control when a test is being conducted under computer control and to respond to manual setpoints when the facility is being operated manually.

Every attempt will be made to design these control systems to be compatible with a direct digital control mode of operation if, at some later time, it should become desirable to incorporate this mode of operation into the CRF.

SECTION 2

GENERAL

2.1 PURPOSE OF THE COMPRESSOR RESEARCH FACILITY

It is anticipated that the Compressor Research Facility will be used for developmental testing of new compressors as well as for extensive research testing on existing compressors. A detailed description of the typical tests that may be conducted in the facility is contained in Section 4 of this volume. In general, the Compressor Research Facility will be utilized to conduct the broad classes of tests discussed below.

2.1.1 STEADY STATE TESTS

During this type of testing, compressor performance data will be generally acquired at a fixed point on the performance map. The data obtained during the steady state test may be both aeroelastic type data and aerodynamic data. Much of the developmental testing on new compressors will be accomplished during steady state operation, including aeroelastic evaluation, stator vane and bleed valve optimization, detailed aerodynamic mapping, stall line determination, inlet distortion studies, etc.

2.1.2 SPEED AND PRESSURE RATIO TRANSIENTS

The CRF will be utilized to acquire data during speed transients which range up to the maximum possible acceleration in the facility, limited by available horsepower and inertia of the drive system. Acceleration and deceleration rates vary according to the compressor or fan under test. During speed transients, compressor pressure ratio may be controlled as a function of percent corrected speed. Pressure ratio transients may be imposed on the compressor along a constant speed line or at any other operating conditions utilizing the pressure ratio control system provided as a part of the CRF. Pressure ratio transients are limited only by the response of the discharge valve and the associated control electronics. Digital data may be acquired during speed transients and/or pressure ratio transients using the high speed digital data system to be provided in the CRF.

2.1.3 DYNAMIC TESTS

Dynamic tests will include relatively high frequency pressure or temperature perturbations at the inlet or in some cases at the outlet. Normally, the pressure and temperature variations at the inlet will be injected at a frequency much higher than the response of the facility control system. Therefore, this type of testing will be accomplished essentially in a facility steady state mode of operation. The pressure and temperature variations will be generated with especially designed equipment upstream from the compressor inlet. In general, data acquired during this type of test will be of a relatively high frequency nature.

2.2 CRF CAPABILITIES

The initial CRF configuration (System I) will be an open cycle facility with a single air flow discharge path. Provisions will be made in this configuration to provide a bypass flow path and a means for enclosing the core compressor flow cycle at a later date. The closed cycle facility is denoted in the Project Analysis Report as System II. A third configuration (System III) which will provide for dual spool operation is also under consideration. This would be a closed cycle facility. A more detailed description of Systems I, II, and III are included in Volume I of this Project Analysis Report.

2.2.1 SYSTEM I

Both single spool axial flow fans and the compressor may be tested in the System I CRF configuration. The initial System I configuration, however, will not allow for testing requiring a dual discharge path, nor will it allow for closed cycle testing of a single discharge path fan or compressor. Capabilities and limitations associated with System I are as follows:

- Mass Flow (15 to 500 lbs/second - corrected-inlet)
- Speed and Maximum Horsepower (3,000 to 16,000 rpm at 30,000 hp and 16,000 to 30,000 rpm at 15,000 horsepower)
- Air Cycle (open cycle only with single discharge path - provisions will be made to close air flow loops on both core flow and bypass paths at a later date)
- Dual Spool Operation (not possible with this configuration)
- Digital Data Acquisition System (500 channels - block sequential or random sampling at up to 24,000 samples per second)
- Analog Data Acquisition System (188 channels - frequency response 0 - 50 kHz)
- Inlet Pressure Range (2 psia to ambient)
- Inlet Temperature (ambient - no inlet temperature control)
- Discharge Pressure Range (ambient to 368 psia)
- Discharge Temperature Range (ambient to 1100^{o}F)

2.2.2 SYSTEM II

The System II configuration will allow for a wider selection of air cycle modes of operation. Tests requiring a single discharge path may be conducted in either an open or closed air cycle. Likewise, tests requiring two discharge paths (core flow and bypass flow) can be conducted with either path or both operating as an open or closed air cycle. Dual spool testing cannot be accommodated in this system. System II capabilities and limitations include:

- Mass Flow Total (15 to 1200 lb/second - corrected-inlet); core (15 to 750 lb/second - corrected-inlet); bypass (100 to 1100 lb/second - corrected-inlet)
- Speed and Maximum Horsepower (3,000 to 16,000 rpm at 30,000 hp and 16,000 to 30,000 rpm at 15,000 horsepower)
- Air Cycle (compressor/fan tests may be conducted using open cycle core flow and bypass, closed cycle core flow and bypass, open cyle single discharge path, or closed cycle single discharge path)
- Dual Spool Operation (not possible with this configuration)
- Digital Data Acquisition System (1,000 channels - block sequential or random sampling at up to 24,000 samples per second)
- Analog Data Acquisition System (278 channels - frequency response 0 - 50 kHz)
- Inlet Pressure Range - open cycle (2 psia to ambient); closed cycle (2 psia to 14.7 psia)
- Inlet Temperature Range - open cycle (ambient); closed cycle (0^{o}F to plus 100^{o}F)
- Discharge Pressure Range - open cyle core (ambient to 368 psia); open cycle bypass (ambient to 44 psia); closed cycle core (3 psia to 368 psia); closed cycle bypass (3 psia to 44 psia)
- Discharge Temperature Range - core (20^{o}F to 1230^{o}F); bypass (20^{o}F to 415^{o}F)

2.2.3 SYSTEM III

The System III concept provides for the same wide selection of air cycle operating modes as System II but with the added advantages of increased horsepower and the capability to test dual spool compressors. This configuration will have the capability to provide 30,000 horsepower to each of two coaxial shafts or 60,000 horsepower to a single shaft. System III capabilities and limitations include:

- Mass Flow Total (15 to 2400 lb/second - corrected-inlet); core flow (15 to 750 lb/second - corrected-inlet); bypass (100 to 2200 lb/second - corrected-inlet)
- Speed and Maximum Horsepower
  - Single Shaft - one drive (3000 to 16,000 rpm at 30,000 hp and 16,000 to 30,000 rpm at 15,000 hp)
  - Single Shaft - two drives (3000 to 12,000 rpm at 60,000 hp)
  - Coaxial Shafts - two drives (3000 to 16,000 rpm at 30,000 hp for both shafts)
- Air Cycle (compressor/fan tests may be conducted using open cycle core flow and bypass, closed cycle core flow and bypass, open cycle single discharge path, or closed cycle single discharge path)

- Dual Spool Operation (can be accomplished)
- Digital Data Acquisition System (2,500 channels - block sequential or random sampling at up to 100,000 samples per second)
- Analog Data Acquisition System (393 channels - frequency response 0 - 50 kHz)
- Inlet Pressure Range -open cycle (2 psia to ambient); closed cycle (2 psia to 14.7 psia)
- Inlet Temperature Range - open cycle (ambient); closed cycle (0 to 150°F)
- Discharge Pressure Range - open cycle core (ambient to 588 psia); open cycle bypass (ambient to 44 psia); closed cycle core (3 psia to 588 psia); closed cycle bypass (30° psia to 44 psia)
- Discharge Temperature Range - core (20°F to 1490°F); bypass (20°F to 415°F)

2.3 MODES OF OPERATION

The Compressor Research Facility will be capable of operation in two separate modes: the "manual mode" and the "automatic mode".

2.3.1 MANUAL MODE

In the manual mode of operation, setpoints for all facility and test item control functions will be provided manually by test operating personnel. This control will be implemented from consoles in the control room. Control systems will be designed so speed transients can be performed in the manual mode. In the manual mode, however, the data acquisition functions associated with the computer will continue to be operated under computer control (data acquisition, data processing, limit checking, and display functions). This control can be preprogrammed or initiated by operator-to-computer communication, i.e., pushbutton or I/O device. Analog data recording and display (vibration, vibratory stress, and clearance measurements, etc.) will be operated in the same manner whether the system is operated in the manual or the automatic mode. In the manual mode, it will be possible to operate the facility for test and checkout without the use of the digital computer.

2.3.2 AUTOMATIC MODE

In the automatic mode, setpoints for the drive system speed, inlet pressure (inlet valve position), pressure ratio (discharge valve position), stator vane position, stage bleed, and test vehicle lubrication oil temperature will be provided by the computer. Setpoints for other functions that must be controlled during the test will continue to be provided manually from control room consoles. In the automatic mode, the digital data acquisition functions will also be controlled by the computer (data acquisition, data processing, limit checking, and display functions). This control can be preprogrammed or initiated by operator-to-computer communication (pushbutton or I/O device). In this mode, setpoints for any of the functions under computer control can be provided as a function of time or any other measured or computed parameters as long as the responses of the control systems are not exceeded. To implement computer setpoint control, the necessary control programs and data inputs will be prestored in the computer prior to the beginning of a given test.

In the automatic mode, any one of the computer control functions can in reality be controlled manually through the computer-operator communications device (I/O typewriter). The operator must only enter the necessary control instructions via this device. The computer will in turn issue the necessary commands to execute the control function. When operating in this manner, one or more of the functions may be controlled by a prestored program while the remainder of the controlled items may be controlled via operator instructions. This provides for a semiautomatic type of operation when the facility is operating in an automatic mode.

2.3.3 TRANSFER OF OPERATION MODES

Facility operation may be transferred from the automatic to the manual mode or from the manual to the automatic mode at any time. In the automatic mode, the computer will cause manual control switches and setpoints to track computer setpoints. In this manner, as the computer controls these various functions in the automatic mode, it will also control the manual "control knobs." The test conductor may at any time elect to change from the automatic to the manual mode by activating the master switch on the test conductor's console. When the switch is activated to the manual mode, all the manual controls will match the setpoints last issued by the computer prior to the change in mode of operation, preventing the possibility of having abrupt perturbations in the system when changing from the automatic to manual mode of operation. If the manual controls were not set by the computer, then at this change in mode of operation the computer setpoints could be widely different from the setpoints currently imposed by the manual control. In this event, the changeover from automatic to manual would cause the drive or other computer - controlled functions to have to make a wide excursion to arrive at the setpoints of the manual controls.

Before entering the automatic mode, the facility will normally be started in the manual mode of operation. While the facility is in the manual mode, the computer reads the current setpoints entered into the various control systems with the manual setpoint controls and records the value of these setpoints in memory. When a transfer from manual to automatic control is implemented, the computer assumes control at the last manual setpoints and thus avoids abrupt perturbations in the system when the transfer is accomplished. In any event, the transfer from the manual to the automatic mode can only be accomplished when the actual operating conditions match the conditions recorded in the computer memory. If the transfer is attempted when this is not the case, a set of interlocks will prevent the change of mode of operations from taking place.

Shutdown or termination of a test will normally be accomplished in the manual mode. However, if an emergency trip or other emergency shutdown measures are necessary while the facility is in the automatic mode, the termination of the test will be accomplished automatically under the control of the digital computer. These emergency shutdown procedures will be preprogrammed into the digital computer software.

SECTION 3

FACILITY OPERATING PHILOSOPHY

SECTION 3
FACILITY OPERATING PHILOSOPHY

3.1 OVERALL OPERATING PHILOSOPHY

For years, high speed digital computers have been used successfully for data acquisition, real-time control, safety monitoring, and mission evaluation in the aerospace industry. For a successful missilelaunch, for example, thousands of events must be initiated in proper sequence within a few milli-seconds of one another. If one of these events does not occur at the right time, the computer must recognize the problem immediately and initiate remedial action or alert launch officials to the malfunction so the countdown can be held. In the Apollo Program, the last few minutes prior to launch is controlled by a computer. Spacecraft and booster systems are checked in the proper sequence automatically. Literally, millions of checkpoints are interrogated and evaluated by the computer during this phase of the countdown. Any malfunction or miscalculation during this crucial time could cause the multi-million dollar launch vehicle to be destroyed, also jeopardizing the lives of the astronauts. Likewise, in the process industries, computers have been more effectively utilized for certain control functions than have human minds.

Computers have not previously been used extensively in controlling or monitoring axial-flow compressor tests but have come into limited use in controlling real time data acquisition and are used to a greater extent in post-test data reduction. With little or no use of computers in a real time capacity during a test, present day compressor testing is a time consuming and therefore costly procedure.

In developing a test and operating philosophy for the compressor research facility, some of the philosophies from the aerospace industries have been adapted and combined with existing compressor test philosophies to provide an efficient concept which will yield more meaningful compressor test results with minimum operating personnel and test time. Under this philosophy, primary responsibility for conducting a test will rest with a test conductor who will operate from a test conductor's console where all the necessary major controls, indicators, and displays will be located, essentially allowing control of all aspects of the test. Supporting the test conductor will be a computer and measurement systems engineer whose primary responsibility will be operation of the digital computer with its associated data acquisition, data processing, and data recording hardware and software. This engineer will also operate the analog data recording and display system and the on-line calibration/reference checking system.

Other personnel supporting the test conductor will include a number of facility engineers and technicians whose responsibility will be to bring the facility on-line to the point where the test will begin and to monitor the operation of major facilities subsystems as the test progresses.

In the event of a facility malfunction during a test, these engineers and technicians will be available to perform troubleshooting and repair activities.

The test conductor will also be supported by test vehicle oriented engineers. The senior test vehicle operations engineer, who will support the test conductor during a test, should be knowledgeable in all areas of test vehicle design and performance and will act as an advisor to the test conductor in the areas of test vehicle performance and safety. The lead aerodynamicist, who will be located at a console near the test conductor, will advise the test conductor on decisions regarding the aerodynamic functions of the test vehicle and will be responsible for making the real time decisions regarding problems or test decisions oriented toward this area. To aid in this task, the aerodynamicist will have at his disposal one or more sophisticated video displays having the capability to display in alphanumeric or graphic formats all major aerodynamic characteristics of the compressor. The lead aeroeleastic engineer with responsibility in the area of vehicle mechanical and structural integrity will also provide support to the test conductor. He will be the test conductor's advisor on any problems or test decisions related to the aeroelastic characteristics of the test vehicle. Depending on the given test, a limited number of engineers and technicians will also support the aerodynamicist and the aeroelastic engineer during the test.

A more rigid test operation philosophy is advocated for the Compressor Research Facility, if compressor testing is to approach the high speed testing currently employed in the aerospace industry. If tests are to be conducted at a reasonably high rate under computer control, then rigid discipline during the test is necessary to prevent confusion and inefficiency in the test procedures. To conduct a high speed test efficiently, good test plans,well thought out and documented prior to the test, are required. Step-by-step procedures are also necessary so that everyone participating in the test knows his exact role.

Under the current compressor testing philosophy, a test plan is evolved as the test progresses. Group decisions are used to determine what test points to record. Once a point is recorded and evaluated by the participating engineers, a new test point is decided upon. Under the new philosophy, this type of testing will be minimized. It is realized that some of this is necessary because the state-of-the-art in compressor design does not allow for accurate predictions of test results in many cases. Whenever possible under the new philosophy, the computer will be used to digest data from a current test point and, after analyzing the data, direct the facility to the new point. Where this is not possible, the facility will be designed so that humans may intervene and make the decision. If possible, however, a time-oriented test with clearly defined steps should be employed. In the CRF, the test can be either executed manually or preprogrammed into the computer for automatic sequencing. In line with the more rigid test philosophies and well-defined test responsibilities with the test conductor as the central focal point, the need to eliminate visitors and nontest participants from the test area is recognized. A visitor's observation room in the test control room would in most cases eliminate the need for nontest participants to be in the working area while a test is in progress.

3.2 CONTROL CONSOLE LAYOUT

The control room will be the nerve center during a test in the Compressor Research Facility. The equipment arrangement and personnel work stations in this room must be well planned to provide an efficient test operation. Figure 3-1 is a preliminary sketch of the recommended control console layout. A detailed discussion of this layout, including a description of each of the major consoles and control elements, is presented in Volume IV of this report.

This layout places the test conductor in the center of the test activities, the logical location since he is the senior engineer and primary decision maker during the test. Not only will the test conductor have computer-controlled video displays, facility controls and numerous facility readouts and status displays on his console, but he will also have an unobstructed view of the facility annunciator/control panel.

Adjacent to the test conductor's console on the right will be the computer and measurement system engineer's console, containing a video display, master computer controls and controls for the timing system, analog data acquisition, reference checking and calibration system, and other items peculiar to measurement and control system operation. A console directly in front of the test conductor will be provided for the lead aeroelastic engineer. This console which contains a video display will be primarily a working table since most of the displays of interest to the aeroelastic engineer will be located on the dynamic display panels. Consoles will be provided for the facility engineer and the test vehicle operations engineer. These consoles, which contain computer-controlled video displays but no control functions, will serve as work stations for these engineers during a test.

3.2.1 TEST CONDUCTOR'S CONSOLE

The test conductor's console will be the master control point for conducting a test and will contain all items necessary to operate the facility in the manual mode of operation during a compressor test or monitor the facility operation when the facility is being operated in the automatic mode. The general operating philosophy dictates that the facility will be started and brought on line from the facility control panel. Once this is accomplished, basic test control will be transferred to the test conductor who will assume control and retain it throughout the test. On the test conductor's console will be the controls necessary to allow the test conductor to control the flow measurement system, inlet pressure, pressure ratio, speed, stator vane and stage bleed operating modes, and test vehicle lubricating oil temperature and pressure. Also on the console will be the master facility operating mode control. Using this control, the test conductor can switch operating mode from the automatic to manual mode of control or from the manual to the

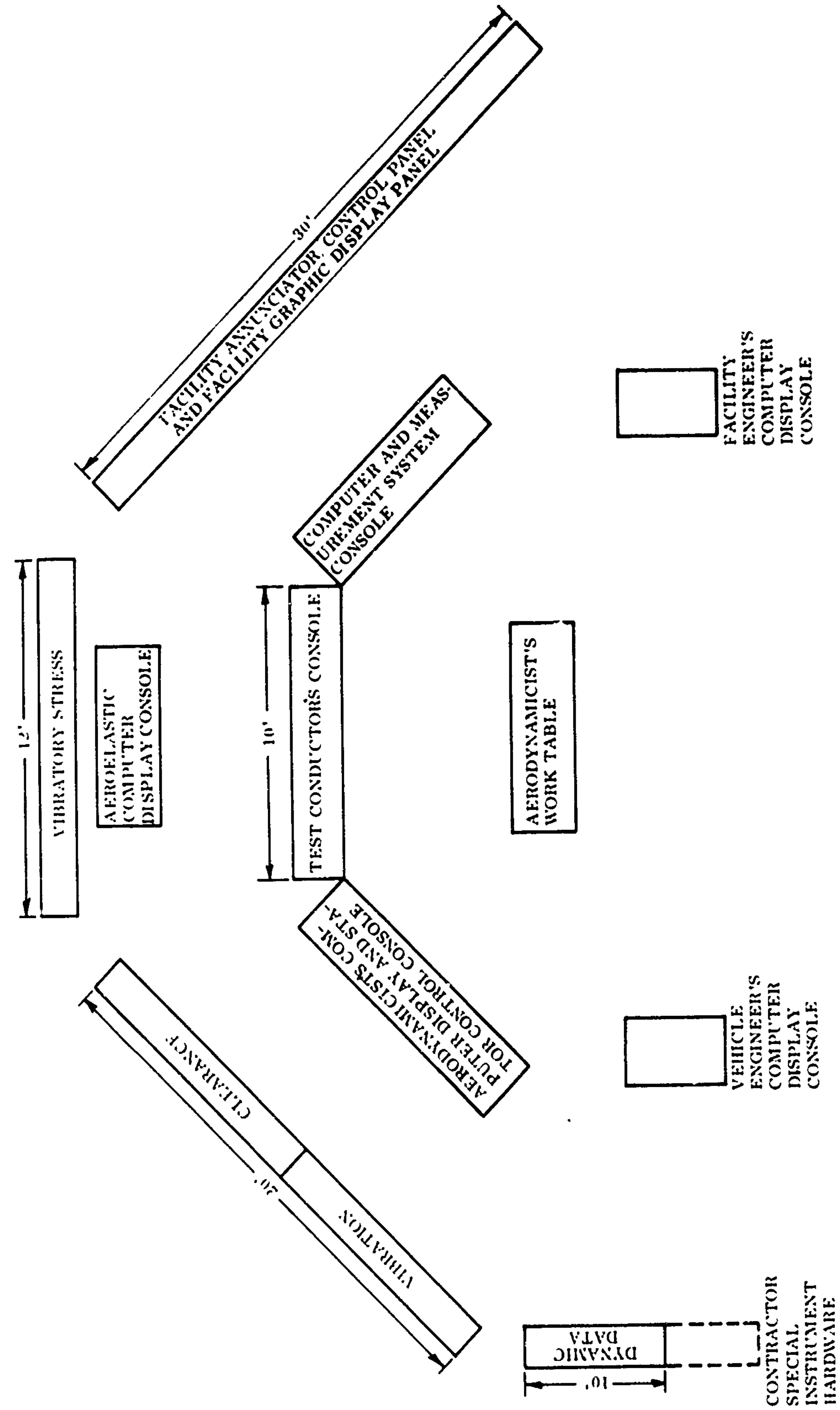


Figure 3-1. Control Console Layout

automatic mode of control. To aid the test conductor during a test, one or more computer-controlled video displays will be located on the test conductor's console. These displays will allow the test conductor to monitor compressor parameters during a test and continuously observe updated graphic plots such as compressor performance maps. Included on this console will be a computer-controlled out-of-limit video monitor which allows the test conductor to continuously monitor up to five facility or test item parameters currently out of predetermined limits. In addition to controls and the out-of-limits video monitor, the test conductor will have on this console several status lights which indicate the status of the computer and measurement system, electric drive, power system, drive lubrication system, and stall indication system. A torque readout, a time-of-day readout, and a communication station will also be on the console. Operating philosophy associated with each of the control functions on this console will be discussed in succeeding paragraphs. A detailed discussion of the actual controls is presented in Volume IV.

3.2.2 AERODYNAMICIST'S COMPUTER DISPLAY AND STATOR CONTROL CONSOLE

The aerodynamicist's console will provide a work station for the lead aerodynamicist during a test. From this console, the aerodynamicist can control an alphanumeric/graphic video display. This display will provide immediate access to data from all measurement channels or any performance parameters that can be computed from this data. The aerodynamicist can call up to 25 alphanumeric or graphic display formats composed of both engineering units data from individual measurements and compressor performance parameters which are computed from the measured data. For example, performance maps can periodically be updated and displayed on the video display as well as plots of pressure coefficient versus flow coefficient, flow function versus efficiency, etc. Under the new operating philosophy, many of the computations previously calculated manually during a test by the aerodynamicist can be accomplished using the computer in conjunction with the video display. With essentially real-time data and performance parameters at his finger tips, the aerodynamicist can make near real-time decisions if necessary at a rapid rate and provide inputs to the test conductor. An out-of-limits video monitor will be located on the aerodynamicist's console in addition to the video display, a time-of-day display and the rotor speed readout. The out-of-limits video monitor will be a duplicate of the one located on the test conductor's console and will always contain the same information as the test conductor's monitor. The stator vane/stage bleed controls will also be located on the aerodynamicist's console. The function mode and the direct mode will be the two modes of stator/stage bleed control. In the function mode, the stator or bleed valve positions will automatically track a predetermined "percent corrected speed versus position" schedule. In the direct mode, stator and bleed valve positions may be adjusted by direct controls independent of speed or other parameters. Setpoints for both the function and direct modes of control may be provided by the computer or by controls located on the aerodynamicist's console, depending on the facility mode of operation. A transfer from the function to the direct mode of control, however, can only be made by using a switch on the test conductor's console. Operating philosophy associated with each item on the aerodynamicist's console will be discussed in more detail in subsequent paragraphs of this volume.

3.2.3 AEROELASTIC COMPUTER DISPLAY CONSOLE

The aeroelastic computer display console will provide a work station for the lead aeroelastic engineer. The items on this console will include a computer-controlled video display and a communication station. Other displays of interest to the aeroelastic engineer will primarily be located on the dynamic data display/status panels directly in front and to the left of this console. It is anticipated that a large percentage of the aeroelastic engineer's time will be spent observing these panels.

3.2.4 COMPUTER AND MEASUREMENT SYSTEMS CONSOLE

The computer and measurement system console will provide a work station for the computer and measurement system engineer during a test. From this console, all data acquisition, data monitoring, data processing, and data recording functions may be controlled. The console will contain the primary computer input/output communications device. Also included on this console will be:

- Reference/calibration controls
- Timing system controls
- Tape search/analog tape controls
- Time-of-day display
- Computer maintenance and operating controls
- Digital data acquisition controls
- Communication station

Even though the computer and measurement system engineer controls all data acquisition functions, directions for making changes in data acquisition modes come from the test conductor unless such changes are clearly defined in the operating test plan.

3.2.5 DYNAMIC DATA DISPLAY/STATUS PANELS

Figure 3-2 is a preliminary layout of the dynamic data display/status panels. Functionally, these panels may be divided into three major sections. The vibration-clearance panel will contain vibration and clearance displays and limit status indicators. The vibration display will consist of monitor scopes for monitoring analog vibration data. X-Y plotters and a multichannel oscillograph will be provided on this panel to plot displacement versus speed and

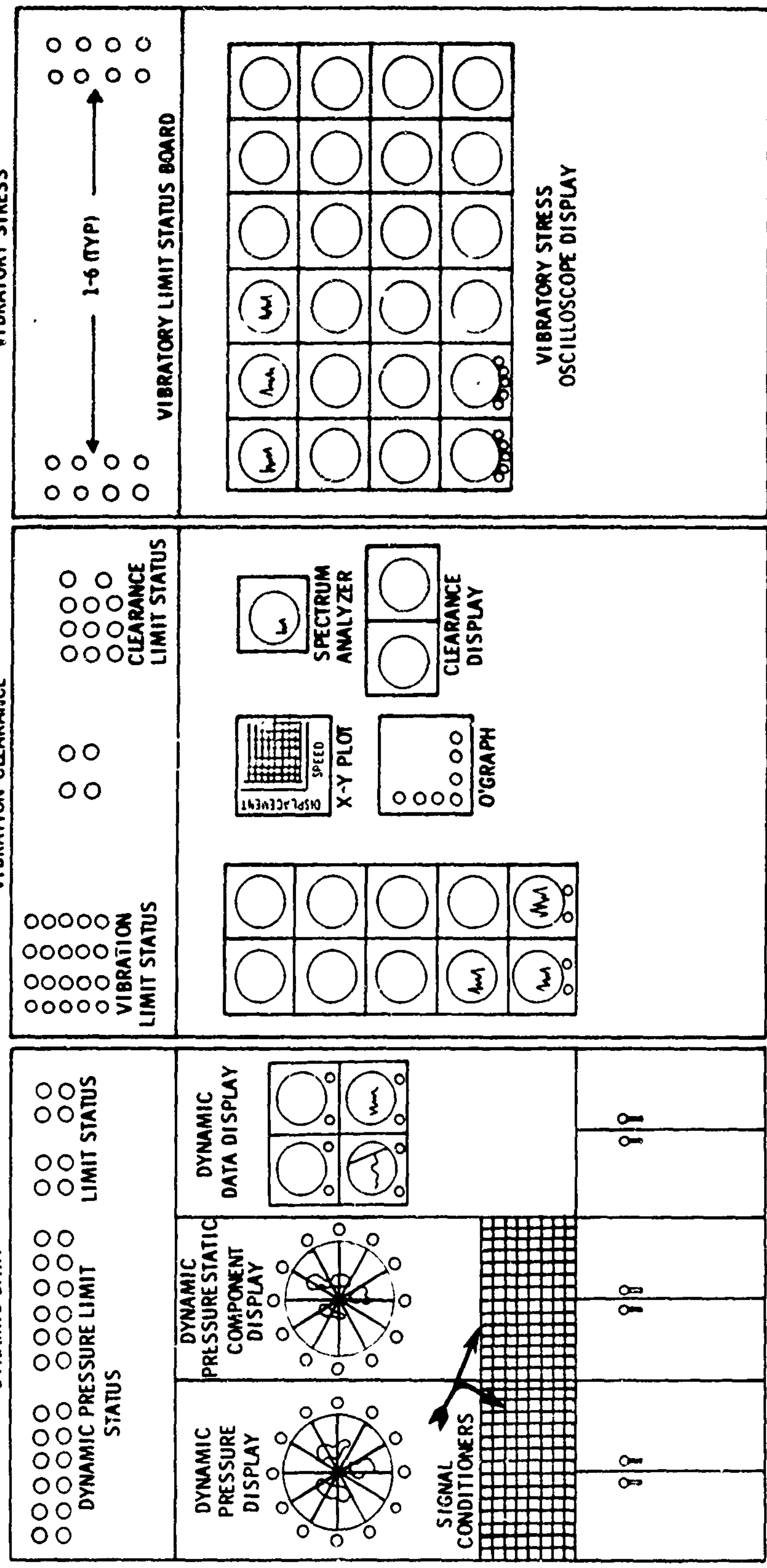


Figure 3-2. Dynamic Data Display/Status Panels

provide hard-copy plots for a limited number of vibration channels. Vibration limit status indicators at the top of the panel will normally be in an off position and will light when vibration channels exceed an upper or lower limit. The clearance display, comprised of two oscilloscopes, will provide for real-time monitoring of two clearanceometer outputs. The clearance limit status indicators at the top of the panel indicate out-of-limits condition for clearance measurements.

The vibratory stress panel will contain vibratory stress displays and vibratory stress limit indicators. Each of the vibratory stress displays (small monitor scopes) will provide a means of monitoring one channel of vibratory stress data. At the top of the panel, the vibratory stress indicators will light up to show out-of-limits conditions for the various vibratory stress channels. The dynamic data panel will be reserved for dynamic pressure data and other aerodynamic high frequency data. The dynamic pressure contour displays illustrated in Figure 3-2 are typical of what might be located in this panel. Monitor scopes are also candidates for dynamic pressure or other dynamic data displays. A more detailed discussion of the items appearing on the dynamic data display/status panels is presented in Volume V.

3.2.6 FACILITY GRAPHIC DISPLAY PANEL

The facility graphic display located above the facility annunciator/control panel will provide a graphic layout of all rotating machinery, interconnecting power lines, and circuit breakers. The panel will indicate the position of all breakers as to OPEN or CLOSED and give an ON-OFF indication for motors. The panel will also indicate all auxiliary equipment including field excitation equipment, breakers, blowers, oil systems, inching motors, etc., and give ON-OFF indications. All primary valves including water and oil will be shown with OPEN-CLOSED indicator lights. Space will be provided on the panel for a graphic illustration of a closed loop air cycle to be added in future CRF configurations (System II and System III). Indicated on the air cycle will be flow paths (both core and bypass) and the status of air cycle hardware such as rotating machinery and heat exchangers as well as cooling water flow provided to the air cycle. Stage bleed flow paths will also be shown on the panel with some indication as to which flow paths are currently active and which are not active. The facility graphic display panel will be a passive display panel. No test vehicle or facility control will be provided from the panel.

3.2.7 FACILITY ANNUNCIATOR/CONTROL PANEL

The primary electric drive system controls will be located on the facility annunciator/control panel. A more complete speed control panel than that on the test conductor's console will be located on this panel as part of the electrical drive system controls. Other electric drive system controls located on the facility annunciator/control panel include drive lubrication system controls, synchronous motor control, excitor motor control, variable frequency bus controls, metering breakers, bus breakers, amplidyne MG set drive motor controls, turning gear controls, and the high speed - low speed damper controls.

Also on this panel will be the primary auxiliary lubrication system controls and numerous annunciators, recorders, and indicators, including bearing temperature monitors and bearing temperature recorders, a power recorder, the torquemetering system indicators, an imbalance monitoring system, a vibration monitoring system and the coupling index and control system. The facility annunciator/control panel will be located below the facility graphic display panel.

3.3 CRF PERSONNEL REQUIREMENTS

The overall operating philosophy of the Compressor Research Facility dictates that the digital computer be used to a maximum extent in controlling data acquisition, test item parameters, and other aspects of the facility during a test. This philosophy in general is designed to minimize the number of personnel and time required to conduct a compressor test and maximize the accuracy of test results. Even with a highly automated facility, however, a number of competent personnel are required to run a test and to set up, calibrate, and maintain the mechanical, electrical, and electronic hardware. Other than personnel required for the technical aspects of the facility operation, a limited number of support personnel are required for the efficient operation of the CRF. A CRF staffing plan which provides personnel to adequately operate the facility is outlined in Table 3-1. This staffing plan is based on a full-time operation which assumes that a test vehicle is installed in the facility and is actively being tested a minimum of 85 percent of the time. Active testing in this case would include pretest setup, test time (machine rotating) and post-test activities. Actual "rotating" time under such a test schedule would range between 25 percent and 40 percent (10 to 16 hours per week based on a 40-hour work week). A number of the positions shown on the staffing plan may not be filled by personnel assigned to the Compressor Research Facility. If major calibration services are to be provided by an established laboratory outside the CRF, a calibration engineer and at least two of the calibration technicians would not be required. Likewise, if the digital computer is maintained under a maintenance contract with a computer manufacturer, the computer system engineer and computer system technicians would not be required on the CRF staff. In many cases, during the test operations the aerodynamicist and the aeroelastic engineers would be provided by the engineering organization requesting the compressor test. Thus, these engineers would not have to be provided by the CRF. The staffing plan in Table 3-1 is evolved around a CRF operation assumming:

- No instrumentation development by CRF personnel
- No complete test item buildup within the CRF by CRF personnel.
- No compressor component bench testing performed within the CRF.

Table 3-1. CRF Staffing Plan

CRF MANAGER

TEST OPERATIONS AND PLANNING
- Test Conductor (2)
- Senior Engineer Test Planning and Procedures (1)
- * Aerodynamicist Senior (2)
  - * Aerodynamicist Junior (2)
  - * Aerodynamicist Technician (2)
- * Aeroelastic Engineer Senior (2)
  - * Aeroelastic Junior Engineer (2)
  - * Aeroelastic Technician (2)
- Computer and Measurement System Engineer (2)
  - Computer and Measurement System Operator (3)
- Facility Operations Engineer (2)
  - Facility Operator (3)

FACILITY ENGINEERING
- Facility Design Engineer (1)
- Mechanical Engineer (1)
  - Mechanical Technician (1)
- Electrical Systems Engineer Power and Drive Systems (1)
  - Electrical Technician (2)
- Installation Engineer (1)
  - Test Setup Technician (10)
- Designer Senior Draftsman (1)
  - Draftsman (1)

INSTRUMENTATION AND CONTROLS ENGINEERING
- Instrumentation and Controls System Engineer (2)
  - Digital Technician (2)
  - Analog Technician (4)
  - Mechanical Technician (1)
- Calibration Engineer (1)
  - ** Calibration Technician (3)

COMPUTER SYSTEMS ENGINEERING
- Computer System Engineer (1)
  - *** Computer Technician (3)
- Computer Program Analyst (1)
  - Computer Programmer (1)
- Computer Clerk (1)

SUPPORT FUNCTIONS
- Production Control (2)
- Logistics (Spares) (1)
- Configuration Control (1)
- Quality Control (2)

* These individuals may be furnished by the compressor design organization.

** This skill will not be required if calibration services are provided by an outside laboratory.

*** This skill will not be required if the computer system is maintained under a maintenance contract with the computer manufacturer.

3.3.1 TEST OPERATIONS AND PLANNING

Personnel who fall into this category will be responsible for conducting the compressor test (including startup, operation of the test vehicle and facility while the test is in progress, and shutdown of the facility after a test is completed). They will be also responsible for test planning and documentation including interface with the test vehicle designer, preparation of test procedures, and preparation of test reports. The personnel who fall into this category are:

- Test Conductor - For a compressor test within the CRF, he will be in effect the test leader, and, in theory, all other participants in a test report to him. The test conductor should have an extensive background in compressor design and testing and should be thoroughly knowledgeable in all aspects of the Compressor Research Facility. All major decisions regarding vehicle safety and test operations will be made by the test conductor during the test but he will consult all other test participants when making test oriented decisions.
- Senior Engineer, Test Planning and Procedures - This engineer will be responsible for the preparation of test procedures and for primary test planning associated with compressor test programs to be conducted in the CRF. He will be supported in this endeavor by all other test operations and planning personnel.
- Senior Aerodynamicist - The senior aerodynamicist will be responsible for the aerodynamic aspects of a test vehicle. During a test, he must operate the video display and monitor the aerodynamic characteristics and performance parameters of the compressor. He will act as advisor to the test conductor during a test regarding decisions of an aerodynamic nature. The senior aerodynamicist should have an extensive background in compressor design and may in most cases be provided by the organization requesting the current compressor test.
- Junior Aerodynamicists and Aerodynamicist Technicians - The junior aerodynamicists/technicians will function in a support role to the senior aerodynamicist during a test. In general, they will monitor the dynamic data display panels associated with dynamic pressure measurements during a test. They may also relieve the senior aerodynamicist at the aerodynamicist's console as necessary and assist the senior aerodynamicist in analyzing aerodynamic type data while the test is in progress.
- Senior Aeroelastic Engineer - The senior aeroelastic engineer will be responsible for all aspects of the test which fall in his area and will act as advisor to the test conductor in this area during a test. The senior aeroelastic engineer should have an extensive background in compressor design and in many cases will be provided by the organization which requests the current compressor test.

- Junior Aeroelastic Engineers and Aeroelastic Technicians - The junior aeroelastic engineers and technicians are responsible for supporting the senior engineer during the test. Their responsibility will include monitoring the vibration and vibratory stress displays on the dynamic data display panels in front of the test conductor's console as well as assisting the senior aeroelastic engineers in making computations and performing real-time analysis during the test. The junior aeroelastic engineers and technicians may be supplied by the organization requesting the compressor test.
- Facility Operations Engineer - The facility operations engineer will be responsible for facility operations during a test and for supervising the facility operators during a test. He will be knowledgeable about the electrical drive system and all support facility systems. In the event of a malfunction or some unforseen event, the facility operations engineer will advise the test conductor of the course of action to take.
- Facility Operators - The facility operators will be responsible for operating the facility systems during a test. One operator will be responsible for operating the electrical drive system and the second operator will operate the other controls on the facility annunciator/control panel. These controls will include the test vehicle lubrication system, hydraulic system, pneumatic system, and electrical power system. A third facility operator will be required to stand by during a test to relieve the other two and also to monitor certain functions on the facility graphic display panel.
- Computer and Measurement System Engineer - The computer and measurement system engineer will operate all computer and measurement systems during a test. His work station will be at the computer and measurement system console, and he will operate both digital acquisition and analog acquistion systems. He will also act as advisor to the test conductor regarding data acquisition, data processing, and computer setpoint control during a test.
- Computer and Measurement System Operators - The computer and measurement system operators will assist the computer and measurement system engineer in operating the analog and digital acquisition systems during a test. They will be responsible for loading tapes and punch cards and monitoring the line printer and X-Y plotter outputs. They will also be capable of relieving the computer and measurement system engineer at the computer and measurement system console for short periods of time while the test is in progress.

3.3.2 FACILITY ENGINEERING

Personnel in this organization will be responsible for maintaining all facility hardware except the computer system, data acquisition systems, facility instrumentation and control system electronics. They will also be responsible for the mechanical aspects of preparing the facility for a test including test vehicle installation in the test chamber. All necessary mechanical systems modifications will be designed and implemented by this group. Personnel requirements for this organization are:

- Facility Design Engineer - This engineer will be responsible for any mechanical hardware design (including facility modifications and/or new facility hardware) necessary to support the CRF operation.
- Mechanical Engineer - The mechanical engineer will be responsible for making decisions associated with the mechanical aspects of the CRF. He will be responsible for supervising the mechanical technician, and, along with the technician, for engineering problems and maintenance associated with the test chamber, air cycle hardware, and the mechanical aspects of the electrical drive system.
- Mechanical Technician - The mechanical technician will assist the mechanical engineer in the maintenance activities associated with CRF mechanical hardware.
- Electrical Engineer - The electrical engineer will be responsible for maintaining the electrical drive system and all electrical power systems and supervising the electrical technicians.
- Electrical Technician - The electrical technician will be responsible for performing maintenance tasks on the electrical drive system and electrical power systems.
- Installation Engineer - The installation engineer's primary responsibility will be the installation of the test vehicle in the test chamber. This includes preinstallation preparation, vehicle installation and post-installation preparation which must be completed prior to the start of data and control system calibration. He will also be responsible for supervising the test setup technicians.
- Test Setup Technicians - Under the supervision of the installation engineer, these technicians will perform the tasks necessary to install the test vehicle in the test chamber and make the necessary electrical and mechanical connections between the vehicle and the facility. These tasks will include installation of adapters, fixtures, brackets and transducers on the vehicle; movement of the vehicle into the test chamber; mounting the vehicle on the test chamber; installation of stator actuators on the vehicle; and making instrumentation connections between the vehicle and the facility.
- Designer and Draftsman - Individuals filling these positions will be responsible for providing drafting support to all CRF personnel.

3.3.3 INSTRUMENTATION AND CONTROL ENGINEERING

The CRF cannot be expected to operate effectively without an adequate instrumentation and control hardware maintenance and calibration program. Also, in preparation for a test, an extensive setup procedure must be completed for the instrumentation and contr ystems. This phase of test preparation will be necessary after vehicle installation has been completed and all connections between the vehicle and facility have been made. The number of personnel involved in these tasks can vary depending on certain factors relating to hardware calibration. If major calibration service is procured from an outside laboratory, the number of calibration technicians may be reduced. Personnel required for this organization are as follows:

- Instrumentation and Control System Engineers - The instrumentation and control system engineers will be responsible for supervising the activities of the instrumentation and control system technicians and for technical decisions relating to setup, maintenance, and/or modification of all instrumentation and control systems.
- Instrumentation and Control Technicians - These technicians fall into three general categories: digital, analog, and mechanical. They will be responsible for maintenance and pretest setup associated with all instrumentation and control system exclusive of the digital computer and its associated peripherals and for channelization, setup, and maintenance on digital and analog data channels of both an electronic and mechanical nature. Installation of transducers and control system actuators will not be included in the tasks assigned to these technicians but will be accomplished by the test setup technicians in facility engineering. The digital technicians will also be responsible for the digital control and acquisition hardware exclusive of the input amplifiers and other computer and associated peripheral hardware. The analog technicians will also be required for maintenance and setup of the analog portion of the control and data acquisition systems; and with respect to the data acquisition systems, they will be responsible for the tape recorders, timing system, signal conditioners and the input amplifiers associated with the digital acquisition system. The mechanical technicians will be responsible for the mechanical aspects of data acquisition control system maintenance and setup.
- Calibration Engineer - The calibration engineer will be responsible for making technical decisions regarding the calibration of transducers, test equipment, and other hardware items associated with the CRF and for supervising the calibration technicians who actually perform the calibration tasks.
- Calibration Technicians - These technicians will be responsible for calibrating the transducers, electrical and mechanical test equipment, control system components, amplifiers, and other hardware items associated with the CRF.

3.3.4 COMPUTER SYSTEM ENGINEERING

This organization will be responsible for maintenance of the digital computer and all peripheral hardware and for providing routine computer programming in support of the CRF operation. If the computer and associated peripherals are maintained by the computer manufacturer under a maintenance contract, the number of computer technicians may be reduced to one. The following personnel will be required for this function:

- Computer System Engineer - The computer system engineer will be responsible for the maintenance of the digital computer and associated peripheral hardware including the multiplexer and A-D converters. He will be responsible for maintenance on the video displays and supervising the computer system technicians.
- Computer System Technicians - The computer system technicians will report to the computer system engineer and will be responsible for performing maintenance tasks on the digital computer and associated peripheral hardware.
- Computer Clerk - The computer clerk will be responsible for tape storage, keypunch and miscellaneous clerical functions associated with the computer maintenance and operation.
- Computer Programmer Analyst - The computer programmer analyst will be the senior computer programmer responsible for devising numerous test programs peculiar to individual test vehicles which will have to be written during the normal course of operation of the CRF. He will also be responsible for making necessary changes in existing systems and/or operating programs, and, in this respect, will support the computer and measurement system engineers in the test operations and planning organization.
- Computer Programmer - The computer programmer will assist the computer programmer analyst in preparing control programs for individual tests and assist the senior programmer analyst in any other programming task that is required in the CRF operation.

3.3.5 SUPPORT PERSONNEL

Certain support functions such as purchasing of spare parts and expendable items, production control, logistics, configuration control, and quality control are required in any facility operation or engineering organization. They will be necessary to the CRF function whether or not they are directly assigned to the CRF organization. These services may be provided as a service to the CRF from an outside organization. Support personnel requirements will be:

- Production Control - A production control function will be necessary to provide schedules and work load forecasts for the CRF management to aid in operating the CRF from a management standpoint. Production control will be especially useful if the CRF is used by several different organizations for testing compressors.
- Logistics - The logistics representative will be responsible for cataloging spare parts, maintaining spare parts stores, providing the necess[illegible] warehousing

facilities, and performing other logistics functions associated with the CRF.

- Configuration Control - Because of the complexity of the CRF, it will be necessary that a stringent configuration control program be implemented and maintained within the CRF facility. All changes to electronic and mechanical hardware must be recorded so that an up-to-date record can be maintained of precisely what the hardware configuration is and what exists in the CRF.
- Quality Control - In a complex facility such as the CRF, quality control is a very desirable function because it will assure that the required periodic maintenance schedules are maintained, that adequate workmanship standards are observed in equipment repair and maintenance, and that necessary calibration procedures are followed in calibrating hardware so that required accuracies and test results can be obtained during a compressor test.

3.4 TEST PLANNING AND DOCUMENTATION

The complexity of the hardware in the Compressor Research Facility and the numerous pretest and test steps that must be executed at the proper time require that a detailed planning phase be completed prior to starting a compressor test to ensure the acquisition of meaningful test results. First, it must be decided what test requirements are to be fulfilled during a testing phase in the CRF; then extensive effort must be initiated to prepare test procedures, measurement programs, data reduction requirements and test reports. The costs and time required to conduct a compressor test make it imperative that this planning be carried out effectively: mistakes in the planning effort can impair the safety of the vehicle or require one or more tests to be rerun at additional expense and time. The number of people involved and the complexity of CRF hardware also make test procedures necessary to ensure each individual participating in the test knows exactly what his role is during all phases of the operation. A detailed measurement program must be evolved prior to the start of test setup because of the numerous data channels that must operate successfully in order for the test to be successful. The large quantities of data which are acquired during a test also necessitate an extensive data reduction cycle to provide useful information which will allow for evaluation of the test vehicle. In order that this data reduction be accomplished in an effective and timely manner, it is necessary that data reduction requirements be well defined and documented prior to the start of the data reduction cycle. After the completion of a test, test reports must be prepared which contain detailed test results, including results of the data reduction, and a description of the hardware performance within the CRF facility. Historical records, in the form of hard-copy plots, hard-copy reports, etc., must be prepared and maintained as a function in the operation of the CRF.

3.4.1 MEASUREMENT PROGRAM

After a test program has been defined for the CRF, a detailed measurement program must be devised to provide data necessary to evaluate the test vehicle and determine if stated test objectives are met. The measurement program should define in detail each measurement channel where data is to be acquired during a compressor test and should specify not only hardware items that will have to be provided on line to complete each measurement channel, but also "road maps" showing the end-to-end channel configuration for each analog and digital measurement channel. This is necessary to provide the technicians and engineers a "road map" which they can use in patching and data routing during facility "setup" in preparation for a test. The road map should show each individual patch that has to be made to complete the end-to-end data channel. Pin numbers will be specified for the various patches that must be completed in the "setup" procedure. Signal conditioners and other items that are used in a measurement as well as input channel numbers for the digital and analog recording systems should be specified by channel number. As a minimum, the measurement program for a CRF test should contain the following information:

- A complete road map showing each end-to-end measurement channel along with all patches that have to be made to complete the channel.
- A measurement channel identification number. Each measurement channel will be assigned a standard alphanumeric or numeric identification number.
- Identification of the transducer by type, range, and accuracy for each measurement channel.
- Identification of the signal conditioner for each measurement channel. This signal conditioner should be specified by a number and labeled on patch boards and on the front panel of the signal conditioning racks.
- Input channel numbers for the various recording devices to be used with each individual measurement channel.
- An engineering units range, a voltage range, and the frequency response for each measurement channel.
- An end-to-end accuracy requirement for each measurement channel.

The measurement program should be prepared prior to starting the compressor test setup. After the measurement program is completed, it should be distributed to all participants in preparation and "setup" for the test. A master copy of this measurement program should be maintained by the test conductor who will utilize the measurement program to check off those channels where channelization has been completed and, in this way, maintain an accurate and up-to-date record on the status of the pretest "setup" for a given test vehicle.

3.4.2 "SETUP" PROCEDURES

Detailed "setup" procedures must be provided because of the complexity of the hardware utilized in the Compressor Research Facility. These procedures should describe in detail each task that is required in the "setup" for a compressor test. "Setup" procedures should be provided to cover the computer and measurement systems, the control systems, the test section and all other items that require pretest "setup". These pretest procedures must also serve as a checkoff sheet which may be used as a record to show which steps have been performed and which are yet to be accomplished. The technicians and engineers responsible foı test preparation and "setup" should check off the appropriate portions of the procedures when that particular task has been completed. The numerous tasks which must be completed in the "setup" phase for a compressor test necessitate maintaining accurate records of this activity. The pretest procedures should contain as much detail as is required to provide adequate instructions to CRF personnel and minimize the probability of human error during "setup", i.e., detailed step-by-step procedures that describe all controls, voltage and current adjustments, and other adjustments that must be made to prepare the facility for a test.

3.4.3 TEST PROCEDURES

Detailed test procedures must also be prepared prior to the start of a test and distributed to each individual scheduled to participate in the test because of the number of people involved and the complexity of the events that must be successfully completed during a compressor test. The events that must occur during the test should be oriented in sequence and described in detail in the test procedure. These test procedures may be time oriented or they may be event oriented. The time-oriented test procedure would be one which has a countdown time attached to it and where all test events or tasks are completed at a given countdown time. Once a test task is completed, the individual responsible for accomplishing the task would report its completion to the test conductor, who keeps a master record of the event completed. This type of test procedure, which is analogous to test procedures used in space vehicle launches, has been found to work very well during a complex, high speed test. An event-oriented test procedure would be one which describes a sequence of events and denotes who is to accomplish each of the events. In this case, at the direction of the test conductor, a test participant would accomplish the event according to the detailed steps specified in his test procedure, then notify the test conductor who marks the event completed and notes the time of completion. In this type of a test, events usually take place in some preplanned sequence; however, they need not take place according to a well-defined time plan such as a detailed mapping test where the test conductor first adjusts the facility to a given data point on a performance map and then after some criteria is met (such as flow meter stablization) acquires a high speed data burst. After the data burst is completed, the test conductor adjusts the facility to a new point on the test vehicle performance map and then again waits until the criteria is met prior to acquiring further data. Here, the time involved between high speed data bursts or other events occurring in the test is dependent upon the time required for the flow meter to stabilize; therefore, the test is not oriented strictly to a time plan. The test procedure, however, should specify in detail all steps that must be completed to successfully conclude the compressor test. No one involved in the test should deviate from this test plan without explicit instructions from the test conductor who is the only one who can authorize such a deviation. Since the lead aerodymanic and aeroelastic engineers participate in the test only in the capacity of advisor to the test conductor, they can advise him that a deviation from the test plan is needed but cannot make that direct decision without the test conductor's concurrence. This again is in line with the overall facility operating philosophy which places the test conductor as the senior responsible engineer for conducting a test.

3.4.4 DATA REQUIREMENTS

Large quantities of data will be acquired during a compressor test. To effectively use this data in evaluating a test vehicle, clear instructions must be provided as to what data reduction is required after the test is completed. Also, real-time data output and display requirements for a test must be specified to allow the test participants to properly initialize the facility during the "setup" operation. A data requirements document which specifies in detail what data is required from the test and what formats and reduction are necessary to provide this data should be prepared prior to the start of the test. It should clearly specify the measurement channels that will be utilized in the various computations to provide the desired outputs. Video displays should be clearly defined so that the proper input instructions may be prepared and stored in the computer prior to the test. Data reduction priorities should be specified so that "quick-look" data reduction may be provided sooner than the more prolonged detailed data reduction.

3.4.5 TEST REPORTS

Test reports are a vital part of a Compressor Research Facility operation since it is these reports that contain the test results. The two types of test reports that must be provided in this type of operation are the "quick-look" test report and the final test report.

3.4.5.1 Quick-Look Report

The purpose of the "quick-look" test report is to get results back to the cognizant engineers at the earliest possible date. Much of the "quick-look" information can be observed on a video display during the actual test; however, it is necessary that certain data undergo preliminary data reduction and be returned to test personnel on a hard-copy plot or a hard-copy printout as soon as possible after a test is completed. The "quick-look" reports provide the information necessary for test personnel to determine if further testing is required or possibly if the test vehicle can be removed from the test section. Also in the "quick-look" reports, invalid test data can in some cases be identified and flagged so that these channels are not erroneously used in further evaluation of a test vehicle. Time slices from the wide band analog tapes can also be dumped out on strip charts for "quick-look" evaluation. A quick-look report should be prepared within hours after a test is completed; the detailed test report will take days or maybe even weeks to complete.

3.4.5.2 Final Reports

The final test report should contain detailed test results including the status of facility performance, detailed evaluation of the test vehicle based on reduced test data, and the necessary recommendations as to further testing, design changes in the vehicle, etc. The final test report may or may not be compiled by CRF operations personnel. The CRF personnel will be responsible for providing detailed data reduction using the digital computer and associated hardware in the CRF, but the reduced data may then be provided to another organization which would prepare the final test report. CRF personnel are obligated, however, to provide a status report on the CRF performance for a given test. This status may or may not be included in the final report but should include documentation concerning the number of measurement channels failing to perform, control system malfunctions observed during the test, deviations from the test plan resulting from CRF hardware malfunction, and a complete list of all measurements exceeding predetermined limits during the test.

3.4.6 HISTORICAL RECORDS

Historical records for CRF tests may be maintained in several forms. An engineering units digital magnetic tape will be prepared from the raw data digital tapes and maintained as a historical record for digital data. All analog tapes will also be maintained as historical records, but, at the discretion of CRF operating management and Air Force policy, may be discarded after a predetermined length of time. Permanent records may be maintained as hard-copy printouts or hard-copy plots from the X-Y plotter. Test reports will also serve as a permanent historical record of test results.

An archive should be maintained for storage of analog and digital tapes which are to be maintained as historical records. This archive may or may not be located in the CRF but should be easily accessible to the CRF operating personnel if it becomes necessary to compare current data with the data which is stored in the archives as permanent historical records.

Facility failure records and maintenance records must be maintained on hard-copy forms, on microfilm, or on digital tape. These records are required for reliability and maintainability analysis as more experience is gained .n facility operation. When sufficient failure and maintenance data is accumulated, it may be used to optimize facility maintenance philosophy and improve hardware reliability.

3.5 OFF-LINE CALIBRATION AND MAINTENANCE PHILOSOPHY

Only limited calibration will be conducted locally at the Compressor Research Facility because of the cost of calibration equipment and calibration laboratory space required. To dedicate a calibration laboratory solely to the CRF would be very expensive because of the accuracy requirements and the wide range of measurement systems and control hardware employed in the CRF. It is proposed, therefore, that all major calibration activity be performed at an established Government calibration laboratory whose standards are traceable to the National Bureau of Standards. Such a laboratory exists at Wright-Patterson Air Force Base. In this laboratory, calibration will be performed in accordance with existing specifications and procedures in use at the calibration laboratory. Unless the individual hardware items (such as transducers or signal conditioners) are suspect of being in an unstable or malfunctioned condition, recalibration of instrumentation hardware and test equipment to be utilized in maintaining the CRF will be performed at regular intervals (three to six months) or between test programs (installation of new compressors or overhaul of the unit under test). Suspect equipment will be recalibrated immediately.

Hardware maintenance will be performed locally at the Compressor Research Facility. This maintenance will either be performed on equipment "in place" or in the small CRF control room maintenance shop. Certain hardware, such as the computer system, will probably be maintained under an Air Force procured maintenance contract. A fabrication shop will be required for pretest preparation and fabrication of certain bracketry and other limited fabrication in preparing the vehicle at the CRF test chamber for installation. The fabrication shop will not be an extensive shop for use in complete compressor buildup and instrumentation, but will be a limited facility for minor fabrication work.

An extensive store of spare parts will be required to successfully operate the Compressor Research Facility. It is suggested that a spares provisioning program be initiated in the CRF which conforms to Air Force logistics procedures currently in effect at Wright-Patterson Air Force Base and other Air Force installations. The manpower required for calibration, maintenance, and spares provisioning associated with the CRF are included in the CRF personnel requirements discussed in paragraph 3.3 of this volume.

3.5.1 CALIBRATION LABORATORY/EQUIPMENT REQUIREMENTS

If the calibration philosophy described above is adopted for the CRF, very little calibration equipment will have to be procured locally to support the CRF. Most of the expensive equipment will be contained in tne established calibration laboratory which would provide calibration services to the CRF. Equipment procurements for CRF calibration hardware would then be limited to test and checkout devices (voltmeters, ohmmeters, oscilloscopes, and potentiometers). This hardware would be suitable for a limited verification of transducer, amplifier, and signal conditioning calibration but would not be suitable for overall calibration or use as primary standards. One exception to this, however, would be equipment for on-line calibration of pressure transducers, which would be supplied as a part of the CRF on-line calibration system and would not be considered as calibration laboratory hardware. An area will be allocated in the control room for a calibration laboratory. The construction of the calibration room is detailed in Volume III; the control room layout is described in Volume IV.

3.5.2 CALIBRATION SUPPORT REQUIREMENTS

Only limited calibration will be accomplished in the calibration laboratory located in the control room of the Compressor Research Facility. Consequently, most of the calibration such as calibration of transducers, calibration of more accurate test equipment to be used in maintaining the facility, calibration of digital voltmeters, etc., must be provided as a service in the form of outside support to the Compressor Research Facility.

To maintain an orderly calibration program, it is absolutely necessary that accurate calibration records be maintained on all hardware which requires periodic calibration or calibration between tests. A calibration program devised specifically for the CRF may be utilized or the standard calibration program required by military regulations may be used. In either case, accurate and up-to-date calibration records are essential for the efficient operation of the CRF.

3.5.3 MAINTENANCE REQUIREMENTS

All necessary maintenance of CRF hardware will be performed within the Compressor Research Facility. Most of this maintenance will be the responsibility of the CRF; however, maintenance of the computer and certain other hardware items may be performed under a special contract with the computer manufacturer. Typically, under such a contract, the computer and all peripherals associated with the computer provided with the system would be covered. A complement of test equipment will have to be supplied to support the maintenance effort. Maintenance procedures will be required which outline in detail all periodic and special maintenance required to keep the Compressor Research Facility in an effective state of operation. A small maintenance shop will be located in the control room. In general, equipment maintenance will be performed with the equipment installed; however, troubleshooting or extensive repairs on modular equipment such as amplifiers, control system components, and certain mechanical hardware can be better accomplished in the maintenance shop. Equipment required to maintain the facility will include both electrical and mechanical equipment such as voltmeters, ohmmeters, multimeters, oscilloscopes, potentiometers, counters, digital voltmeters, wrenches, welding equipment, micrometers, and other electronic equipment and electrical/mechanical hand tools.

Maintenance records must be accurately kept to ensure efficient facility operation. The record system must be described in detail in the maintenance procedures generated for the CRF. Manpower required to maintain CRF hardware is included in the CRF personnel requirements discussed in paragraph 3.3 of this volume.

3.5.4 FABRICATION SUPPORT REQUIREMENTS

A limited capability must be provided as a part of the CRF to fabricate bracketry and other items required to prepare the test vehicle for installation in the test chamber. Electrical cable fabrication and other electrical fabrication will also be required on a limited basis within the CRF. Elaborate fabrication facilities which are required to instrument and build up a compressor will not be provided as a part of the CRF. Compressor buildups and instrumentation are discussed in more detail in paragraph 3.8.1 of this volume.

3.5.5 SPARES PROVISIONING

Adequate spare parts must be maintained for replacement of components that fail, to ensure effective operation of the Compressor Research Facility. It is recommended that a spares provisioning program which would conform to the logistics programs currently inplemented within other Air Force facilities be implemented when the CRF becomes operational. Such a logistics program would provide the means of identifying spares, cataloging spare parts, ordering spares to maintain an adequate spares stock, a spare part acceptance procedure with the required quality control, and a warehousing technique which allows spares to be drawn from stores when needed for installation in the CRF.

3.6 FACILITY CONTROLS

Control systems flexible enough to accommodate a wide range of test vehicles and test programs must be provided in a state-of-the-art Compressor Research Facility. These controls must contain the necessary limiting features to prevent facility or test item damage during operation and yet provide the resolution, stability, and repeatability necessary for conducting a meaningful test which results in accurate test data. The speed controls, pressure controls, stator and stage bleed controls, and auxiliary lubrication system temperature control must be capable of manual operation when the facility is operating in the manual mode or computer setpoint control when the facility is operating in the automatic mode. These controls must be flexible enough to allow steady state tests, speed transients, and dynamic tests to be conducted in either mode of operation. During the design phase, the control panels and consoles must be designed with human engineering considerations to minimize the possibility of human error during operation and provide an effective man/machine interface. The operating philosophy associated with the facility controls parallels the overall operating philosophy: minimize manpower and time required to conduct a compressor test and maximize facility flexibility and capability to provide meaningful test results.

3.6.1 ELECTRICAL DRIVE CONTROLS

All electrical drive controls necessary to start, operate during a test, and shutdown will be located in the CRF control room. Under the proposed operating philosophy, the electrical drive would be started by utilizing controls located on the facility annunciator/control panel. Control would be transferred to the test conductor's console after the drive is brought to some predetermined speed. The test conductor would operate the drive with the controls in this console until the compressor test is completed, then control would be transferred back to the facility annunciator/facility control panel. A normal shutdown would then be initiated utilizing the controls at the facility annunciator/control panel.

The electrical drive controls on the facility annunciator/control panel will be located on three separate subpanels. These will be referred to as the master speed control panel, the drive lubrication system panel, and the start/stop control panel in succeeding paragraphs. The electrical drive controls on the test conductor's console are speed controls and are located in the panel referred to as the test conductor's speed control panel. A number of electrical drive indicators, annunciators, and recorders, including bearing temperature indicators, vibration recorders, and facility annunciators and alarms, will also be located on the facility annunciator/control panel.

3.6.1.1 Speed Control

The electrical drive system speed will be controlled from either the master speed control panel included as a part of the facility annunciator/control panel or from the test conductor's speed control panel located on the test conductor's console. Typically, the auxiliaries, the constant speed MG set, and the converter set are started from the drive system start-stop panel, then the 30,000 hp synchronous motor is started. The master speed control panel is utilized to bring the drive system to the speed scheduled for test start. After determining that the drive system is operating properly and prior to the start of the test, speed control will be transferred to the test conductor's speed control panel for the duration of the test. The electrical drive system startup procedure is detailed further in paragraph 3.11.3 of this volume.

A typical layout of the master speed control panel is shown in Figure 3-3. This layout is not intended to represent the final design concept of the panel but has been included to facilitate the discussion of speed control operating philosophy. Two alternate approaches are being considered in designing the speed control system, an analog system and a digital system. However, the digital system is recommended because of its ease of operation and added flexibility (see Volume I). This choice is reflected . Figure 3-3 and is the one discussed here in conjunction with speed control operating philosophy.

At the extreme top of the master speed control panel are two lights labeled AUTOMATIC and MANUAL (see Figure 3-3). One of these lights will come on to indicate the current facility operating mode. Four in-line digital readouts are below these lights: the COMPRESSOR ROTOR SPEED will display actual rotor speed of the compressor at all times the CONVERTER FREQUENCY will display the converter output in cycles; the COMPRESSOR ROTOR SPEED

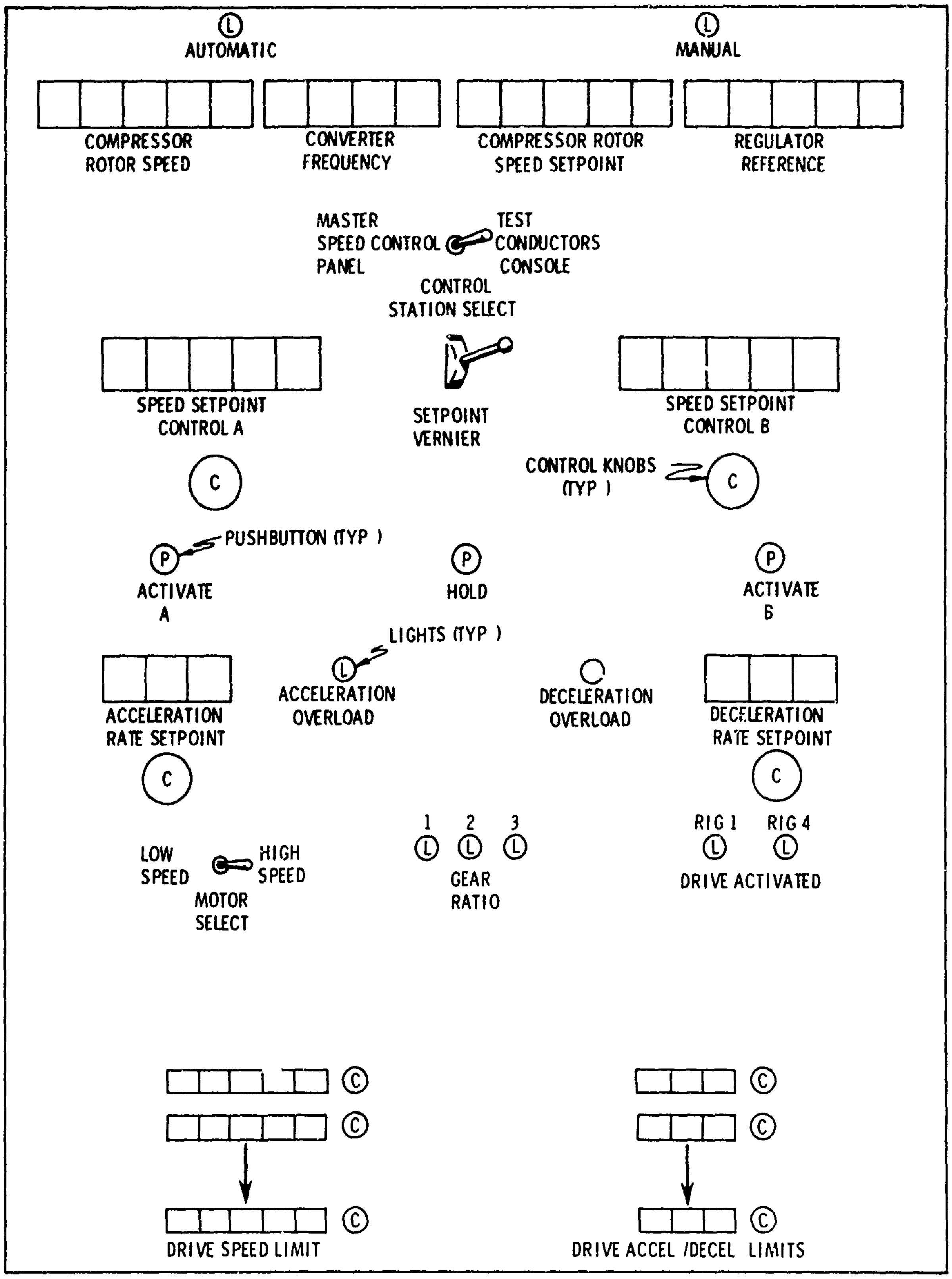


Figure 3-3. Master Speed Control Panel

SETPOINT will provide a setpoint to the speed control system by the computer when the facility is operating in the automatic mode or manually using one of the controls on this panel or on the test conductor's speed control panel when the facility is operating in the manual mode; and the REGULATOR REFERENCE will provide actual reference at the output of the multiplexing and match section of the speed control system. During steady state operation, the value displayed on this readout will be equal to the value shown on the COMPRESSOR ROTOR SPEED SETPOINT readout. When speed is being changed from one value to another at some predetermined acceleration or deceleration rate, the COMPRESSOR ROTOR SPEED SETPOINT will display the compressor speed when the speed change is completed while the REGULATOR REFERENCE will display the actual reference provided to the system as the speed moves along the controlled acceleration or deceleration ramp. The toggle switch located below the four digital readouts, the CONTROL STATION SELECT, may be used to transfer speed control from the master speed control panel to the test conductor's speed control panel or vice-versa. When this switch is in the MASTER SPEED CONTROL PANEL position, speed may be controlled from the master speed control panel. Likewise, when the switch is in the TEST CONDUCTOR CONSOLE position, speed may be controlled from the test conductor's speed control panel. Transfer of speed control can only occur when the speed is in the steady state condition. Even though the position of the transfer switch may be changed, the actual transfer of control will not be affected until the speed ramp is completed if a speed ramp is in progress. The two small lights above the labels to the right and left of the toggle switch will indicate which controls located below the CONTROL STATION SELECT switch may be used to change the compressor rotor speed setpoint. A new speed setpoint may be entered in either the control A on the left or control B on the right. To activate the setpoint, the approximate pushbutton (ACTIVATE A or ACTIVATE B) located below the controls must be depressed. When a new setpoint is entered into the system, the COMPRESSOR ROTOR SPEED SETPOINT display at the top of the panel will change to the value of the new setpoint. A SETPOINT VERNIER located between control A and control B may be used to make small changes in the rotor speed setpoint displayed on the COMPRESSOR ROTOR SPEED SETPOINT readout and which in turn results in small changes in compressor rotor speed. The sensitivity of the SETPOINT VERNIER may be changed by rotating the handle of the vernier control. To increase speed with this control, the control level will be moved upward; to decrease speed, the lever will be moved downward. SPEED SETPOINT CONTROL A, SPEED SETPOINT CONTROL B, and the SETPOINT VERNIER can be used only to change the compressor rotor speed setpoint when the facility is operating in the manual mode. In the automatic mode, these three controls are inactive and cannot be used to change the value displayed on the COMPRESSOR ROTOR SPEED SETPOINT readout. In the automatic mode, only the computer can change the compressor rotor speed setpoint. Just as in the manual mode, however, the value currently displayed on the COMPRESSOR ROTOR SPEED SETPOINT readout will be the current setpoint being supplied by the computer.

The pushbutton labeled HOLD may be used to "freeze" the speed at the actual value. The HOLD pushbutton will inhibit any further speed change (in automatic or manual mode). In the automatic mode, the HOLD pushbutton will transmit an interrupt to the computer which will stop any further execution of the control program in progress. The process control program may be continued through the manual to automatic transfer procedure. In the manual mode, the speed will remain at the actual value when the HOLD pushbutton is depressed, and subsequent speed changes may be made by reactivation of the normal manual control (ACTIVATE A, ACTIVATE B, or VERNIER). A backlight will illuminate the HOLD pushbutton while the drive is in a HOLD condition.

Setpoints for acceleration and deceleration rates may be entered into the speed control system using the ACCELERATION RATE SETPOINT and the DECELERATION RATE SETPOINT controls. The two displays corresponding to these controls are digital readouts which actually indicate the setpoints in rpm per second. In the manual mode, the values displayed on the digital readouts may be adjusted or changed using the control knobs directly below the displays. In the automatic mode, the value appearing on these displays will be provided by the computer and the control knobs will be deactivated. Any time a speed change is initiated by going from the speed setpoint on control A to the speed setpoint on control B or vice versa, the speed change would be made at the rate indicated on the ACCELERATION RATE SETPOINT display or the DECELERATION RATE SETPOINT display, depending upon whether the speed change is going from a lower to a higher speed or from a higher to a lower speed. If a speed change is attempted at a rate beyond the capability of the system, either the light labeled ACCELERATION OVERLOAD or DECELERATION OVERLOAD will illuminate, and the drive will continue to accelerate or decelerate at maximum possible rate until the new speed setpoint is reached. Then the light will go out.

The MOTOR SELECT switch will provide a means of selecting the high-speed or the low-speed motor. At the right of this switch are three lights indicating the current gear ratio. The appropriate light will come on automatically after the gears are installed. The lights labeled RIG 1 and RIG 4 are the DRIVE ACTIVATED lights which indicate the rig selected for operation at the drive start-stop panel. Two sets of limit controls will be at the bottom of the master speed control panel: the set on the left will provide a means of setting drive speed limits (limits which the drive speed cannot exceed either under the manual mode of operation or under computer control); the controls on the right provide for setting drive acceleration/ deceleration limits (also limits which cannot be exceeded under manual control or under computer control). The drive speed limits and the drive acceleration/deceleration limits are facility limits and not necessarily test vehicle limits. Test vehicle limits (speed and acceleration/ deceleration) will be provided on the test conductor's speed control panel. When the CONTROL STATION SELECT switch is in the TEST CONDUCTOR'S CONSOLE position, the SPEED SET-

POINT CONTROL A, SPEED SETPOINT CONTROL B, SETPOINT VERNIER, ACTIVATE A, ACTIVATE B, HOLD, ACCELERATION RATE SETPOINT, and the DECELERATION RATE SETPOINT controls will become inactive on the master speed control panel and control of these functions will be transferred to the test conductor's speed control panel. All other controls on the master speed control panel will remain active (whether the CONTROL STATION SELECT switch is in the MASTER SPEED CONTROL PANEL or TEST CONDUCTOR CONSOLE position.

A possible layout of the test conductor's speed control panel is presented in Figure 3-4. (This layout is not intended to represent the final design concept but has been included to facilitate the functional discussion of speed control operating philosophy.) Most of the controls on the test conductor's speed control panel are duplicates of those located on the master speed control panel. At the top of the test conductor's speed control panel are a series of three lights labeled AUTOMATIC, MANUAL, and CONTROL ACTIVE. The AUTOMATIC and MANUAL lights will indicate the current operating mode for the facility; the CONTROL ACTIVE light will come on when speed control is transferred to the test conductor's speed control panel and will remain illuminated until control is transferred back to the master speed control panel. The COMPRESSOR ROTOR SPEED readout will display the actual compressor speed at all times (whether speed is controlled from the master speed control panel or the test conductor's speed control panel). The COMPRESSOR ROTOR SPEED DISPLAY on this panel is a parallel readout to the COMPRESSOR ROTOR SPEED display on the master speed control panel. Both of these will be driven by the same signal regardless of which panel is currently utilized to control the speed. The COMPRESSOR ROTOR SPEED SETPOINT display will indicate the setpoint provided to the system at any time (setpoint provided manually or by the computer). This display is also connected in parallel to the COMPRESSOR ROTOR SPEED SETPO[illegible] display on the master speed control panel. Both of these displays will be updated as new setpoints are provided by either the controls on the master speed control panel, the controls on the test conductor's speed control panel, or the digital computer. The display labeled COMPRESSOR PERCENT CORRECTED SPEED is unique to this panel. This display will indicate the compressor percent corrected speed for the current inlet temperature and will always indicate compressor percent corrected speed (whether speed is controlled from the master speed control panel or the test conductor's speed control panel). The SPEED SETPOINT CONTROL A, SPEED SETPOINT CONTROL B, SETPOINT VERNIER, ACTIVATE A, and ACTIVATE B controls on the test conductor's speed control panel will serve the same function as the corresponding controls on the master speed control panel. A given speed setpoint may be dialed into a control and activated, causing the setpoint to be transferred to the COMPRESSOR ROTOR SPEED SETPOINT display and consequently entered into the speed control system. To initiate a controlled speed ramp to another speed setting, the new speed setting will be entered

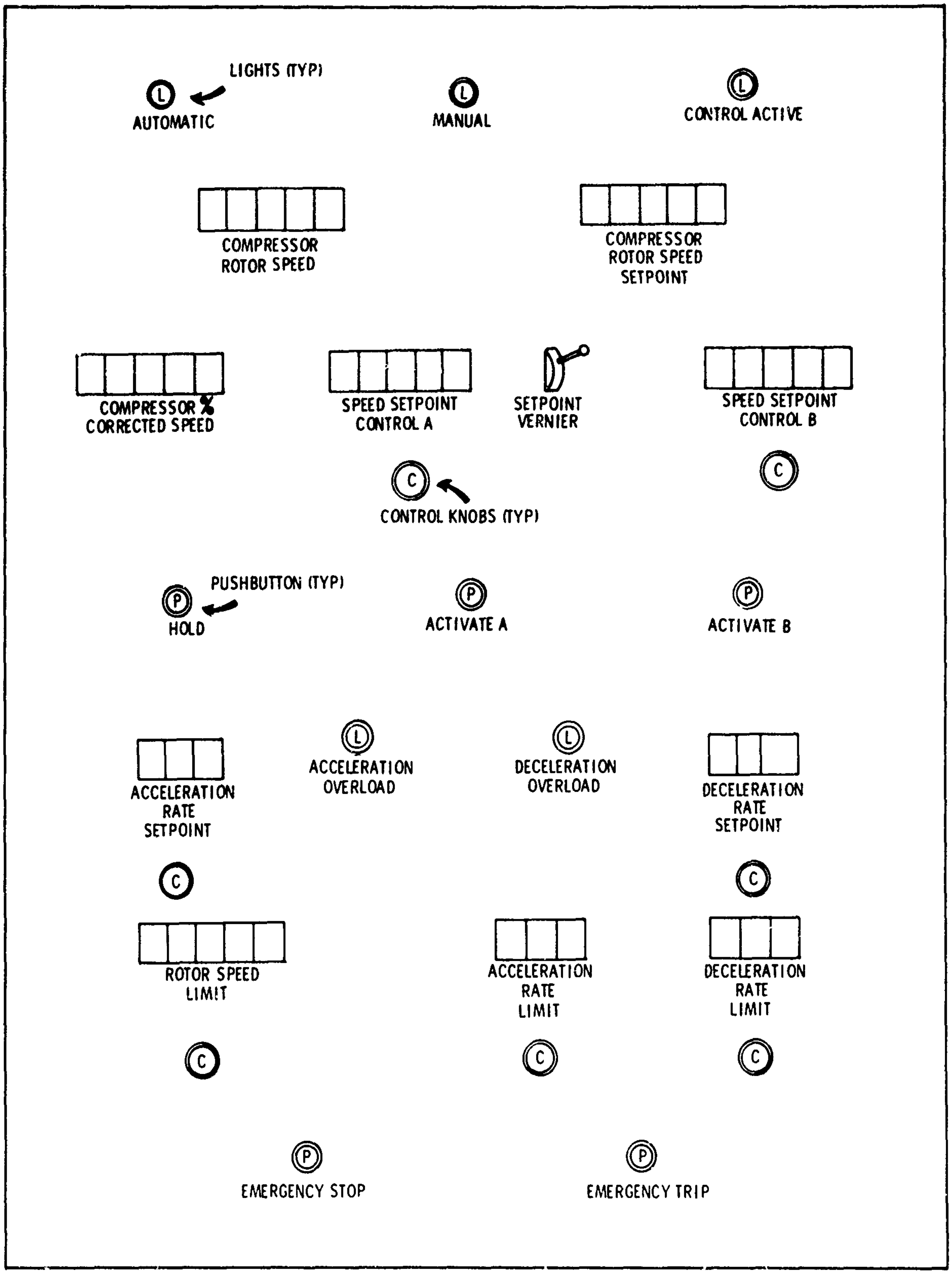


Figure 3-4. Test Conductor's Speed Control Panel

into the B control and the ACTIVATE B pushbutton depressed at the proper time, causing the new setpoint to be entered into the speed control system and displayed on the COMPRESSOR ROTOR SPEED SETPOINT readout. The drive will then either accelerate or decelerate at the selected rate to the new setpoint. The ACCELERATION RATE SETPOINT and the DECELERATION RATE SETPOINT controls may be utilized to provide the necessary acceleration and deceleration setpoints. When the facility is operating in the manual mode, the corresponding control knobs may be used to adjust the acceleration and deceleration rate setpoints. When the facility is operating in the automatic mode, these values will be supplied by the computer; however, the corresponding displays will still indicate the current setpoints and the control knobs will be deactivated. The HOLD pushbutton on this panel will serve the same purpose as the corresponding control on the master speed control panel. When this pushbutton is depressed, all further speed changes (both speed changes which are being executed under manual or computer control) are frozen at the actual speed value. After the pushbutton is depressed a second time, the computer program controlling speed may be continued through the manual to automatic transfer procedure. If the facility is operating under manual control, upon termination of the "hold" by depressing the pushbutton a second time, the speed control system will continue with the activity in progress prior to the initiation of the hold. The control knobs associated with the acceleration rate setpoint and deceleration rate setpoint controls will be deactivated when the speed is being controlled from the master speed control panel; however, the displays will be wired in parallel with the corresponding displays on the master speed control panel. Therefore, the current setpoints will be displayed on both speed control panels (whether the setpoints are provided manually or by the computer). The ROTOR SPEED LIMIT control may be used to set the appropriate speed limit for the compressor currently under test. Likewise, the ACCELERATION RATE LIMIT and the DECELERATION RATE LIMIT controls may be used to set the necessary acceleration and deceleration limits for the vehicle under test. These controls will not be operated under computer control but will be operated manually (in antomatic or manual mode). An emergency stop and an emergency trip control are located at the bottom of the test conductor's speed control panel. These may be used by the test conductor if it is necessary to stop the drive system because of some unforeseen test vehicle or facility problem. When the EMERGENCY TRIP pushbutton is depressed, all main rotating equipment will be automatically deenergized and allowed to coast to a stop. When the EMERGENCY STOP control is activated, the electrical drive system will decelerate the compressor to zero speed in the minimum possible time. The emergency stop may also be initiated automatically by the vibration safety cutoff hardware (when the vibration of the gearing or the jackshaft exceeds predetermined limits). When speed is controlled from the master speed control panel, the control knobs associated with the speed setpoint controls A and B, the setpoint vernier control, the activate A and B pushbuttons, and the control knobs associated with the acceleration and deceleration rate setpoints as well as the hold control will be deactivated. The COMPRESSOR ROTOR SPEED, the COMPRESSOR ROTOR SPEED SETPOINTS, COMPRESSOR PERCENT CORRECTED SPEED, ACCELERATION RATE SETPOINT, and the DECELERATION RATE SETPOINT displays will continue to display corresponding parameters when control is executed from the master speed control panel. The values on these displays will be the same as the values on the corresponding displays on the master speed control panel. The three limit controls at the bottom of the panel will continue to be active (whether speed is controlled from the master speed control panel or the test conductor's speed control panel). Speed control is detailed further in Volume IV of this report.

3.6.1.2 Other Electrical Drive Controls

Other electrical drive controls which will make up a section in the facility annunciator/control panel will be located in panels adjacent to the master speed control panel. These controls will be the drive lubrication system controls and the drive START-STOP control. The drive lubrication system will be controlled from the drive lubrication system panel. Controls on this panel will include a control to initiate the automatic lubrication system startup sequence.

The controls necessary to start the electrical drive system will be located on the drive start-stop control panel. As a result of the Phase I project analysis, automatic startup capability using three master switches will be provided as part of the electrical drive system controls (Volume IV). The controls necessary to accomplish this will be located on the drive start-stop panel. The automatic startup of the auxiliaries, the constant speed MG set, and the frequency converter will be initiated from a master start switch on the panel at which time a light will come on indicating that the drive is ready for start. The operator will then initiate a drive startup. When the starting sequence has been completed, a "RUN" switch will be used to transfer control to the master speed control panel. A more detailed discussion of electrical drive system startup is presented in paragraph 3.11.3 of this volume.

Other controls located on the electrical drive section of the facility annunciator/control panel will include the controls associated with the 12,400-hp synchronous motor, the frequency bus, the 440-volt generator room auxiliaries, the turning gear, and the 440-volt drive auxiliaries.

3.6.2 PRESSURE CONTROL

A pressure control system will be provided to control both inlet pressure and compressor pressure ratio. This control will be implemented in the open cycle configuration by actually controlling the position of the inlet and discharge valves. Included in the pressure control system will also be a stall prevention capability and a mode of operation allowing direct control of the inlet and discharge valve position.

3.6.2.1 Inlet Pressure/Inlet Valve Control

Inlet pressure will be controlled by a closed loop control system in which the actual inlet pressure setpoint may either be set manually or automatically. The inlet pressure control will have a dual mode of operation. In the pressure control mode, the inlet pressure will be maintained at the given setpoint; in the position mode, the inlet valve position will be maintained at a position setpoint.

A possible control panel layout for the inlet pressure/valve position controls is presented in Figure 3-5. (This layout is not intended to represent the final design concept of the control system but has been included to facilitate the functional discussion on inlet pressure/valve position control operating philosophy.) Functionally, the inlet pressure/valve position controls and associated displays will be comprised of four in-line displays, two control knobs, and two inlet pressure mode control buttons. The display denoted by INLET PRESSURE will be a readout of actual inlet pressure at a given instant. Below it will be the INLET PRESSURE SETPOINT displays of the actual setpoint set in at any given time (provided manually or by the computer). If the inlet pressure/valve position control is in the POSITION mode of operation, the INLET PRESSURE SETPOINT display will display the actual inlet pressure; therefore, the INLET PRESSURE display and the INLET PRESSURE SETPOINT display will indicate the same readings. In the manual mode of operation, the control knob below the INLET PRESSURE SETPOINT display will be used to provide the setpoint when pressure is being controlled. Likewise, the top display on the right will be an INLET VALVE POSITION display which will indicate the actual position of the valve at any given time. Below the INLET VALVE POSITION display will be the INLET VALVE POSITION SETPOINT display that indicates the actual setpoint provided by the computer or the control knob directly below. If pressure is being controlled rather than position, the INLET VALVE POSITION SETPOINT and INLET VALVE POSITION displays will read the same. All readings appearing on the pressure and position displays on this control panel will be in engineering units. The actual values displayed may be routed to the digital computer.

If more than one valve is required at the inlet to regulate inlet pressure, then the INLET VALVE POSITION and INLET VALVE POSITION SETPOINT displays would be calibrated to read "percent open" of the combined valve arrangement. That is:

$$P = \sum_{i=1}^{N} \frac{P_i W_i}{N}$$

where:

P = "percent open" for the combined valve arrangement

P_i = "percent open" of each of the valves

W_i - A factor relating the ratio of the full open flow area for the ith valve to the full open flow area for the largest valve. W_i for the largest valve would be 1. If the combined valve arrangement is composed of identical valves, then W_i = 1 for all valves.

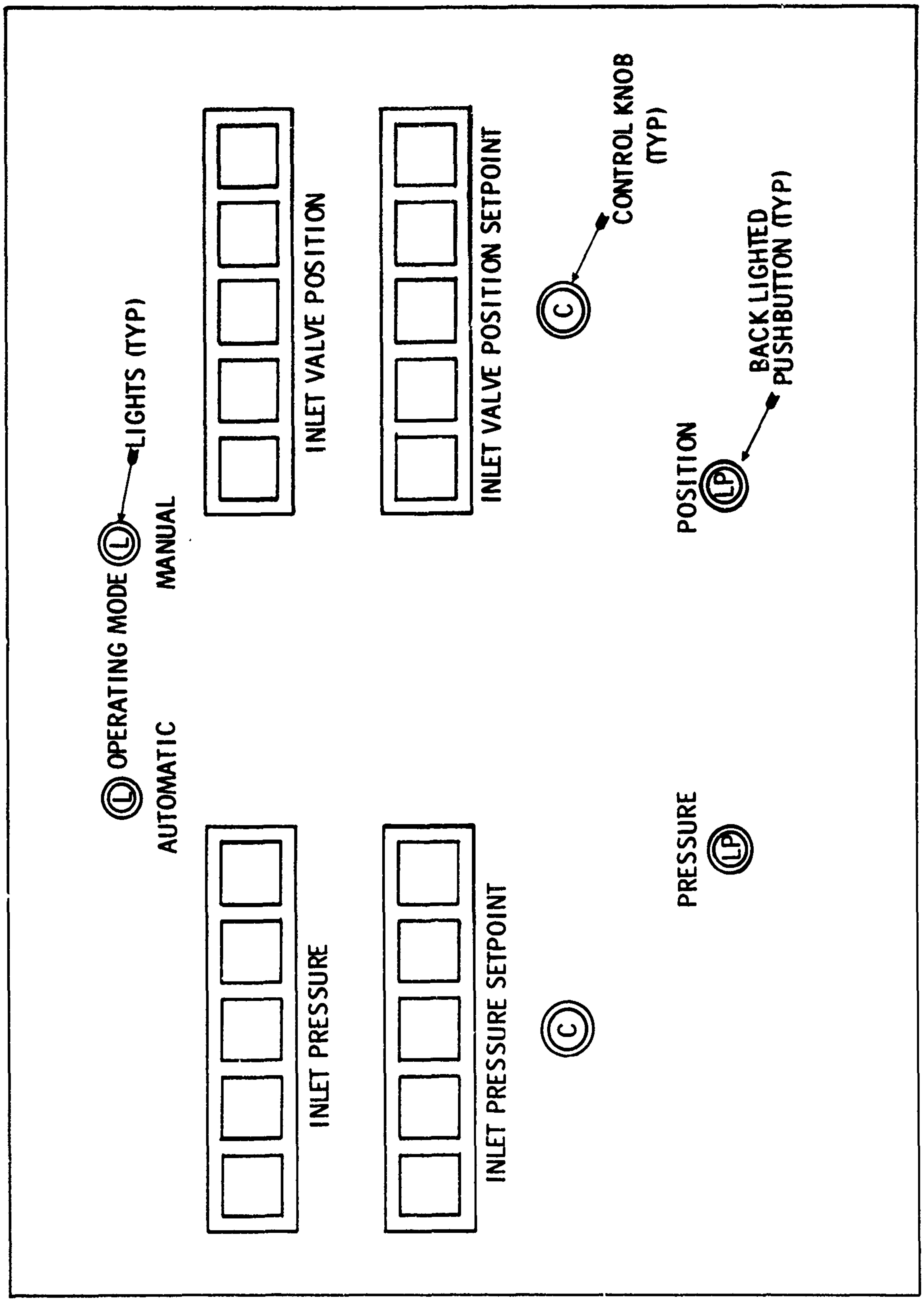


Figure 3-5. Inlet Pressure/Valve Position Controls

N = number of valves in the combined valve arrangment

Where more than one valve is used, the position setpoint reference would be applied to the "valve programmer" section of the control system which would automatically provide a position reference to each of the valves in the proper sequence to achieve the desired "percent open" position for the combined valve arrangement.

The two backlighted pushbuttons below the control knobs provide for selecting POSITION or PRESSURE control. When the system is in the automatic mode of operation, the computer will control these pushbuttons and select either the pressure or position operating mode (the mode selected will be indicated by the pushbuttons' light). In the manual mode, once either pressure or position mode has been selected and the pushbutton activated, then the backlight will light up on the button that is depressed.

When the inlet pressure/valve position control is operating in the pressure mode, the inlet valve will be modulated to provide a constant inlet pressure. The response of this system will be such that the inlet pressure will be maintained constant (within the tolerance specified in Volume IV of this report) over any speed transient, flow transient, or pressure ratio transient that might be injected into the test vehicle by the facility controls. It is not planned, however, that the inlet pressure will ever be varied as a function of speed or other test item variables.

In open cycle operation where the compressor discharge is exhausted to atmosphere (14.7 psia), inlet pressure might be lowered below a value causing some compressors to enter an unsafe operating region and possibly go into stall. The inlet pressure might also be lowered to the point where the lubrication oil scavage will not operate effectively. To prevent this, safety limits will be built into the inlet pressure/valve control system. These limits will make it impossible to adjust or maintain the inlet valve reference at a level which causes inlet pressure to decrease below a safe value. If an attempt is made to do this, manually or with the computer, in either the pressure or position control modes, the system will cease to respond to the setpoint references before inlet pressure reaches an unsafe value. As an additional safety factor, the inlet valve will open to a selected position automatically in the event of power failure, emergency stop or trip, or stall detection. Manual overrides of this feature will be provided near the valve for maintenance work.

The digital computer may also be used as a safety alarm device to diagnose problems or malfunctions in the inlet pressure/valve control system. For example, at frequent intervals the computer can compare the inlet pressure read from the inlet pressure/valve control system sensors to the average inlet pressure being measured with the digital data acquisition system. If these values differ from a predetermined value, then the computer can provide a necessary alarm. The computer can also relate inlet valve position to inlet pressure for any given mass flow using an appropriate transfer function, and, if these values fail to correspond within expected limits, the computer can provide the necessary alarm.

A mechanical manual valve position control and position indicator will be provided at the inlet valve(s) to aid in maintenance operation.

3.6.2.2 Pressure Ratio/Discharge Valve Position Control

The pressure ratio or discharge valve position may be controlled manually or by the digital computer through this control system. Pressure ratio may be controlled in a direct mode (specified setpoints independent of other parameters) or via a function generator. In the function control mode, pressure ratio will be varied as a function of compressor percent corrected speed. The function control and the functional form of the speed versus pressure ratio relationship may either be controlled manually or by the computer. A possible layout of the control functions for pressure ratio/discharge valve position control is presented in Figure 3-6. This layout is not intended to represent the final design concept of the control system but has been included to facilitate the functional discussion on the pressure ratio discharge valve position control operating philosophy. As shown in this layout, below the discharge valve position and pressure ratio controls are four back-lighted pushbuttons which allow control of the various modes of operation of the pressure ratio/discharge valve position control system. In the automatic mode, the computer will control these switches and the status of the switches will be indicated by the lighted or non-lighted status of each switch. In the manual mode, the switches will be activated manually, but similarly the status will be indicated by the non-lighted condition of the switch. The two top switches allow for the selection of either the pressure ratio or position modes. When pressure is being controlled, the two bottom switches will provide for either functional control (pressure ratio control as a function of speed) or direct control. Under direct control, the actual pressure ratio setpoint will be provided by either the computer or the manual control. The PRESSURE RATIO display will indicate the actual pressure ratio for the compressor at any given time.

Below this display, the PRESSURE RATIO DIRECT SETPOINT will indicate the actual setpoint provided by either the computer or the manual control when the system is operating in the direct pressure ratio control mode. In the function pressure ratio control mode, the PRESSURE RATIO DIRECT SETPOINT display will track the PRESSURE RATIO display above it; thus, when control is changed from function to direct, the direct setpoint will always correspond to the actual pressure ratio provided under function control. The function control for the pressure ratio will be provided by a function generator which has percent corrected speed supplied as an input. The output of the function generator is a pressure ratio reference signal which is a function of percent corrected speed. The function generator generates the output functions using the "10 member pressure ratio versus speed" table currently displayed on the 20 readouts labeled PRESSURE RATIO VERSUS SPEED ($\%N/\sqrt{\theta}$) FUNCTION SETPOINT. The left

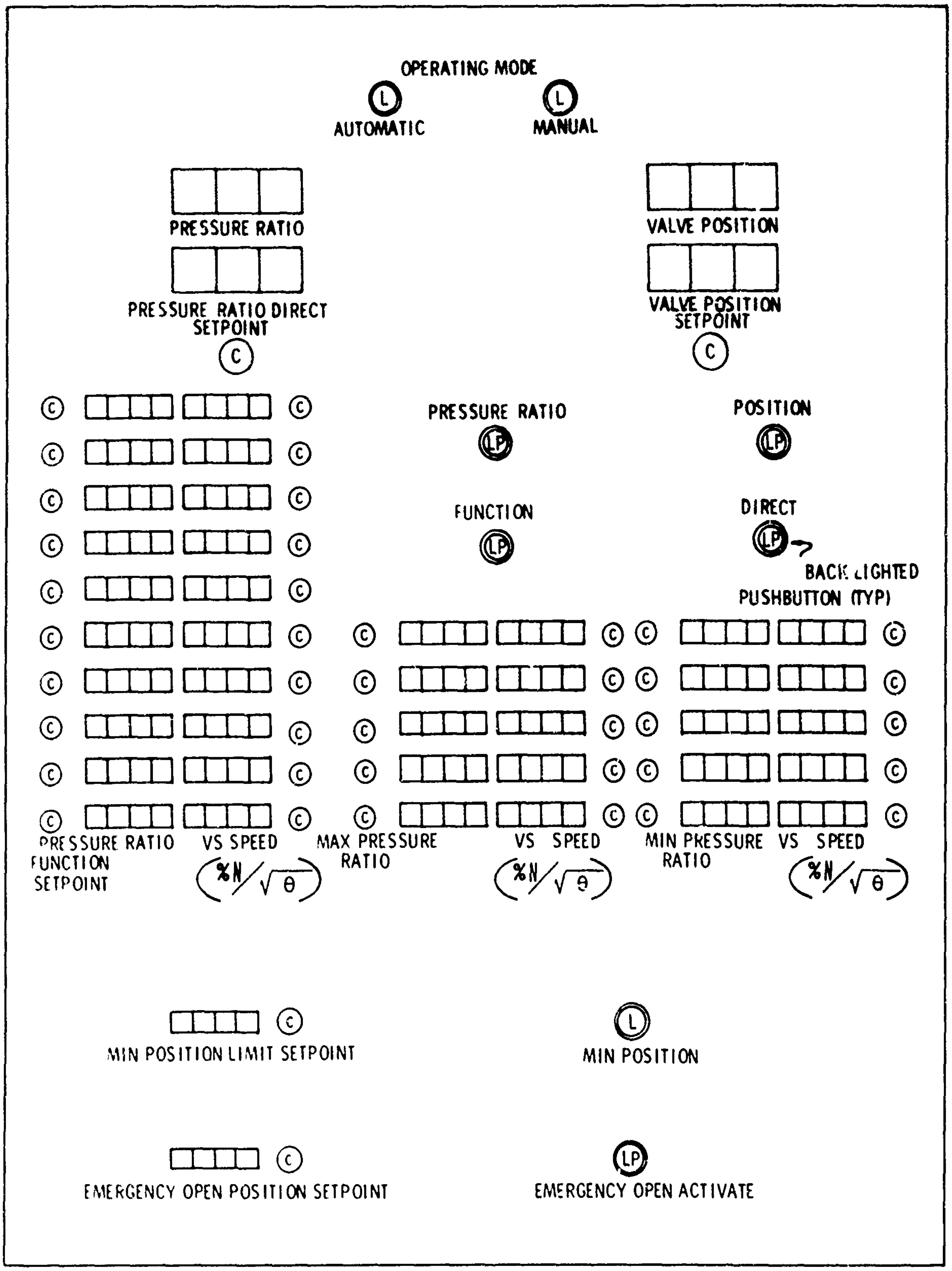


Figure 3-6 Pressure Ratio Discharge Valve Position Control Panel

readout column will contain 10 pressure ratio values on the desired "pressure ratio versus speed" trajectory; the right column will contain the 10 corresponding percent corrected speed points. The output of the function generator may be represented by a smooth curve which passes through the points denoted by the 10 pairs of numbers. In the manual mode, the control knobs adjacent to the 20 readouts will allow a given "pressure ratio versus speed" trajectory to be entered into the system manually. Each knob may be used to set the proper table value into the associated readout. In the automatic mode, however, the control knobs are disengaged and the "pressure ratio versus speed" table defining the desired trajectory will be entered into the readouts by the digital computer. In this manner, the computer can actually generate the function of "percent corrected speed versus pressure ratio" by supplying the proper table. When position is being controlled by the control system, the two pressure ratio displays at the top left will both indicate actual pressure ratio so that the actual pressure ratio setpoint (although not activated) will track the actual pressure ratio controlled by the direct valve position control. The display at the upper right labeled VALVE POSITION will indicate actual discharge valve position regardless of the control mode. The display directly under it, VALVE POSITION SETPOINT will actually indicate the discharge valve position setpoint when the control system is used to control discharge valve position. The setpoint displayed will be supplied by the manual control knob when the facility is operating in the manual mode and will be the actual setpoint provided by the computer when the system is operating in the automatic mode of operation. When the system is used to control pressure, these two displays will both show actual discharge valve position. The setpoint indicated by the bottom display will in that way track the actual valve position when pressure ratio is controlled. The control of the discharge valve position as a function of speed or other compressor parameters will not be provided; however, this could be accomplished in the automatic mode by having the digital computer actually generate the function via software and issue the appropriate direct setpoint position commands to track the desired parameters. When facility control is transferred from the automatic to the manual mode all pressure ratio setpoint (function or direct) and position setpoint displays and readouts will retain the setpoints last issued by the computer until new values are entered by the associated manual control knobs.

A minimum/maximum "pressure ratio versus speed" limiting capability has also been incorporated into the pressure ratio/discharge valve position control. These limits will be provided by two function generators: one to generate the maximum "pressure ratio versus speed" function setpoint. This feature of the control system will provide a stall prevention technique. An input to both the maximum and minimum function generators will be percent corrected speed. Output of the maximum function generator will be a pressure ratio upper limit which is a function of percent corrected speed and the output of the minimum function generator will be a pressure ratio lower limit which is a function of percent corrected speed. The functional relationship between speed and the outputs of both of these function generators can be controlled by the entry of "pressure ratio versus speed" tables. These function generators are identical to the one used to generate the "pressure ratio versus speed" trajectory except they only require a five-member "pressure ratio versus speed" table and they cannot be controlled by the digital computer. The limits for the maximum "pressure ratio versus speed" function and the minimum "pressure ratio versus speed" function can only be set manually. Thus a pressure ratio maximum and minimum limit can be set which cannot be violated either manually or with the computer during a test (pressure-direct or function - or position mode).

For example, the compressor performance map (Figure 3-7) shows the stall line and the operating line along with the constant speed lines. If for a given test the upper and lower pressure ratio limit lines are defined as shown on the map, they will represent pressure ratio limits that are not to be exceeded accidently during the test. From the map, five points can be selected along both the maximum and minimum limit lines so that a smooth curve drawn through these points would coincide with the limit lines. The coordinates of these points then represent the table setpoints that must be entered into the maximum and minimum pressure ratio limit function generators to set the desired limits. Prior to entering the tables, the span and zero for each function generator must be calibrated to accommodate the required output voltage ranges. Span and zero controls will be located on the function generators, not on the pressure ratio/discharge valve position control panel. To enter the tables into the function generators, the manual control knobs will be adjusted until the correct numbers appear in the adjacent readouts. If at any time during a test the actual pressure ratio reaches an upper or lower limit, it will not exceed this limit but will track it as a function of percent corrected speed. This is accomplished internally by substituting the minimum or maximum function generator output signal for the pressure ratio reference to the control system. Either the MIN LIMIT or MAX LIMIT light will illuminate if the system is operating at one of the pressure ratio limits.

In reference to Figure 3-7 again, if the test plan calls for a non-linear speed trajectory from A to B and then a decelerating speed trajectory along the operating line, either the manual or the automatic mode of operation could be utilized. The tables which represent the trajectories from A to B and C to D may be obtained by selecting 10 points along each of these curves on the performance map. The coordinates of these points (table setpoints) would then be prestored in the computer if the run is to be done in the automatic mode or recorded on a test conductor's test plan if the trajectories are to be done in the manual mode. Prior to the test, the function generator span and zero adjustments would be made to accommodate the range of the tables. With the initial conditions set at A (pressure ratio/discharge valve position control set with PRESSURE selected on appropriate pushbutton and FUNCTION selected on the other pushbutton), the table for the trajectory from A to B would be entered into the function generator so that the correct numbers appear in the PRESSURE RATIO VERSUS SPEED FUNCTION SETPOINT

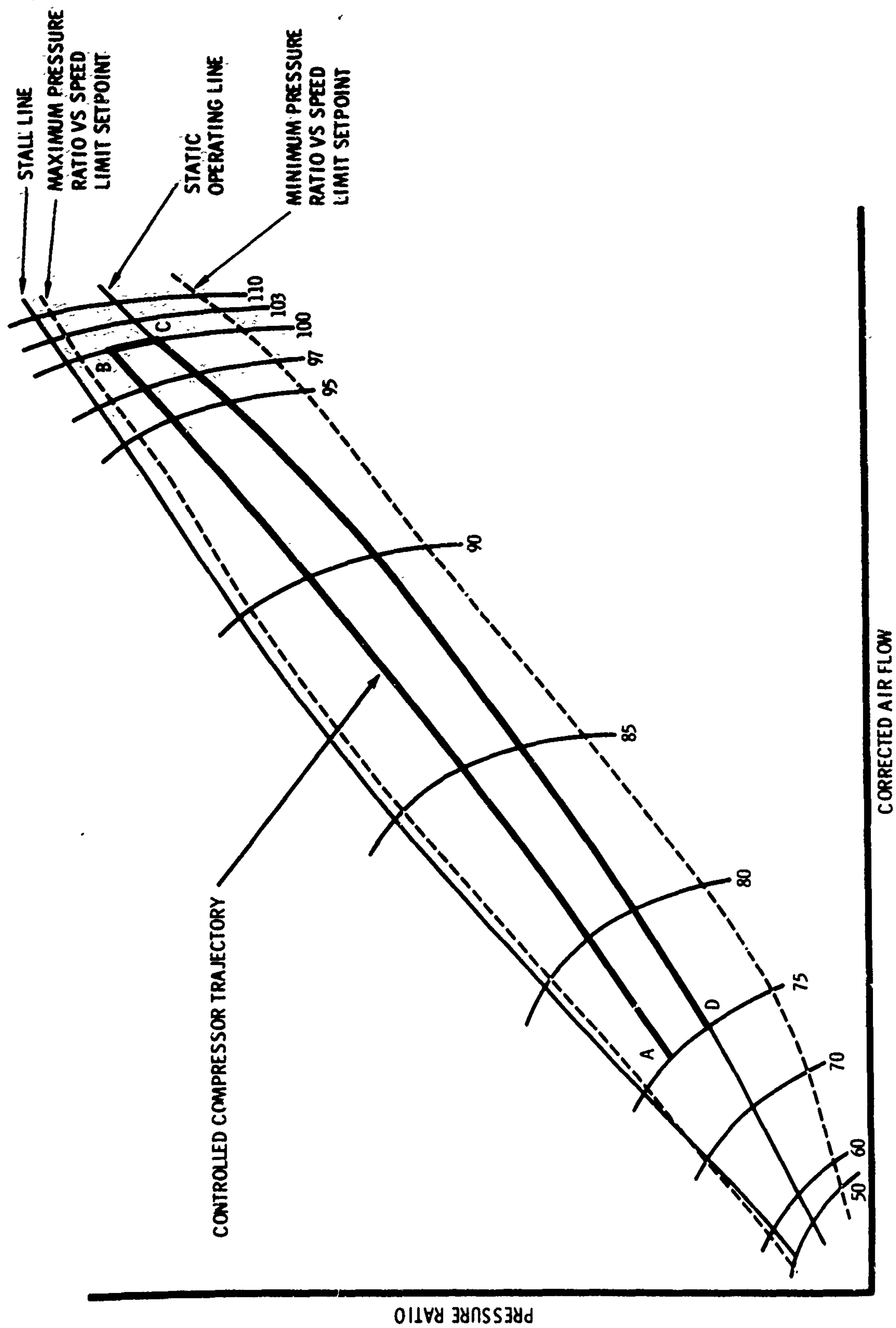


Figure 3-7. Typical Performance Map

displays. This again may be accomplished either by the digital computer or manually. On the speed control panel, B would be entered as a new setpoint and the rate of change for traversing from A to B set. The speed trajectory would be initiated either manually or automatically by the computer and the speed trajectory started. The pressure ratio would track speed from A to B based on the function generator output. Upon terminating the speed trajectory at B, the pressure ratio control would be changed from FUNCTION to DIRECT (manually or by the computer). The pressure ratio direct setpoint would decrease along the constant speed lines from B to C (by utilizing the control knob on the control panel in the manual mode or by the computer in the automatic mode). When the pressure ratio point C is reached, the control knobs on the PRESSURE RATIO VERSUS SPEED FUNCTION SETPOINT control would be manipulated to enter the table for the trajectory between C and D (manually or provided by the computer). When the displays have been reset, the direct pressure ratio control would be changed to function pressure ratio control and the required speed trajectory from C to D would be initiated through the speed control system with the output of the "pressure ratio versus speed" setpoint generator causing the pressure ratio to track speed between points C and D.

In addition to the maximum and minimum "pressure ratio versus speed" limits, two other safety or BACKOFF controls, a minimum valve position limit control and an emergency open position control, have been placed on the pressure ratio/discharge valve position panel.

The minimum valve position limit control will provide for a minimum discharge valve closure limit setpoint. Once a given value is entered into the MIN POSITION LIMIT SETPOINT display, no other pressure ratio or valve position reference can cause the discharge valve to move to a more closed position than indicated on this display. When the discharge valve is at this limit, the MIN LIMIT light will come on. The minimum position limit setpoint may be entered into the MIN POSITION LIMIT SETPOINT display using the adjacent control knob in the manual mode or by the computer in the automatic mode.

The emergency open position control (located at the bottom right of the control panel) has been placed on the pressure ratio/discharge valve position panel to permit emergency discharge valve opening when required. This control knob provides a means of adjusting the emergency open position setpoint to the desired value which appears on the EMERGENCY OPEN POSITION SETPOINT display. This is a precalculated position to which the discharge valve may revert in an emergency. The emergency open position setpoint may be activated either by the EMERGENCY OPEN ACTIVATE pushbutton, by the stall detection system, or by an emergency stop activation. Whether the emergency open is activated by the stall detection system, an emergency stop, or manually, the back light on the EMERGENCY OPEN ACTIVATE pushbutton will light up instantly when this control is activated.

All displays or readouts located on the pressure ratio/discharge valve position control panel may be connected to the digital computer. The digital computer can be used in several ways

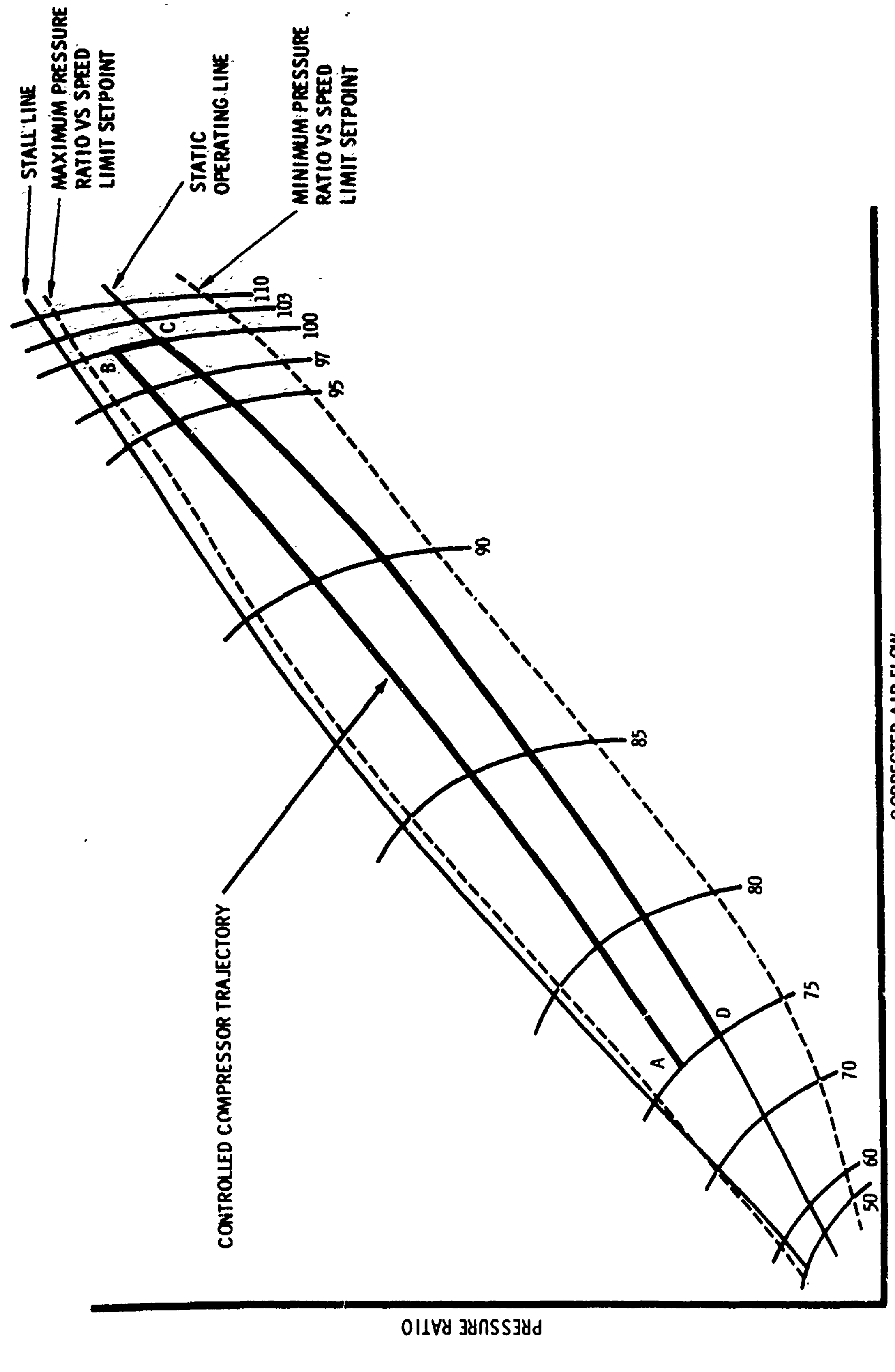


Figure 3-7. Typical Performance Map

speed line. The second method of operation provides a means of stator vane optimization at given speed points either by the use of the computer or manual control. Bleed valve settings can be controlled likewise. The design goal is to make the stator vane control, electronics, and the bleed valve control electronics interchangeable. A change of actuator in the loop is all that is required for conversion although this would require a different sensing element to sense stator vane angle or bleed valve position. Actuators for stator vane control will be mounted on the test item or attached to the ceiling or floor of the test chamber. Because of this, the actual actuators may vary from one test item to the other.

A possible layout of the stator vane bleed control panel is presented in Figure 3-8. (This layout is not intended to represent the final design concept of the control system but has been included to facilitate the functional discussion on stator vane/stage bleed control operating philosophy.) This panel contains a set of individual controls at the top for each of the 25 closed cycle controls. Two displays are located at the top of the No. 1 control loop. STATOR ANGLE/BLEED VALVE POSITION is a display of the actual stator angle or position of the bleed valve being controlled. Directly under that, the STATOR ANGLE/BLEED VALVE POSITION SETPOINT reflects the current setpoint when the system is operating in a direct mode. The setpoint may be provided by the control knob immediately below the display in the manual mode or by the computer in the automatic mode.

Two columns of ten displays with associated control knobs are located below the display. These controls will be utilized when the control system is in the function mode. The function controls may be operated either manually or by the computer and provide for setting a function generator whose input is corrected speed and whose output is a stator angle or valve position reference. The two sets of controls represent the manual or computer input of a table to the control system. The elements of this table are the percent corrected speed and stator angle or valve position as labeled on the control panel. After the function generator has undergone span and zero calibration, a stator schedule may be entered into the control system by setting the speed points (zero percent, 50 percent, 60 percent, 70 percent, etc.) in the left hand column of controls and the corresponding stator angle or valve position in the right hand column of controls.

For example, if at zero speed the stator schedule calls for a 50 degree setting, then 50 would be entered on the control knob for the first point. Likewise, at 50 percent speed, if the stator schedule is 48.9°, then this would be set in using the right hand control knob. This would be continued on down through as many of the speed points (up to 10) as necessary to define a particular stator vane or bleed valve trajectory.

An alternate method of generating position vs percent corrected speed trajectories is through the use of a special digital computer. This method was considered during the project analysis and found to be feasible. Further consideration will be given to the use of a special-purpose digital computer for this application during design. If a special-purpose digital computer is

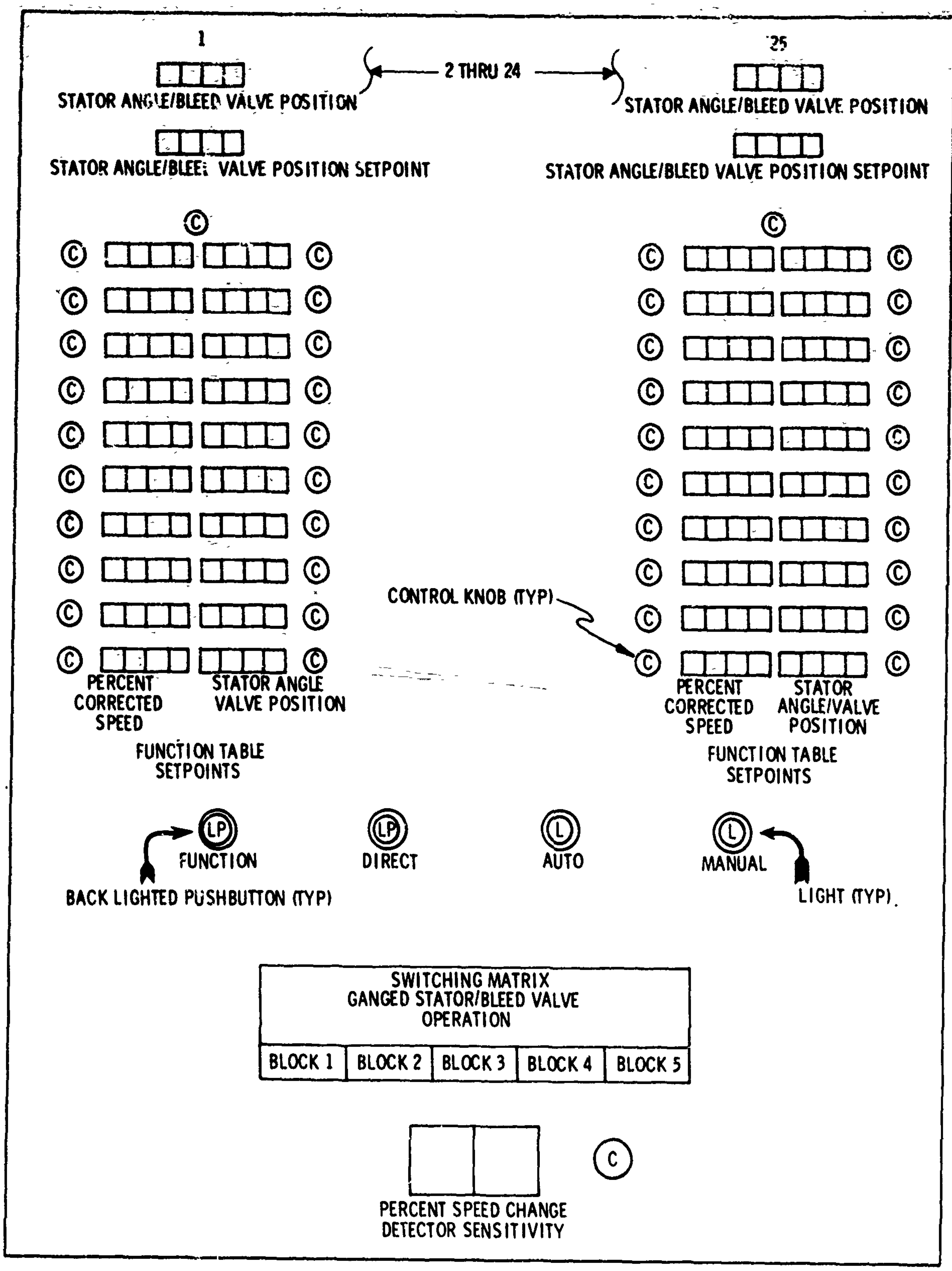


Figure 3-8. Stator Vane/Bleed Valve Control Panel

used in lieu of the function generators, the overall operating philosophy would remain unchanged.

Again, it must be emphasized that this stator schedule may be either entered manually or by the computer. When the compressor is undergoing a speed transient, the stator vane/bleed valve will then track speed according to the predetermined values set in the table. If there is a requirement to change the stator schedule during an actual test, the control system would be returned to the direct mode of control. It would then be possible for either the computer or operator to change the stator angle via the direct mode of control. Once the change is made by the control knob on the control panel or by the computer, it will be reflected on the STATOR ANGLE/BLEED VALVE POSITION SETPOINT display. While the system is still in the direct mode of operation (at constant speed), the appropriate value can be transferred from the stator angle valve position display corresponding to the given speed on the function table setpoint controls (via computer or manual control). Once the stator schedule has been adjusted and prior to going to a new speed, control will be reverted to the function method of control so the stator vane or bleed valve may track a given speed change. Below the individual stage controls are two back-lighted pushbuttons which allow manual control of the control system operating mode (function or direct). In the automatic mode, these switches will be operated by the computer. The status of these switches (operated manually or by the computer) will be indicated by the lighted condition of one of the switches. Also, two lights immediately to the right of these pushbutton controls will indicate the status of the facility operation (automatic or manual mode). Below the pushbutton switches and lights will be a switching matrix control to allow the 25 individual control loops to be ganged together in any combination in up to 5 blocks, allowing experimentation in ganging stator vanes together during the stator vane optimization testing. In the ganged mode, all of the stator vanes (or bleed valves) operating in a single block will be controlled by a single function generator; i.e., the function generator would be providing a common signal to each controller in that particular block. This method of ganging provides a very accurate linear coupling of stators or bleed valves. If non-linear ganging is required, this can be accomplished by the proper selection of individual stator or bleed valve schedules.

Below the switching matrix is a display and associated control labeled PERCENT SPEED CHANGE DETECTOR SENSITIVITY. The function of this control is to adjust the sensitivity of a speed change detector included in the stator vane/stage bleed controls to cause an automatic transfer from direct control to function control if speed changes more than some preselected percentage while the stator vane/bleed controls are operating in the direct mode. The amount of speed change allowed before the transfer takes place may be set by utilizing the PERCENT SPEED CHANGE DETECTOR SENSITIVITY control. This control is calibrated in percent and provides a range from .1 to 9.9 percent in .1 increments. It has a twofold purpose:

- It provides a safety feature. If a high pressure ratio compressor is allowed to change speeds over a wide speed range with variable stator stages in a fixed position, the compressor may go into a severe stall. The automatic transfer to the function mode which causes stators to track speed prevents this from happening inadvertently.

- It allows for a selected speed change before the mode transfer is activated which permits a series of tests to determine stator schedule tolerances and study the effect of flight control system lag on compressor performance.

In the event of stall detection by the stall detection system or the activation of an emergency stop or trip, the stator vane/bleed valve controls will automatically switch to the function mode if they are in the direct mode at the time. The switch will also take place if power is lost.

3.6.4 TEST VEHICLE LUBRICATION SYSTEM CONTROLS

The test vehicle lubrication system is required to supply lubricating oil to the test vehicle bearings and a facility drive shaft bearing in the proper quantities and at the designated pressure and temperature. Not only must the system have the capability to supply oil to vehicle bearings, but it must also supply oil to the shaft journal and thrust bearing (a Kingsbury thrust bearing) since some test vehicles will require a thrust bearing to be tested in the CRF. Journal and thrust bearings have substantially different requirements from other test vehicle bearings. They typically require a high flow at relatively low pressures while the other test vehicle bearings can typically be expected to require low flows at pressures higher than those required for the thrust bearing. Figure 3-9 is a preliminary sketch of the test vehicle lubrication system. Refer to Volume III, paragraph 3.9.2 for a detailed discussion of this system.

Scavenging of the lubrication system on the test vehicle will be required to assure flow through the bearing areas. If the oil return system is allowed to operate at atmospheric pressure, a substantial "holdup" in the bearing area and an increased oil leakage into the vehicle flow system would result which may, at reduced inlet pressures, cause coking of vehicle components. "Holdups" in the vehicle bearings may cause these bearings to run flooded and thus result in bearing failure. The scavenging system will be capable of handling oil seal leakage for the compressor air paths into the lubrication system since test vehicles may operate in the CRF with inlet pressures as low as 2 psia.

Figure 3-10 is a possible layout for the test vehicle lubrication system control panel which is part of the facility annunciator/control panel. (This layout is not intended to represent the final design concept for the panel but has been included to facilitate the functional discussion on test vehicle lubrication system operating philosophy.) Seven individual oil supply points will be provided inside the test tank, six of which may be used for test vehicle bearings and one of which may be used for the Kingsbury thrust bearing arrangement, or two of which may be used for the Kingsbury arrangements and five for vehicle bearings, if necessary in the particular test setup. The two lights at the top of the test vehicle lubrication system control panel labeled AUTOMATIC and MANUAL will indicate whether the facility is operating in the automatic or manual mode. The two digital readouts near the top of the panel (See Figure 3-10) labeled

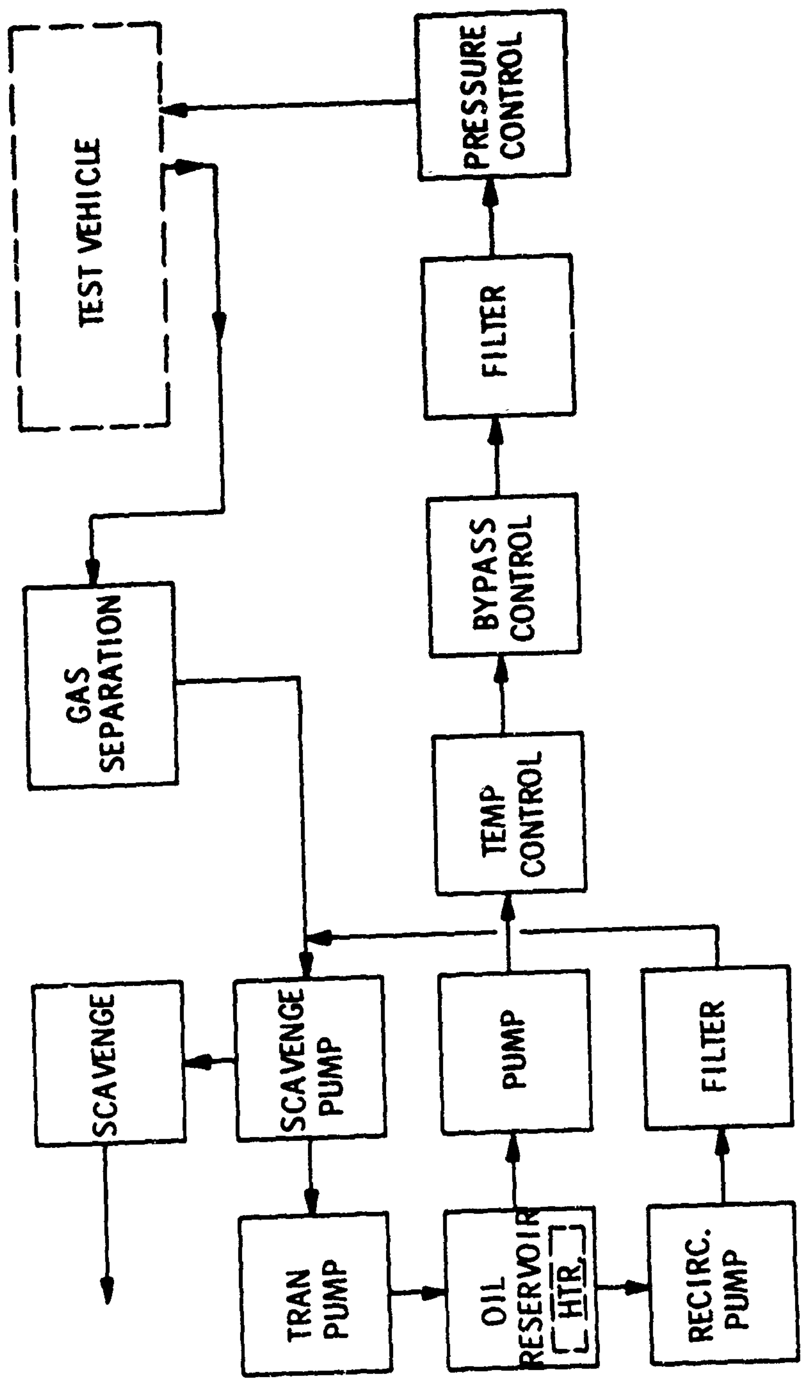


Figure 3-9. Test Vehicle Lubrication System

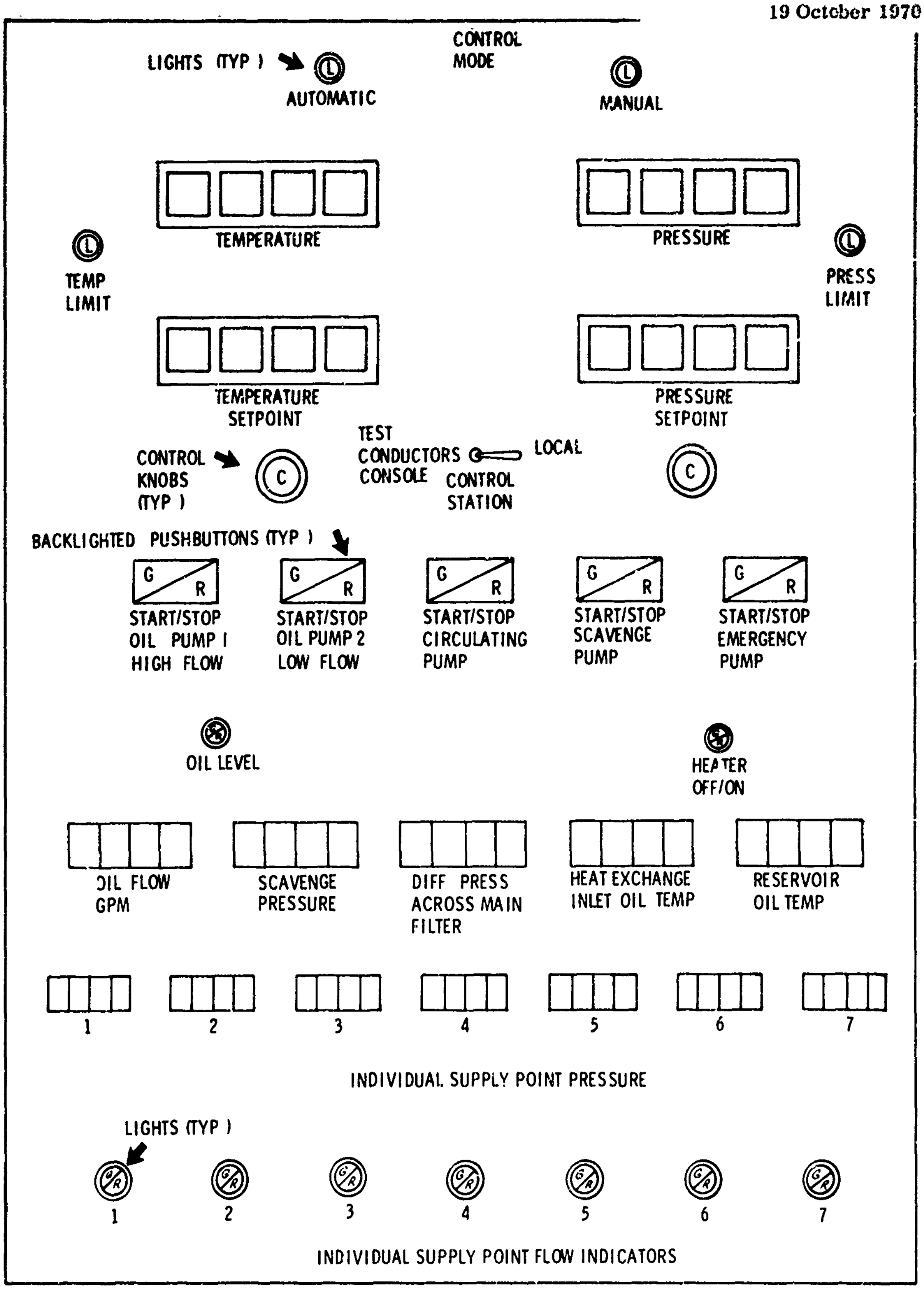


Figure 3-10. Test Vehicle Lubrication System Control Panel

TEMPERATURE and PRESSURE will display the actual oil temperature and pressure at the main vehicle header. The controls below the pressure and temperature readouts will be the setpoint controls for this temperature and pressure. The TEMPERATURE SETPOINT and PRESSURE SETPOINT controls will provide setpoint references for control of oil temperature and pressure at the main vehicle header or supply point. These setpoints may be adjusted using the control knobs below the digital setpoint displays; i.e., the clockwise rotation of these knobs will cause the values appearing on the setpoint displays to increase while a counterclockwise rotation of the knobs will cause the values to decrease. In the manual mode, the control knobs may be used to adjust both the temperature and pressure setpoints; in the automatic mode, however, the setpoint on the TEMPERATURE SETPOINT display will be provided by the digital computer, and the control knob will be deactivated. The setpoint for pressure, on the other hand, will continue to be supplied by the manual control knob even when the facility is in the automatic mode. No computer control of lubricating oil pressure will be provided. The two lights labeled TEMP LIMIT and PRESS LIMIT will illuminate to indicate when the actual temperature and pressure (the values displayed on the TEMPERATURE and PRESSURE readouts) depart from the setpoints by more than ±20 percent. If the pressure drops below the pressure setpoint by more than 20 percent of the value of the setpoint, the emergency pump will also start to provide additional oil to the compressor to prevent test vehicle damage. The toggle switch located below the temperature and pressure setpoint controls may be used to transfer setpoint control to a panel on the test conductor's console. When this switch, CONTROL STATION, is in the LOCAL position, the setpoint control knobs on the test vehicle lubrication control panel will be active and setpoints may then be provided from the panel. If this switch is in the TEST CONDUCTOR'S CONSOLE position, setpoint control will be transferred to the test conductor's console and the setpoint control knobs on the test vehicle lubrication system control panel will be deactivated. The TEMPERATURE, PRESSURE, TEMPERATURE SETPOINT, PRESSURE SETPOINT, TEMP LIMIT, and PRESS LIMIT displays and lights will perform the same function whether control is accomplished from the test conductor's console or the main test vehicle lubrication system control panel. These displays and lights are wired in parallel with the corresponding displays and lights on the test conductor's console and both sets of displays and lights will always provide the same indication. The row of backlighted pushbuttons below the control transfer switch will function to start and stop the various oil pumps. These pushbuttons must be depressed to start or stop the pumps. When the pumps are off, they will be illuminated with a green backlight. Interlocks will be provided to prevent pump stoppage during test operations. The emergency pump can be started manually using the designated pushbutton or it will come on automatically when the oil pressure drops 20 percent below the current setpoint. The two lights below the pump START-STOP pushbuttons will indicate the status of reservoir oil level and the reservoir oil heaters. If the OIL LEVEL light is green, then oil level will be adequate. However, if this light turns red, the oil level will be below the minimum limit. The HEATER OFF/ON light will be green when the heater is off and red when the heater is on. A series of digital readouts will indicate oil flow, oil pressures, and oil temperature throughout the system. The digital readout labeled OIL FLOW GPM will be a direct display of the value measured by the flow meter in the main header. The SCAVENGE PRESSURE will be the value of the pressure measured in the scavenge manifold by a pressure transducer. A differential pressure drop across the filter in the main oil flow supply will be displayed on the readout labeled DIFF PRESS ACROSS MAIN FILTER. The temperature of the oil before it enters the heat exchanger will be measured and displayed on the digital readout labeled HEAT EXCHANGER INLET OIL TEMP. The reservoir oil temperature will be displayed on the digital readout marked with that title Below these digital readouts, a row of seven small digital readouts will be provided to display the pressures appearing at each of the individual supply points which may be connected to the test vehicle bearings or the Kingsbury thrust bearing. The seven lights below these readouts will indicate the status of flow at each of the individual supply points, green if the flow is adequate and red if the flow is below a safe limit. All readings on the displays on this control panel will be in engineering units. The actual values being displayed may be routed to the digital acquisition system in the control room. A parallel output from each of these displays will be hardwired to patch DA and PC system. All controls, displays, and status indicators located below the CONTROL STATION switch on the test vehicle control panel will be active whether pressure and temperature setpoints are controlled from this panel or from the test conductor's console.

The test vehicle lubrication system control panel will be operated by a facility engineer stationed at the facility annunciator/control panel during a test. This engineer would monitor all readouts on the test vehicle lubrication system control panel and advise the test conductor of any abnormal conditions, but would make setpoint changes and perform other control functions only at the direction of the test conductor.

Figure 3-11 is a possible layout of the test conductor's test vehicle lubrication system control panel. This layout is not intended to represent the final design concept for this panel but has been included to facilitate the functional discussion of test vehicle lubrication system operating philosophy. The controls on this panel will be duplicates of the controls at the top of the main test vehicle lubrication system control panel and, consequently, will perform identical functions. The temperature and pressure displays will provide readouts of actual oil temperature and pressure supplied to the test vehicle. The pressure and temperature setpoint control knobs and corresponding displays will provide displays of the control system setpoints and a means of controlling these setpoints when the test conductor's console is the active control station. In the automatic mode, the temperature setpoint control knob will be deactivated and the computer will supply the setpoint and display it on the TEMPERATURE SETPOINT

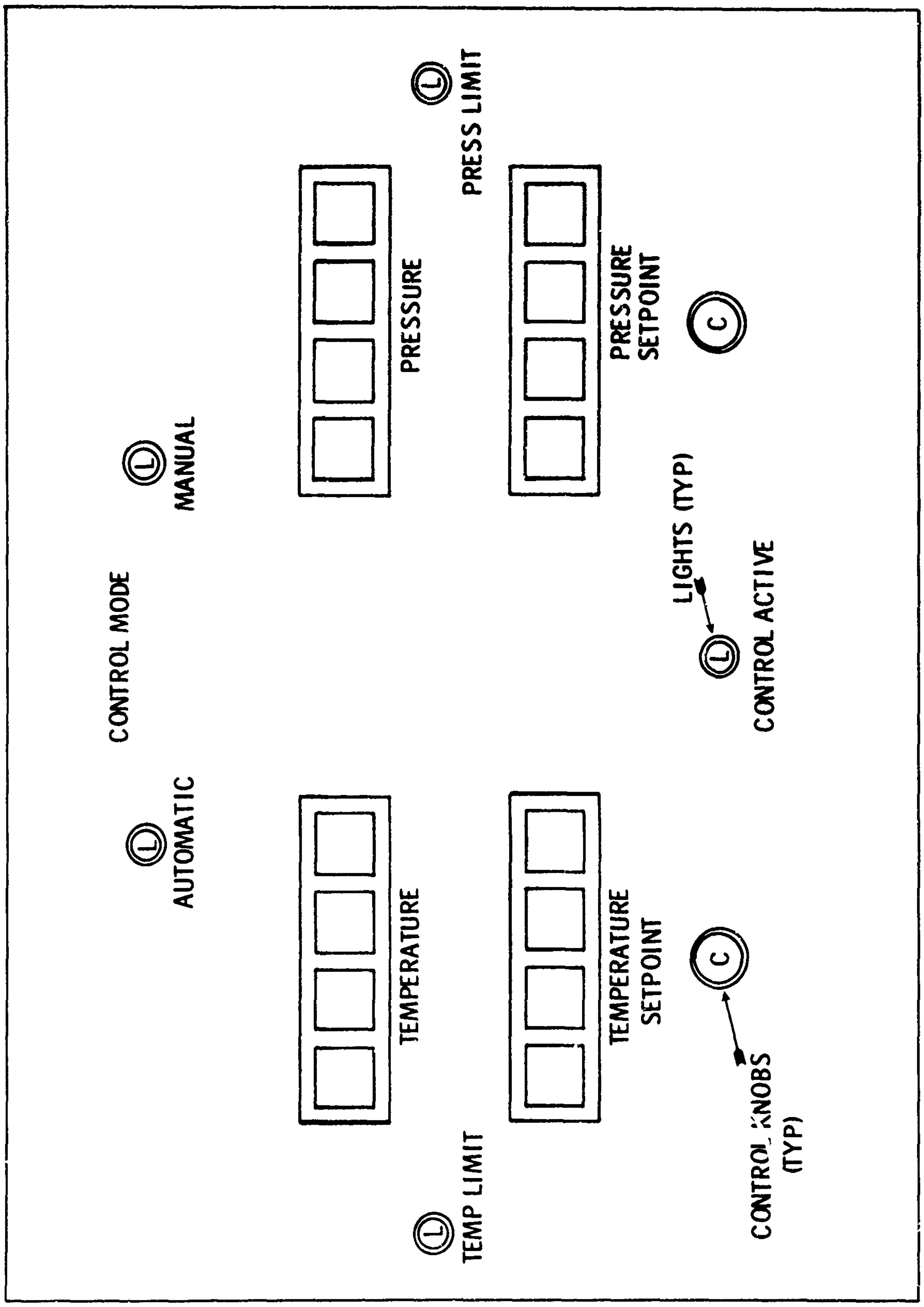


Figure 3-11. Test Vehicle Lubrication System Control Panel (Test Conductor's Console)

readout. The TEMP LIMIT and PRESS LIMIT lights will serve the same purpose on this panel as on the test vehicle lubrication system main control panel. The light at the bottom of the panel labeled CONTROL ACTIVE will illuminate when control is transferred to the test conductor's console and will remain on until control is transferred back to the main test vehicle lubrication system control panel.

During a test, control of the test vehicle lubrication system may be accomplished from the main vehicle lubrication system control panel or from the test conductor's console (at the discretion of the test conductor). Even if control during the test is accomplished at the test vehicle lubrication system control panel, the test conductor can monitor pressure and temperature and pressure and temperature setpoints with the displays on his console.

3.6.5 OTHER CONTROLS

Other miscellaneous controls required to successfully operate the Compressor Research Facility (System I) during a compressor test will include the following:

- Pneumatic system controls (shop air)
- High pressure hydraulic system controls
- Electrical power controls

The physical controls for these systems will be located in the control room on subpanels of the facility annunciator/control panel.

The pneumatic system controls will be primarily ON-OFF controls for the shop air compressor and the associated air pressure indicators and LOSS OF PRESSURE alarms. The hydraulic pressure controls will consist of ON-OFF switches for the main hydraulic pump and the backup hydraulic pump along with hydraulic pressure readouts and hydraulic pressure limit alarms. A hydraulic temperature indicator display will also be included among these controls. Electrical power controls will include those necessary to control primary power, regulated power, and emergency backup power. These controls will be ON-OFF switches and the meters and indicators required to monitor voltage, current, power, etc. The pneumatic, hydraulic, water system, and electrical power controls will be operated by a facility engineer stationed at the facility annunciator/control panel during pretest startup and during test operations.

3.7 COMPUTER AND MEASUREMENT SYSTEM OPERATING PHILOSOPHY

The computer and measurement system will be operated by the computer and measurement system engineer from the computer and measurement system console in the control room (except for video displays which may be operated from the various consoles). A preliminary layout of the control room consoles is shown in paragraph 3.2 of this volume.

The heart of the acquisition and control system for the Compressor Research Facility will be the digital computer which will serve as a valuable aid in compressor testing. Using the digital computer and associated peripherals, high speed data at rates up to 24,000 samples per second can be acquired and processed in real time or near-real time. The computer with its peripherals can convert this data to engineering units as necessary, display the data, print the data, and record it on discs or magnetic tape. Performance parameters can be computed in near-real time and displayed or recorded as necessary. Graphic plots of many of the compressor parameters can be constructed, updated, and displayed on command using video displays. These same plots can also be provided in hard-copy form using an X-Y plotter provided as a part of the computer peripherals. In the automatic mode, the computer will provide setpoint control for speed, inlet pressure, pressure ratio, compressor stator vanes, stage bleed, and test vehicle lubrication temperature. The computer will provide the computational capability necessary to perform all digital data reduction associated with compressor tests conducted in the CRF. The computer system will also have the capability to process general purpose scientific programs when it is not being utilized in compressor testing or data reduction.

Wideband analog tape recorders will be supplied as part of the computer and measurement system to record high frequency data. The wideband tape recorders will provide frequency responses up to 50 kHz for recording dynamic pressure, vibratory stress, and other high frequency data. Data recorded on analog tapes may be digitized at a "slowed-down" rate on an off-line basis utilizing the digital computer and its input peripheral equipment. Once digitized, this data can be processed by the more convenient digital techniques. A timing system will be furnished to supply a master time-of-day reference to all data records; this system will provide a digital code to the computer, an IRIG-B code to the analog tape recorders, and a slow time code to the strip chart recorders. The timing system will also have a translation mode enabling it to read the IRIG-B code from the analog tapes and translate to an equivalent digital code for the computer during the off-line conversion of analog data to digital data.

A flow measuring system will be provided to accurately measure steady state flow and (with some reduced accuracy) to measure transient flow up to the maximum response of the facility controls. The flow measuring system will be controlled from and displayed on the test conductor's console.

The Compressor Research Facility will be self contained insofar as data reduction is concerned. All foreseeable data reduction requirements associated with compressor testing may be satisfied using the hardware system provided for the CRF. The digital computer will be sized to provide the necessary resolution, storage capability, and speed to allow accomplishment of all digital data reduction. Reduction of analog data can be accomplished by digitizing it at a "slowed-down" rate and then performing the reduction using digital techniques. For "quick-look" purposes, a limited number of analog data channels can be "observed" using the spectrum analyzer or the oscillograph located on the dynamic data display status panel.

Every effort will be made in planning and designing the Compressor Research Facility computer and measurement system to provide hardware which is flexible, easy to set up and operate, requires few operating personnel, and provides maximum data accuracy. Universal signal conditioning will be furnished to increase measurement system flexibility and a flexible patching and data routing system will be provided to allow virtually any measurement point to be patched into any digital or analog system input. A calibration and reference checking system will be provided to minimize setup and maximize accuracy and ease of operation.

3.7.1 SENSORS AND SIGNAL CONDITIONING

Probes, sensors, and signal conditioning require little or no man-machine interface during an actual test. Installation, setup, and checkout of these items will be accomplished before test start. An exception would be some minor troubleshooting and repair during a test. Many of the probes and sensors will be on or near the test item while signal conditioners will be in the signal conditioning room. It is anticipated that the signal conditioning room can be manned at compressor speeds up to 50 or 60 percent of full compressor speed. Consequently, some troubleshooting could take place in the signal conditioning room while the compressor is running in a standby mode. (The compressor pretest buildup, instrumentation, and post-installation preparation is detailed in paragraph 3.8 of this volume.) Pressure transducers not installed on the test vehicle will be mounted in an environmentally controlled compartment adjacent to the test tank or near the ceiling in the signal conditioning room.

In this case, pneumatic lines will be routed from the sensing point (rake or probe) through test tank penetrations to the transducers. In general, and especially in the tests where transient phenomena are to be measured, pneumatic line length between the sensing point and the transducer should be minimized to increase frequency response. Sizing of the line should also be a careful consideration with respect to frequency response. Either copper or plastic tubing may be used as pressure measurement lines.

The design and selection of instrumentation to be installed inside the compressor is an important aspect in the preparation for a test program since a failure in this instrumentation can cause severe damage to a compressor and require that the compressor be removed from the facility, disassembled, and reinstalled prior to further testing. Needless to say, this is both time consuming and an expensive endeavor which should be avoided if possible. Since the loss of certain sensors may require removal of the test item from the tank and the subsequent reinstallation, spare instrumentation such as spare rotor and stator strain gages, spare bearing temperature thermocouples, etc., should be installed in the compressor during initial instrumentation buildup when possible. The process of instrumenting a compressor is discussed further in paragraph 3.8 of this volume.

Signal conditioning hardware will be located in the signal conditioning room directly below the test section (refer to paragraph 3.8.7 of this volume for discussion of data system setup including signal conditioning setup). Signal conditioning setup will usually be completed prior to the test run. Setup consists generally of adjusting zero and span of the combined sensor and signal conditioning unit. In most cases, the signal conditioners will provide excitation to the transducers. A large number of the signal conditioners will be of the "universal" type which can be mated with several different types of transducers by changing a mode card and a calibration card. This capability will permit the same signal conditioner to be used for measuring several physical phenomena or physical parameters, decreasing the total number of signal conditioners required to accomplish compressor testing. Signal conditioners dedicated to a single purpose will be a "single purpose" special signal conditioner rather than the universal type. This optimum mix of universal and conventional signal conditioners will reduce overall costs of measurement systems hardware. Another feature of all signal conditioners will be the capability to supply a measurement signal reference which can be used with the reference checking system to check measurement channels on a day-to-day basis and provide the ability to correct calibration curves when errors are caused by zero and gain drift. This reference will be initiated in the signal conditioner based on a relay closure which will be initiated by the reference check/calibration system.

3.7.2 PATCHING AND DATA ROUTING

Figure 3-12 is a typical routing diagram for the CRF computer and measurement system. Data will generally be routed from the test vehicle (rakes, probes, transducers, and other sensors) through a tank penetration to patch panel number 1 located in the signal conditioning room. Pressure transducers not located inside the test chamber and thermocouple reference junctions will be located between the tank penetrations and patch panel 1. These pressure transducers will be located in the signal conditioning room near the ceiling or in an environmentally controlled compartment adjacent to the test tank to minimize tubing runs required between pressure pickups and the actual pressure transducers. The output of patch panel number 1 will be wired to the input of the signal conditioning while the output of the signal conditioning will be routed to patch panel number 2, also located in the signal conditioning room. Patch panel number 3 located in the signal conditioning room will be the output to the control room. The output of patch panel number 3 will be routed through tunnels to patch panel number 4 in the control room. Patch panel number 4 will serve as a distribution point for all data channels to the recording devices in the control room. Facility measurements and control system display readouts will be hardwired to patch panel number 4 in the control room where they may be patched into any of the data recording systems. All patch panels will be clearly marked with numbers and designators to minimize human error during the data routing setup. Patch cords will be the plug-in type to ensure ease of connection. It should be pointed out also that all data routing and patching will be accomplished prior to the beginning of a test as part of the setup activity.

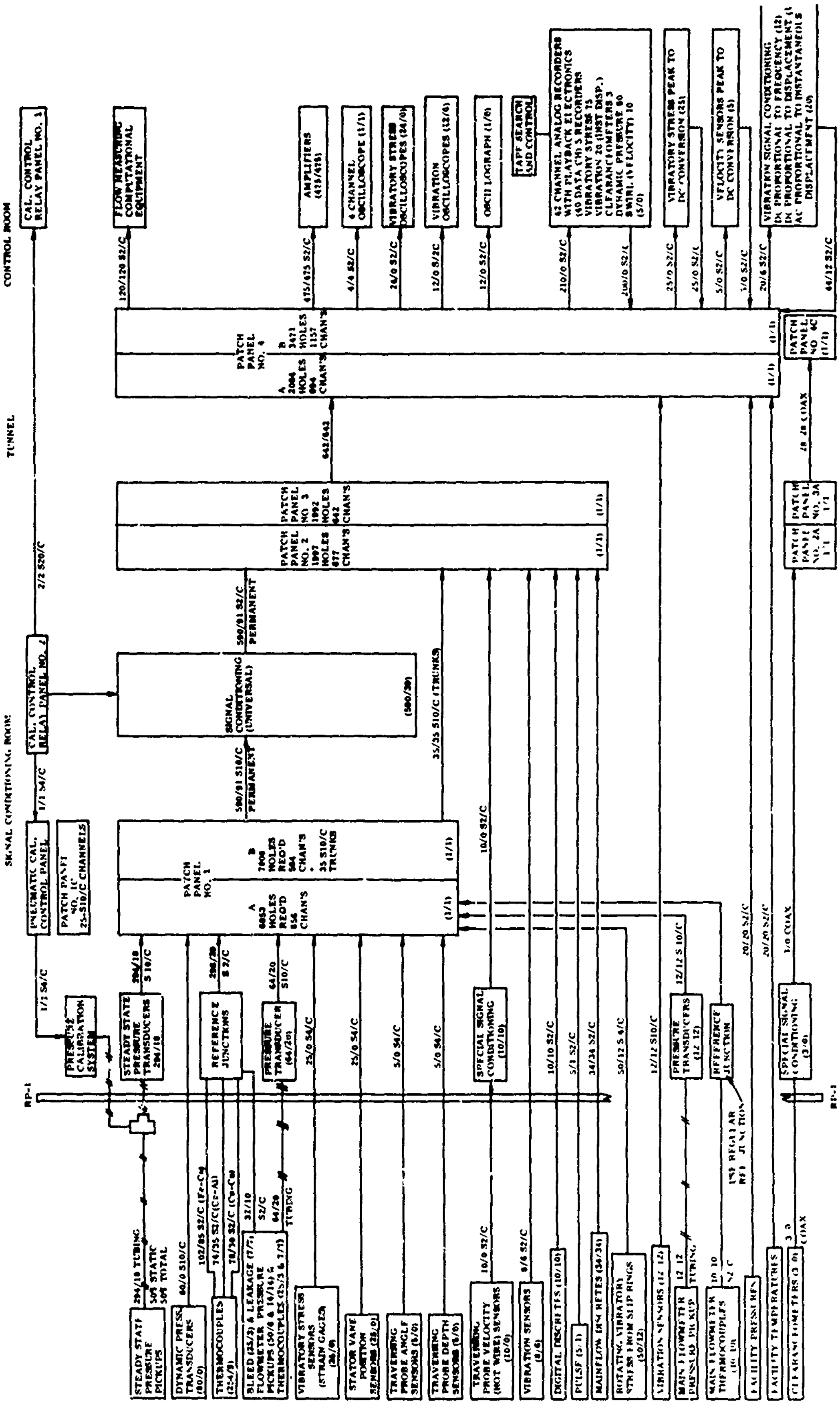


Figure 3-12. Data Routing

3.7.3 DIGITAL DATA ACQUISITION AND PROCESSING SYSTEM

The digital computer and associated peripherals other than the video display will be operated from the computer and measurement system console during a test providing that a standard remote computer control console can be incorporated into this console. For maintenance purposes, it will also be possible to operate the central processing unit and each peripheral using local controls at the individual device. No attempt will be made here to show the computer control panel functional layout since it will depend largely on the computer selected for the CRF, but typically, the computer control panel will contain two main sections, a maintenance section and a computer operations section. The maintenance section will, in general, contain memory error detection indicators, register select and display controls, a memory fault detection indicator, and other displays and indicators used to troubleshoot and/or detect malfunctions in the computer; the operating section will contain the controls necessary to operate the computer including power, ON AND OFF, a CPU RESET AND CLEAR control, an I/O RESET, a CPU LOAD a system RESET CLEAR control, a MODE control, a RUN control a WAIT control, an EXTERNAL INTERRUPT control and a COMPUTE control. A key lock will be provided on the console to prevent unauthorized changes in test and operating programs. This lock will be designed so that when the key is inserted and the lock is turned to one position, none of the system operating programs can be altered; when the lock is in the second position, certain programs may be altered via the operator's console or one of the computer peripherals; and, in the third position, the lock will permit any of the operating programs to be changed. Only the responsible person will have the key to permit a computer program change to be made.

3.7.3.1 Operator - Computer Communications

Several operator-computer communications devices will be on the computer and measurement system console and on the other control room consoles. The controls for the video displays will be essentially an operator-computer communications device which permits the operator to communicate with the computer in the form of requests for given video displays and instructions to the computer to change a given video display format. The video display operating philosophy is discussed further in paragraph 3.7.3.5 of this volume.

The operator-computer communications devices on the computer and measurement system console will fall into two major categories: the main I/O device (an I/O typewriter with video display or similar device) and special purpose I/O devices (such as the CALIBRATION/REFERENCE CHECK and ACQUISITION controls). In general, it will be easier for the operator to enter information into the computer and request various functions from it using special I/O devices; this will be especially true if the information and requests are routine and repetitive in nature. Because the special I/O devices serve a specific purpose, they are less likely to cause human error than an I/O typewriter (or similar device) when frequent use is required. The main I/O device is necessary, however, to provide the necessary flexibility in operator-computer communications such as program debugging and providing instructions to the computer of a nonrepetitive nature. The special purpose I/O devices will be discussed in conjunction with their respective functions in the succeeding paragraphs.

3.7.3.2 Real-Time Data Acquisition

All digital data acquisition control will be provided by the computer whether the facility is operating in the manual or the automatic mode. Block sequential and random are the two basic modes of data acquisition control. In the block sequential mode of operation, the channel number where a data scan is to start and the number of channels to be scanned in sequence will be provided to the computer as instructions. The computer then, at the appropriate time, will issue the addresses necessary to acquire data from the channels in the scan block in sequential order at 24,000 samples per second. The size of the block may be from one channel to the total number of channels provided in the system; the number of blocks may range from one up to 500. In the random mode of data acquisition, the computer will provide a separate address to acquire a single data word. When the computer is informed that acquisition is complete for the data word, it will issue another address to acquire the next data word. In both the block sequential and random data acquisition modes, 24,000 samples per second may be achieved.

Peripherals utilized by the computer in the acquisition of data will include the input programmable amplifiers, the multiplexer, the analog-to-digital (A-D) converter, and the CPU interface hardware. The programmable amplifiers will be differential high accuracy amplifiers with six programmable gain ranges. Manual selection of gain for each amplifier may also be made at the front of that amplifier. When the gain selection switch on the front of the amplifier is in the programmable position, the gain for that amplifier will be selected by the computer by checking the signal level of each channel and selecting the gain providing maximum resolution for that channel. These gain selection checks will be made by the computer periodically on a time available basis. The amplifiers also have programmable filters so that the low pass filter cutoff points may be adjusted to coincide with the scan rates utilized at any given time. The low pass filters are necessary to eliminate aliasing errors present because of the digitizing process so that the desired accuracy (.05 percent from the input to the signal conditioner to the data recorded on the digital tape) may be achieved. The high differential input to the amplifiers will also tend to eliminate noise generated by the electrical drive system in the 0 to 93 Hz range. The output of the amplifiers will be routed to a high-speed multiplexer capable of sampling 24,000 inputs per second. The output of the multiplexer will be the input to the analog-to-digital converter which converts the analog data to 14-bit (plus sign) words which are routed to the computer. The required identification will be attached to each word in the CPU interface hardware so that the word may be carried through the computation system and recorded on digital tape. All addresses and synchronization signals required for the acquisition process will be supplied by the digital computer. Part of the data acquired during an acquisition cycle will be used in the real-time processing sequence; however, this will not eliminate the need to record all data in raw form on digital magnetic tape. Part of the facility measurements will be acquired and stored on discs where the data may be retrieved quickly for troubleshooting or monitoring purposes. Even though the facility data will be acquired and temporarily stored on discs, it will also be recorded in raw form on magnetic tape. After a predetermined time, all but the most current facility measurements data stored on discs will be discarded. Real-time data acquisition may be controlled via prestored programs loaded in the computer prior to tests or via the acquisition control panel on the computer and measurement system console. Control can also be accomplished via the main operator-computer communications device; however, this is not recommended except for special cases or nonstandard operating requirements. The main I/O device may also be utilized to alter a prestored scan program during a test (again not recommended as a standard mode).

It is recommended that the acquisition control panel be used for manual control of the data acquisition process. Figure 3-13 is a possible layout for the acquisition control panel. This layout is not intended to represent the final design concept but has been included to facilitate the functional discussion on data acquisition operating philosophy. The acquisition control panel will be essentially divided into three sections, the monitor mode section, the fast acquisition mode section, and the computer mode control section. Frequently, in compressor testing, it is desirable to have the digital computer monitor several or all of the measurement channels while the compressor parameters are being adjusted from one point to another on the performance map and acquire a high speed data burst when the new point is reached. The monitor mode and fast acquisition mode will allow this to be accomplished manually from the acquisition control panel. Prior to the test, three monitor programs and three fast acquisition mode programs will be selected and prestored in the computer. After a test is started, any one of the monitor mode programs may be selected from the monitor mode section of the panel by properly positioning the MONITOR PROGRAM NUMBER switch. The indicator labeled REPETITION RATE will display the basic repetition rate at which data is acquired in this mode (.01, .1, 1.0, 10, 100, 1000, etc., scans per second). For example, if a monitor program is selected where the REPETITION RATE is .1 and the scan rate is 24,000 samples per second, the acquisition system would acquire a complete data scan once every ten seconds at a rate of 24,000 samples per second. To initiate a high speed data burst, it is first necessary to select the desired fast acquisition mode program using the MODE NUMBER switch and then the required scan duration using the SCAN DURATION control on the fast acquisition mode section of the acquisition control panel. When the scan duration and the mode program number have been selected, the fast acquisition mode may be initiated by depressing the INITIATE pushbutton

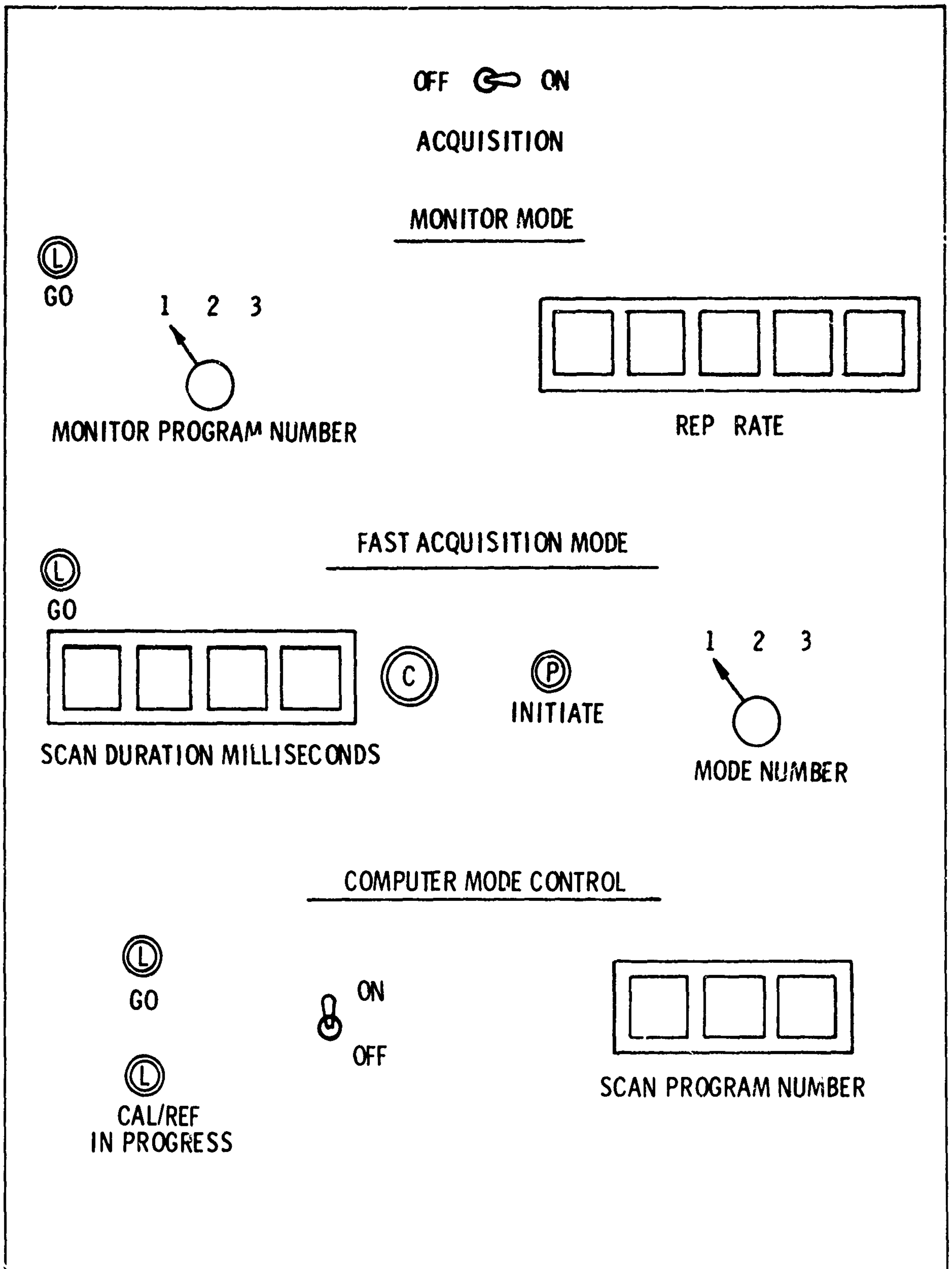


Figure 3-13. Acquisition Control Panel

in the center of the panel. When the fast acquisition mode is initiated, it will replace the monitor mode of acquisition and will be in effect for the time duration on the SCAN DURATION control. When the high speed data burst (fast acquisition) is completed, the system will automatically revert to the monitor mode. The monitor and fast acquisition programs will normally be loaded into the computer as a deck of punched cards via the card reader. These programs may vary from test to test; however, the basic monitoring and fast acquisition mode programs are expected to remain essentially constant for a given test vehicle. The third section of the acquisition control panel will be essentially a monitoring section indicating when the computer is selecting preprogrammed scan modes and executing them as the test progresses. One switch on the panel will provide a means of transferring the scan program to the computer mode control or overriding it and returning it to the monitor mode panel. For the monitor mode panel to currently be controlling the monitor mode of acquisition, the ON-OFF switch on the computer mode control panel must be in the OFF position. When this switch is in the ON position, control is transferred to computer mode control and the scan program prestored in the system and currently being executed will appear on the three-digit display on the front of the computer mode control section of the panel. The computer mode control panel and the data acquisition system will provide for up to 999 different scan programs to be prestored in the computer (on discs, in core, or on magnetic tape as applicable) and executed based on either an internal or external interrupt. This allows extreme flexibility in controlling data acquisition for the CRF. Regardless of the position of the ON-OFF switch on the computer mode control section of the panel, the fast acquisition mode may be initiated at any time. Depression of the INITIATE pushbutton on the fast acquisition section of the panel will cause overriding not only the monitor mode but also the computer mode control if the system is operating in computer mode control. When the fast acquisition mode program is finished (the fast acquisition scan mode will continue for the time duration set on the SCAN DURATION display), the acquisition mode will revert to computer mode control if the ON-OFF switch is in the ON position or to the monitor mode if the ON-OFF switch is in the OFF position. The current mode of acquisition will always be indicated by the lights labeled GO on patch panel. When a mode is in effect, the corresponding GO light will come on and remain on until the mode is changed. In addition to the monitor mode, fast acquisition mode, and computer mode control, a third mode of operation will be a calibration/reference check mode initiated from the calibration/reference check control panel. If a calibration or reference check is in progress, the light labeled CALIBRATION/REFERENCE IN PROGRESS will light to indicate status. A master acquisition ON-OFF switch located at the top of the acquisition control panel must be in the ON position if data acquisition is to be initiated in any mode. If the computer is being used for something other than data acquisition and the associated real-time functions, this switch should be in the OFF position.

To illustrate the use of the acquisition controls, consider a typical compressor test such as steady state performance mapping. During the test, data is to be acquired along one constant speed line in the manual mode and completed in the automatic mode. The manual monitor and fast acquisition mode controls will be more convenient for use during a test when the manual mode is in effect, but it will be more convenient to use the computer mode control method of acquisition for a preprogrammed test conducted in the automatic facility mode. Before test start, then, three monitor programs and three fast acquisition mode programs would be devised, coded, and punched on cards. Both the monitor and the fast acquisition mode programs would be loaded into the computer via the card reader. Likewise, programs to be utilized in the computer mode control would be devised, coded, punched on cards, and loaded into the computer via the card reader. These programs would be retained in core or written on discs as applicable.

To facilitate the discussions of the hypothetical compressor test, refer to the typical compressor performance map represented by Figure 4-3 in paragraph 4.1.3.1 of this volume. Before facility start, the acquisition system will be started normally on the slowest monitor mode preprogrammed into the computer by positioning the main acquisition switch to ON and the computer mode control ON-OFF switch to OFF (monitor mode). At this time, the facility would be started and brought up to the initial data point on the performance map (the intersection between the static operating line and the 50 percent corrected constant speed line). If the test procedure required a high speed data burst of one second duration for each data point, the operator would dial in 1,000 milliseconds on the SCAN DURATION indicator utilizing the adjacent control and select the proper fast acquisition program utilizing the MODE NUMBER control. When the operator is ready to acquire the data, the INITIATE pushbutton would be depressed; when the data point acquisition has been completed, the scan rate will automatically revert to the monitor mode scan control. The test conductor would adjust the facility to data point number 2 (as denoted on the performance map in Figure 4-3) when data point 1 is complete. The test conductor will inform the computer and measurement system engineer of readiness to take another point when the new data point is reached. The INITIATE would be depressed, initiating another high speed data scan for the duration on the SCAN DURATION indicator. Then the acquisition control would again revert to the monitor mode, and the test conductor would repeat this procedure until all data points have been acquired along the 50 percent constant speed line.

If the test plan calls for the acquisition of data along the 70 percent constant speed line in the automatic mode of facility operation, the initial conditions required to transfer the facility from manual to automatic control would be entered into the computer, permitting transfer by the master AUTOMATIC-MANUAL control switch on the computer and measurement system engineering console. When the transfer to automatic facility control has been completed, the operator would reposition the ON-OFF switch on the computer mode control section of the acquisition control panel to the ON position, changing the acquisition control mode from monitor to computer. The computer would assume complete control of data acquisition at this time and the facility would move automatically to point number 13 on the performance map. Based on preprogrammed criteria (flow meter stability, predetermined time period, etc.), the computer would automatically initiate a high-speed data scan. The number of the acquisition program currently executed by the computer would appear on the SCAN PROGRAM NUMBER readout. Upon completion of the high speed acquisition for data point number 13, the computer would automatically change the scan rate to a preprogrammed slower monitoring rate and the facility would automatically move to data point number 14. After the stability criteria or preprogrammed waiting time has been met, another high speed data burst would be initiated. This procedure would be repeated until all data points have been acquired under automatic facility control at which time the facility would be transferred from automatic control back to manual control. The ON-OFF switch on the computer mode control section of the scan control panel would be repositioned to the OFF position, causing the acquisition system to revert to the monitor mode program currently dialed in on the MONITOR PROGRAM NUMBER switch on the monitor mode section of the scan control panel. If this concludes the test, the facility would be brought down to an idle position and then shut down according to the normal shutdown procedures. When the electrical drive system has been brought to a stop, the master acquisition mode switch would be positioned to the OFF position, stopping data acquisition. A calibration or reference check may be performed with the master acquisition switch in either the OFF or ON position. The main I/O operator-communications device or the video display may be used to change a scan program already loaded into the computer system. The instruction to be changed in a given program may be superseded by another instruction using the proper program line number references. This can only be accomplished, however, if the key lock switch on the computer and measurement system console is in the proper position; i.e., if this switch is in the full lock position, no program changes to any scan rate or any other control or operating program can be accomplished from the video display or the computer and measurement system console. Extensive changes in scan rate programs or any other program are not recommended while a compressor test is in progress unless the compressor is brought down to idle speed and remains there long enough to allow the change to be accomplished.

3.7.3.3 Real-Time Data Processing

Several data processing programs must be executed by the digital computer in real time or near-real time including limit checking, conversion to engineering units, formatting data for the video displays, averaging data for individual measurement channels, and computing performance parameters. Real-time data processing will be initiated automatically through interrupts associated with other I/O devices or accomplished routinely with other functions such as data acquisition. Data processi' g programs and associated data will be loaded into the computer prior to a test either as separate programs or as subroutines of larger control programs.

For example, limit checking would be initiated by identifying the limits and the channels to be checked and loading this information at the time the data acquisition programs are loaded. Likewise, video display formats would be identified, coded, punched on cards, and loaded into the system prior to a test. The operating programs will utilize the data to cause the proper data processing sequence to occur. For example, data will be converted to engineering units automatically as needed for hard-copy printouts, video displays, or compution performance parameters. Parameters identified for given video display formats will be computed automatically to fulfill the uodating program requirements for the video displays. A great deal of planning and other considerations are required to devise programs operating in the real-time environment so that the data processing accomplished will provide data useful in real time during a compressor test.

3.7.3.4 Real-Time Setpoint Control

In the automatic mode, the computer will provide setpoint control for compressor speed, pressure ratio, inlet pressure, stator vane angle, stage bleed, and test vehicle lubrication temperature and, in this setpoint mode, will supply references (either analog or digital signal) to the individual closed cycle analog control systems maintaining these references. The closed cycle controls will continually modulate actuating devices to maintain the references supplied by the computer.

Under the present operating philosophy, it is not anticipated that direct digital mode of operation will be employed, but it could be accomplished by the computer monitoring the control system sensor and continually supplying setpoints to the control systems to maintain desired settings. This would, however, be a time-consuming mode of operation for the digital computer since it would have to sample the control sensors very rapidly and issue control setpoints at an equally rapid rate to maintain the desired control references. Control programs for the facility automatic mode of operation are stored in the computer system prior to the start of the test. Examples of these programs would include speed trajectory, steady state mapping, stator vane optimization, and stage bleed optimization. The control programs would specify parameters for speed trajectories and steady state points on the performance map. Data acquisition rates for each trajectory and point would also be specified prior to the start of the test. Normally, a control program is oriented toward time; that is, the program is designed to sequence through a set of events according to some time-oriented test plan. A control program need not be time oriented, however. For example, if several data points must be acquired along a constant speed line but a data point can only be acquired after the standard deviation of the flow measurement has decreased below .05, the computer would move the facility to a specified data point on the performance map and continually monitor the flow measurement until the standard deviation of the data acquired from this flow measurement has decreased below .05. The computer would then initiate a high speed data burst to record the required data and move to the next data point where the computer would monitor the flow measurement until the desired criteria had been met, then repeat the procedure described above. The sequence of events could vary in time according to time required for the flow measuring system to stabilize when it moves from one data point to the other. Neither would time be the major parameter of a test program if the computer were allowed to decide where to go to acquire further data such as in stator vane optimization. The computer would move the stators on a given stage a specified amount, acquire data, and make an analysis to determine further movement of stators required. Based on this data, the computer would decide what new angle to attempt to improve compressor performance. This is an iterative process continued until the computer has reached some prespecified optimization goal for the stator vanes.

Alterations to a prestored control program can be made using the main operator-computer communications I/O device but only if the key lock on the computer and measurement system console is in the proper position; otherwise, this safety device would inhibit control program change.

The operator-computer communications I/O device on the computer and measurement system console facilitates operation in a semiautomatic mode when the master facility mode control switch is in the AUTOMATIC position (when the facility is in the automatic mode of operation). This semiautomatic mode consists of controlling the facility partly by using a stored program and partly by entering some of the control instructions in real time via the operator - computer communications I/O device. For example, speed might be controlled using the I/O device while pressure ratio and inlet pressure are controlled through a prestored control program such as when data is acquired along constant speed lines on a performance map and the test plan specifies that data be acquired along five constant speed lines where these lines are determined by the operator as the test progresses. With the proper control program stored in the computer, the operator could use the I/O device on the computer and measurement system console to direct the computer to the proper speed. The computer would automatically acquire the required number of data points along the given speed line. The operator would then instruct the computer via the I/O device to change the compressor speed. After the new speed is attained, the computer would automatically acquire the proper number of data points along the constant speed line and inform the operator when the acquisition cycle is complete. The operator could view the data, decide on the next speed line, and provide the next instruction (via the I/O device) to the computer which would provide the setpoint for the next speed line and then reinitiate the acquisition cycle to acquire the required data points. This would be repeated until the complete test had been finished.

3.7.3.5 Visual Displays

Visual displays in the form of graphic and alphanumeric video displays and out-of-limits video monitors (CRT's) will be included as part of the computer system. The video displays with associated controls will be located on the control room consoles and the out-of-limits video monitors will be on the aerodynamicist's computer display and stator control console and the test conductor's console. These out-of-limits video monitors are identical, parallel readout devices driven by the same computer command. The video displays can present test data (individual measurements or computed parameters) in predetermined alphanumeric or graphic formats. Using the graphic capability, compressor performance maps, work coefficient versus pressure coefficient plots, and graphic plots of any other compressor parameters may be presented on the graphic video displays. These graphic plots can be maintained on discs, updated as required, and displayed at the discretion of the operator. A wide variety of alphanumeric and graphic data can be obtained in real time by the aerodynamicist or other test engineer. This will be a valuable aid in making real-time decisions during compressor tests.

Under previous compressor testing philosophy at other facilities, this data would not be available until after a test is completed. No attempt will be made here to present a preliminary control panel for the video displays because the particular controls and associated functions will depend on the displays actually selected for the CRF application. The operator will, however, have the capability to call up multiple formats for presentation on the video displays. These can be displayed and updated via a pushbutton or automatically by the computer once every three to five seconds (depending on the format currently displayed). The controls for the video displays will also provide a capability for the operator to change the content of any one of the display formats at his discretion, although only when the key lock switch on the computer and measurement system console is in the proper position. The video displays may also be used as a program debugging aid by the computer and measurement system engineer who will be able to display any instruction from any of the programs stored on disc or in the computer core and make changes to these programs as needed through the display control panel or the main operator-computer communications device on the computer and measurement system console.

The OUT-OF-LIMIT video monitors are designed to provide the aerodynamicist and the test conductor an instantaneous look at the data channels exceeding predetermined limits. They will provide specific information on up to five channels of data exceeding limits. Figure 3-14 is a possible layout for the OUT-OF-LIMIT video monitor format. This layout is not intended to represent the final design concept for the format but has been included to facilitate the functional discussion on operating philosophies associated with these displays. Figure 3-14 shows four columns of indicators on the left side of the display: SECOND LOW LIMIT, FIRST LOW LIMIT, FIRST HIGH LIMIT, and SECOND HIGH LIMIT. The purpose of these indicators is to indicate the limit which has been exceeded; in line with the limit-checking capability of

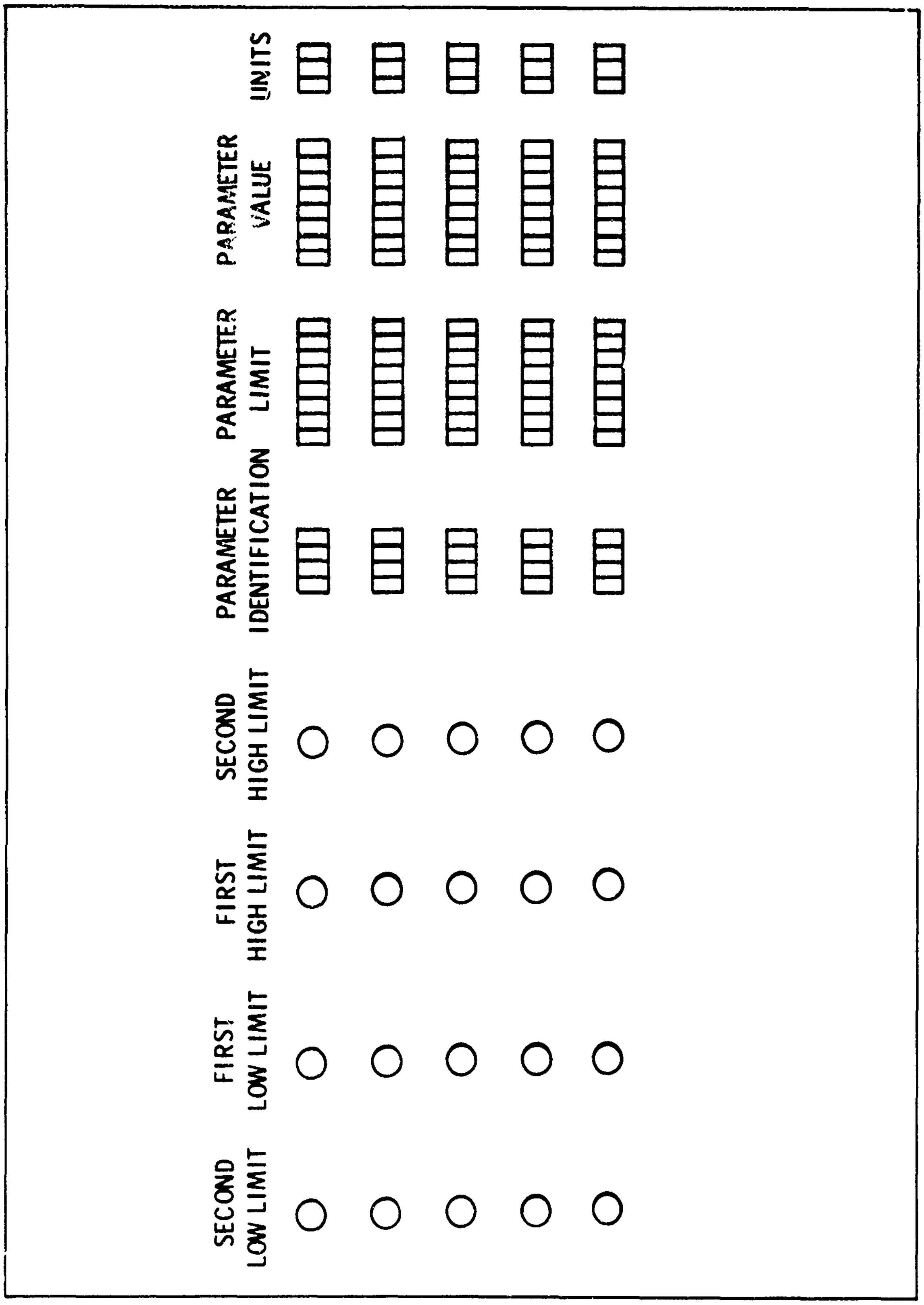


Figure 3-14. Out-of-Limits Video Monitor

the computer system, two high limits and two low limits have been provided. Under the PARAMETER IDENTIFICATION column the identification number for the measurement where the limit has been exceeded will appear. In the PARAMETER LIMIT column, the actual value of the limit which has been exceeded will be displayed. This may be the first high or low limit or the second high or low limit depending on which one has been exceeded. Under the column labeled PARAMETER VALUE, the actual value of the parameter in engineering units will appear. This value will be updated (at a minimum of once every three seconds) to provide the observer with the actual parameter value on a near-real time basis. The column to the right labeled UNITS will indicate the engineering units associated with the parameter values being displayed. The OUT-OF-LIMIT video monitors will be controlled by the computer based on a preprogrammed criteria and will not require any external control from an operator.

3.7.3.6 Hard-Copy Output

A line printer and an X-Y plotter may be used for providing hard-copy output from the digital acquisition and process control system on either an on-line or off-line basis. The line printer will be capable of printing individual measurements or performance parameters in near-real time during a test. The formats for these printouts would have to be preprogrammed into the computer prior to the test. Change of formats can be accomplished during the test using the operator-computer communications device on the computer and measurement system console.

The X-Y plotter may be used to make any X-Y plot involving individual measurements or performance parameters during the test or to provide off-line copy outputs. During the test, unless hard copy is required, it is recommended that the video displays be used for real-time X-Y plots for visual observation as opposed to using the X-Y plotter for this purpose. Both the line printer and X-Y plotter will be driven by the digital computer and require little or no operator intervention during the actual operation. Manipulation of these devices during the test would be primarily a software setup problem and all formats and other programming associated with these devices would be taken care of during programming preparation for a test.

3.7.3.7 Background Processing

In most current data acquisition and process control computer installations,the data acquisition and process control functions and batch processing functions are performed sequentially. However, this method of operation is inefficient since the average function performed by the computing system does not require the total available resources of the system and results in the systems being idle for significant periods of time while the system is operating in the data acquisition and process control mode.

For example, during a monitor mode of data acquisition, the data acquisition, data processing and process control functions require only a fraction of the storage space and computation and input/output capability of the system. To increase the computation system, a multiprogramming executive operating system providing a background processing mode will be provided as part of the data acquisition and process control system. This system will permit batch processing programs to be run on a "time-available" basis while a test is in progress and will ensure that as much of the total computer system time as possible is utilized.

Following implementation of this system, the background jobs will be time shared with the data acquisition and process control functions on a low priority basis; i.e. when current acquisition and process control jobs have been completed and the computer is experiencing idle time, the background job will be brought into core from disc and executed. Additionally, the computer may be used for data reduction or to run general purpose scientific programs during the idle time. To run general purpose programs in a background mode during the test, the programs and associated input data should be loaded prior to the start of the test. The programs and the input data will be stored on discs where they will be available when the computer is ready for them. A separate magnetic tape unit should be allocated for output resulting from the background programs during the test, to avoid recording this output on the same tapes as the test-related data. In addition to the background processing of batch programs, a normal batch processing mode will be available on an off-line basis for data reduction and execution of any general purpose scientific program written in the proper programming language.

3.7.4 TIMING SYSTEM

If data recorded by different recording techniques (the digital system, analog tape recorders or strip chart recorders) is to be correlated, than a common time code must be placed on each of these records to serve as a reference. If such a time code is not provided, it is virtually impossible to correlate test data from the different recording sources. Correlation of test data from dynamic or transient tests is difficult or impossible without a good time reference on all records. A timing system will be provided in the CRF to provide a uniform time code to all recording devices. The timing system will provide a digital code (hours, minutes, seconds and milliseconds) to the digital systems and a standard IRIG-B code which may be recorded on the edge tract of analog magnetic tapes. A slow time code (hours, minutes, and seconds as applicable) at repetition rates ranging from 1 per second to 1 per hour will be available for strip chart and/or other analog recorders. Timing pulses from the timing system will be routed to patch panel number 4 for distribution as needed in the facility. Repetition rates of these pulses will range from 1 pps to 1,000 pps.

Necessary control of the timing system can be accomplished through the use of the controls on the time code generator control panel on the computer and measurement system console. Figure 3-15 is a possible layout for the time code generator control panel. This layout is not intended to represent the final design concept of the panel but has been included to facilitate the functional discussion on timing system operating philosophy. At the top of the time code generator control panel is a time-of-day readout in hours, minutes, and seconds. This represents the time code being generated within the time code generator. Below the time-of-day readout is a rotary switch which is the MODE SWITCH. The extreme counterclockwise position on this switch is a POWER-OFF position. (Other positions include the PRESET, HOLD and GEN.)

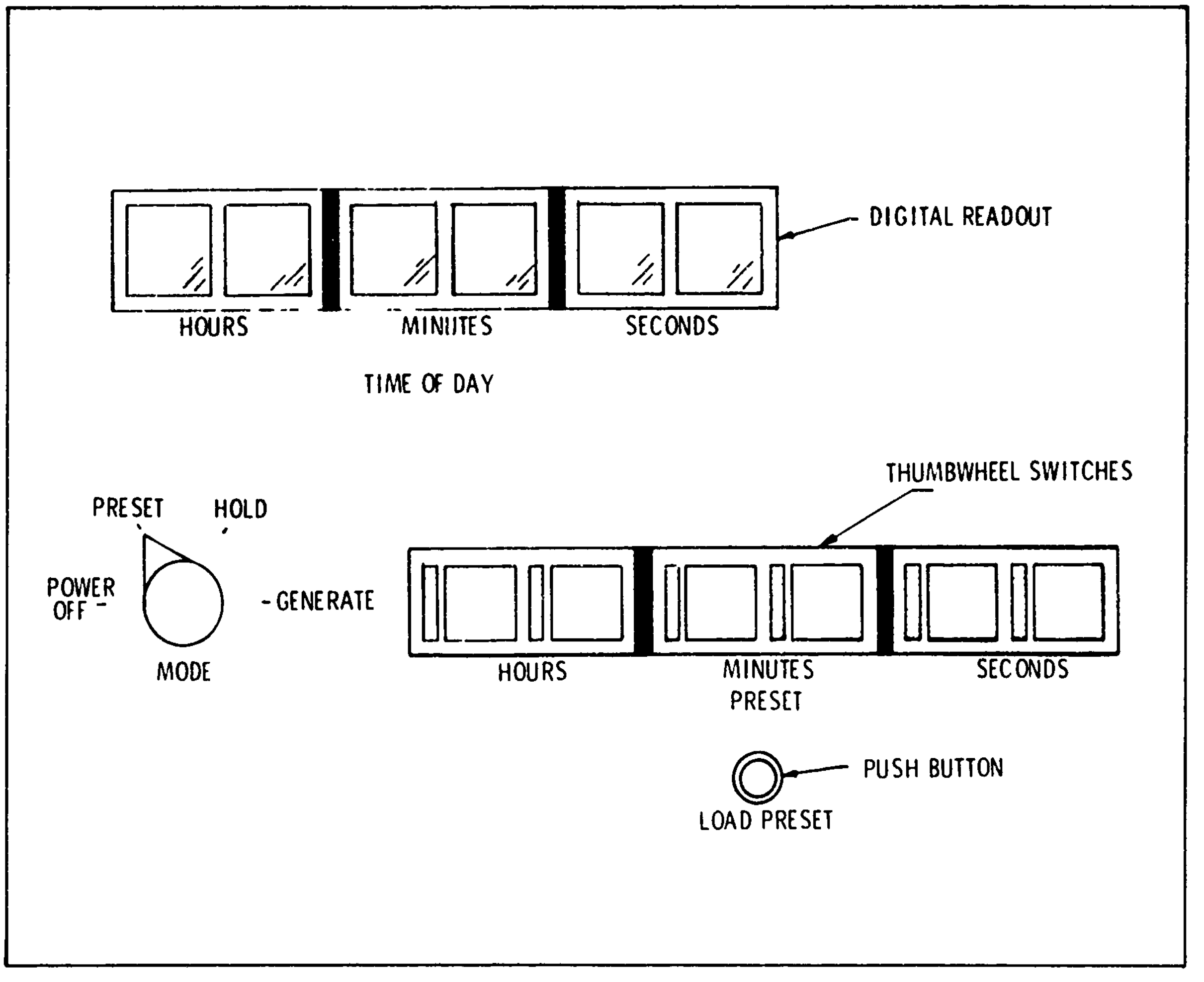


Figure 3-15. Time Code Generator Control Panel

When this switch is in the PRESET position, the generator may be set to a specified preset time-of-day prior to being started. The initial value of the time-of-day for the generator may be loaded into the PRESET control using the thumb wheels designated for that purpose. With the MODE SWITCH in the PRESET position and the proper time-of-day preset in the present in the preset controls, this value may be transferred to the master time-of-day readout by depressing the LOAD PRESET pushbutton. By moving the mode switch into the HOLD position, the generator will maintain a hold position with no outputs. When the mode switch is moved to the GEN position, the generator will provide a time-of-day output starting with the initial time-of-day which has been preset into the master time-of-day readout. The time code generator can be stopped by moving the mode switch to the HOLD position or resetting it to the PRESET position. The only time the PRESET mode and the associated thumbwheel switches would be used is when the generator has been turned off and there is a need to reset and restart it. It is anticipated that in actual practice the time code generator would be allowed to run 24 hours per day. Therefore the PRESET feature would not be used frequently.

3.7.5 ANALOG RECORDING AND DISPLAY SYSTEM

The analog recording and display system is required to conduct meaningful compressor tests. It is recommended that 188 channels of analog recording capability be provided in the CRF (see Volume I). These analog recorders are required to record wideband data such as vibratory stress, vibration, clearance measurements, dynamic pressure, and other high frequency data. Frequency response on these recorders will range up to 50 kHz. The analog display system will consist primarily of monitor scopes to be used for the purpose of monitoring vibratory stress, vibration, and clearance data. A layout of a possible analog display panel (dynamic data display/status panels) is presented and discussed in paragraph 3.2.5 of this volume. A more in-depth discussion of the analog recording and display system may be found in Volume V.

The analog recording system will be controlled from the computer and measurement system console using the controls on the analog tape control panel and tape search/time code reader control panel. However, the capability to operate individual recorders locally at the recorder will be retained to aid in the calibration and maintenance of the recording hardware. Figure 3-16 is a possible layout of the analog tape control panel. The layout is not intended to represent the final design concept for the panel but has been included to facilitate the functional discussion on analog tape recorder operating philosophy.

On the analog tape control panel is an independent set of controls for each analog tape recorder. Observing Figure 3-16, note that the controls for each tape recorder consist of two rows of back-lighted pushbuttons. The top row consists of the typical analog tape transport controls, while the bottom row is the speed select controls for the transport. Speeds which may be selected using these pushbuttons include 3-3/4, 7-1/2, 15, 30, 60, and 120 inches per second. The top row of pushbuttons include REWIND, RUN, STOP, master START/STOP, RECORD and WIND controls. These are standard controls with the exception of the master START/STOP switch. When this switch is depressed, the recorder may be started and stopped from the master control switch located at the bottom of the analog tape control panel. The purpose of the master control switch is to allow for all or part of the recorders to be started and stopped together. The master START/STOP switch may be used to control two or more of the recorders while the others remain on an independent START/STOP control.

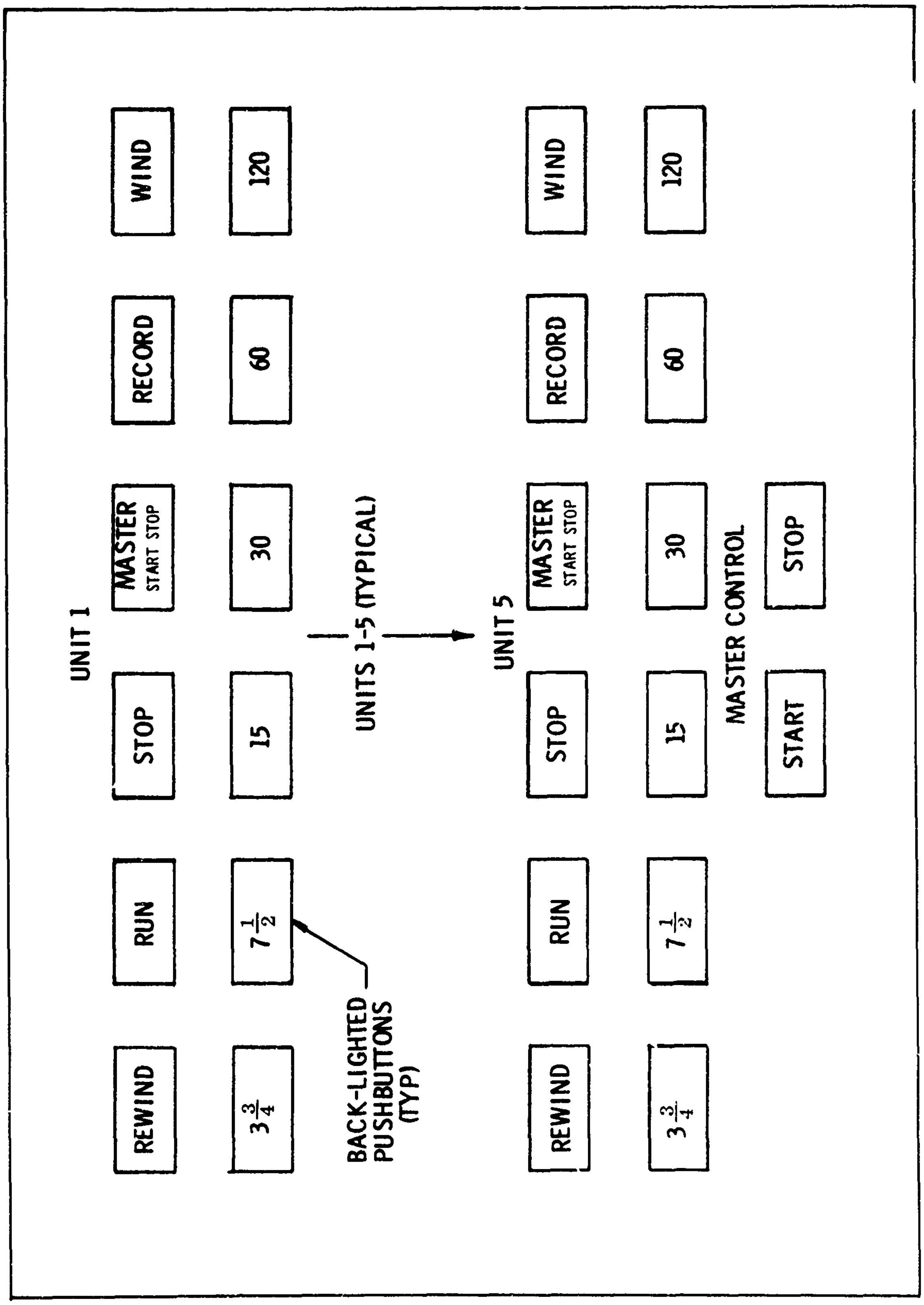


Figure 3-16. Analog Tape Control Panel

Analog displays are located in the dynamic data display/status panels. These displays will be controlled from that panel by front panel controls. There will be no remote capability on the computer and measurement systems console to control these displays.

To play back analog data and digitize it off-line to enable computer utilization for data reduction of analog tape data, it is necessary to have the capability for tape search and time code reading. This will be accomplished by a tape search/time code reading unit working in conjunction with the analog magnetic tape recorders and timing system. This unit will allow the computer and measurement system engineer to search an analog tape to the desired point and then play back the tape at the recording speed or at a reduced speed so that data may be "quick looked" or digitized for further data reduction. During the playback sequence, the tape search/time code reader will read the IRIG-B time code from the edge track of the analog tape and convert it to a digital code for the digital computer. Likewise, if the data from analog tapes is to be dumped onto paper records (oscillograph or strip chart recorders), the time code will be converted from IRIG-B to a slow code suitable for paper records recording. The tape search/time code reading process may be controlled from the tape search/time code reader control panel on the computer and measurement system console.

A possible layout of this panel is presented in Figure 3-17. (This layout is not intended to represent the final design concept of the control panel but has been included to facilitate the functional discussion on the operating philosophy associated with the tape search/time code reader subsystem.) At the top of the panel is a time-of-day readout in hours, minutes and seconds which will display the time that is actually being read from the analog magnetic tape. Below the time-of-day readout are two thumb-wheel in-line digital controls for presetting system start and stop times. These controls have the capability to be set to hours, minutes, and seconds. When a tape search is initiated, the unit will search for the time preset in the START control. The unit may search either in the forward or reverse direction depending on the position of the tape relative to the start point when the search is initiated. The time-of-day set in the STOP control is the time when the playback will be discontinued. When a time is set in the START control and another is set in the STOP control, the tape search/time code reader unit will search until it finds the start time, then initiate a playback which will continue until the stop time is reached.

Directly below the start and stop controls is a control labeled MODE which serves as a power switch and determines the search mode for any given tape search. The extreme counterclockwise position of this switch is the POWER-OFF position. The next position is labeled SEARCH AND READ. With the switch in this position, the tape will be searched until start time is reached and then automatically read until stop time is encountered. When the MODE switch is in the SEARCH TO START position, the unit will search the tape until the start time is reached and then stop until reinitiated by manual intervention. The extreme clockwise posi-

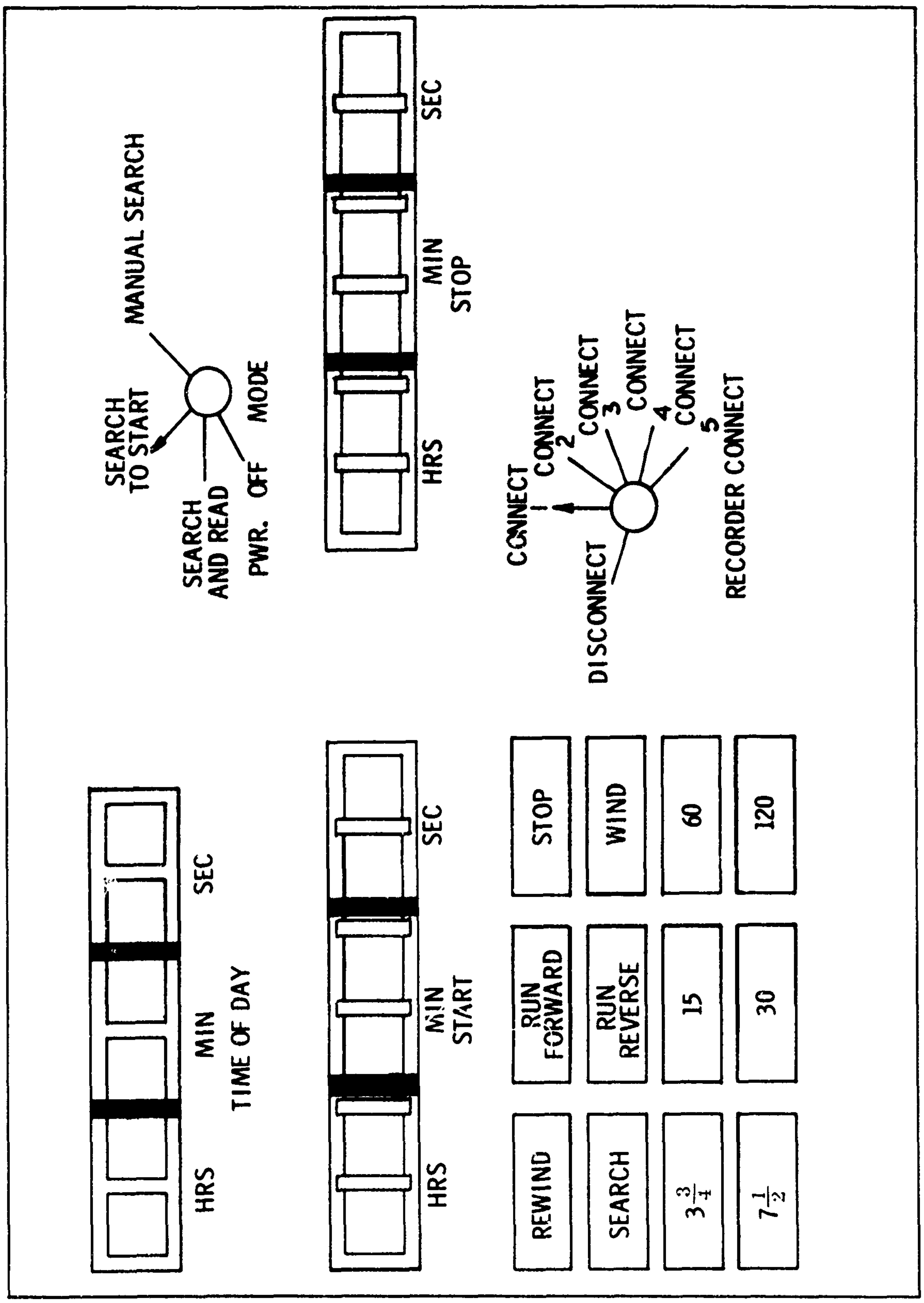


Figure 3-17. Tape Search/Time Code Reader Control Panel

tion on the MODE switch labeled MANUAL SEARCH provides for a manual search mode in lieu of the automatic search. The manual search may be accomplished by starting the recorder using the controls on the lower portion of the panel and observing a time-of-day display until the desired time is reached, at which time the operator can initiate the required action depending on the purpose of the tape search.

A rotary switch at the lower right of the panel labeled RECORDER CONNECT is the master connect switch allowing the tape search/time code reader to be disconnected from recorders or connected to any one of the five recorders controlled from the computer and measurement system console. The backlighted pushbuttons at the bottom of the panel provide for tape transport control when a tape search or playback is initiated. When the RECORDER CONNECT switch is positioned to any of the recorder connect positions, the transport controls on the tape search/time code reader panel will become active for the transport indicated by the RECORDER CONNECT switch. The tape transport controls include REWIND, WIND, RUN-FORWARD, RUN-REVERSE, STOP, and SPEED, allowing transport operation in six speed ranges from 3-3/4 to 120 inches per second. The other backlighted pushbutton labeled SEARCH initiates an automatic tape search when the mode switch is in either the SEARCH AND READ or the SEARCH TO START position. Outputs of the tape search/time code reader are the same as the outputs of the time code generator discussed in paragraph 3.7.4 of this volume. During the playback operation, a digital code (in addition to the continuous digital code supplied by the main time code generator) will be supplied to the computer. For this reason, the computer must have the capability to read two time-of-day inputs since the time-of-day from the time code generator and the time-of-day from the tape search/time code reader will be supplied to the computer in parallel during a playback operation. The tape search/time code reader will provide a slow code to any of the strip charts or oscillograph recorders as necessary.

To provide the capability for searching an analog tape and transcribing the information onto another analog tape at another speed, the tape search/time code reader will also have an IRIG-B output producing a one to one transfer of time information from one analog tape to the other.

3.7.6 REFERENCE CHECKING/CALIBRATION SYSTEM

A method of reference checking all types of measurements and providing on-line calibration for selected pressure measurements will be provided in the CRF computer and measurement system. Both reference checking and calibration provide a valuable means of preventing data system inaccuracies resulting from day-to-day drifting of measurement channel in-line components. Reference checking on an individual channel basis can be accomplished from the front panel of each signal conditioner. Both reference checking and calibration on a total system basis will be controlled from the reference checking/calibration control panel on the computer and measurement system console.

During a reference check, the reference checking system will provide the necessary excitation to close relays in the individual signal conditioners which in turn provide various calibrated output voltage steps simulating measurement signals. These output signals may be provided by a voltage substitution method as in the case of thermocouples or may be provided by other methods such as the shunt technique employed with strain gage pressure transducers. The reference check will detect drift or malfunctions caused by all in-line items in the measurement channels except transducers and the cabling between the transducers and signal conditioners. However, on-line calibration provides an end-to-end calibration (including the transducers) since up to six levels of known pressure stimuli are applied directly to the transducers. To achieve the accuracy required in compressor testing, it is essential that this on-line calibration be provided for pressure measurements.

With the reference checking/calibration system, all reference checks on pressure measurements must be completed prior to the start of the test; however, it is conceivable that reference checks on other measurements as well as on-line calibration could be accomplished during the test without interfering with data acquisition if enough time is allocated for this activity. In general, however, both reference checking and calibration will be accomplished prior to and immediately following a test.

Reference checking may be used to check a day-to-day reference on each measurement channel while test setup is in progress. As the measurements are brought on line, they will be reference checked on a daily basis to determine if any zero drift, gain change, or other hardware malfunctions have occurred prior to the actual acquisition of test data.

The reference check/calibration system will be controlled from the reference check/calibration control panel on the computer and measurement systems console. The reference check/calibration control panel is divided into two sections with the left section of the panel used to control reference checking and the right section used to control on-line calibration. This panel will control both the manual and automatic modes of reference checking and calibration. In the manual mode, each reference check or calibration is stepped through manually, while in the automatic mode, each calibration is stepped through in sequence automatically. Figure 3-18 is a possible layout of the reference check/calibration control panel. (This layout is not intended to represent the final design concept of the panel but has been included to facilitate the functional discussion on operating philosophy associated with the reference check/calibration system.)

The first step in performing a manual reference check is to position the REFERENCE STEP switch to position 1 and depress the INITIATE button. At this time, proper logic and relays will be operated causing each signal conditioner undergoing reference check to provide the first calibrated signal level (20 percent of full scale or some other value depending on the particular measurement type). Normally, when the INITIATE button is depressed, the computer will

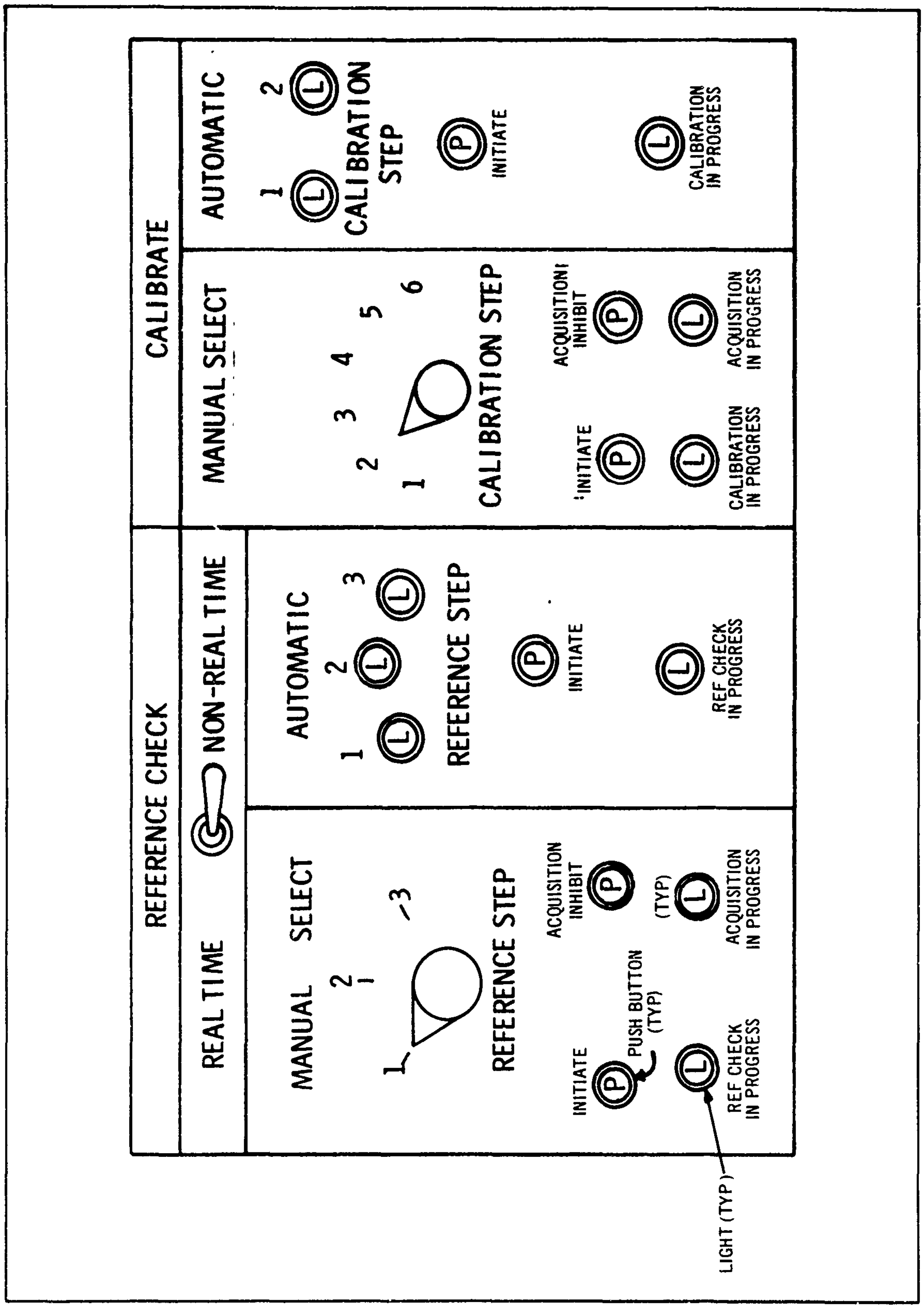


Figure 3-18. Reference Check/Calibration Control Panel

automatically acquire 48 data samples from each channel included in the reference check; however, if the operator wishes to inhibit or delay the data acquisition for a given length of time, he will depress the ACQUISITION INHIBIT pushbutton. There will be no data acquisition until this pushbutton is released, at which time the computer will acquire 48 samples of data from each channel. The ACQUISITION IN PROGRESS light will remain on when the computer is actively acquiring data for a given reference checkpoint and will go out when acquisition is complete. To manually complete the next reference check step, the operator will reposition the REFERENCE STEP switch to the number two position and then depress the INITIATE pushbutton. Forty-eight data points will be acquired and recorded from each measurement channel unless the ACQUISITION INHIBIT pushbutton is depressed. If this pushbutton is depressed, then the acquisition will be delayed until the pushbutton is released. Once the pushbutton is released, the computer will acquire 48 data points from each channel as in the first reference check step. To acquire data from reference step number 3, the operator must reposition the REFERENCE STEP switch to the number 3 position and repeat the procedure. The light labeled REFERENCE CHECK IN PROGRESS will come on when reference step 1 is initiated and will remain on until reference step 3 is completed.

To initiate an automatic reference check, the operator depresses the pushbutton labeled INITIATE on the auto section of the reference check panel. The system will then step through reference steps 1, 2, and 3 automatically and acquire 48 samples of data from each channel being referenced checked. When step number 3 is complete, the REFERENCE CHECK IN PROGRESS light at the bottom of the panel will go out. This light comes on when the automatic reference check is initiated and will remain on until completion.

On-line calibration is conducted in a manner similar to a reference check. As with reference checking, there is an optional manual or an automatic mode. To initiate a manual calibration, the operator first positions the CAL STEP switch to step number 1 and depresses the INITIATE pushbutton. This causes the first level of standard pressure to be switched to each transducer in the channels being calibrated. After a predetermined delay which is built into the system, the computer will automatically acquire 48 samples of data from each channel being calibrated (unless the ACQUISITION INHIBIT pushbutton is depressed). If the ACQUISITION INHIBIT pushbutton is depressed, data acquisition will be delayed until this pushbutton is released. The ACQUISITION IN PROGRESS light will come on when data acquisition is started and go off when acquisition is completed for a given step. To acquire data from steps number 2 through 6, the operator positions the CAL STEP to each of the two through six positions on the switch and repeats the procedure using the INITIATE pushbutton and, if necessary, the ACQUISITION INHIBIT pushbutton. The light at the bottom of the panel labeled CALIBRATION IN PROGRESS will come on when calibration is initiated for step 1 and will remain on until the calibration is complete for step number 6.

To initiate an automatic calibration, the operator depresses the INITIATE pushbutton on the automatic section of the panel. This will cause the system to step through two standard pressure steps and record 48 data points for each channel on each step. The light labeled CALIBRATION IN PROGRESS at the bottom of the panel will come on when the automatic calibration is initiated and will go off on completion.

At the top of the reference check panel is a toggle switch labeled REAL TIME - NON-REAL TIME. If a reference check is conducted in a non-real time environment (when a test is not in progress) this switch could be positioned to the NON-REAL TIME position. On the other hand, if a reference check is conducted while a test is in progress, this switch must be in the REAL TIME position. The purpose of this switch is to prevent certain groups of pressure measurements from being reference checked while a test is in progress, yet allow all other channels to be referenced checked during the test. A complete discussion on the reference check/calibration system may be found in Volume V.

3.7.7 FLOW MEASUREMENT SYSTEM

A flow measurement system will be provided to permit air mass flow measurement under both transient and steady state operating conditions. This system will utilize the bellmouth for transient flow measurements and a critical or subcritical venturi flowmeter on the discharge for steady state measurements.

To cover the required flow range, several venturis of varying sizes will be required. The switching of these venturis to cover the various flow ranges can be made by remote control from the test conductor's console. To provide a real-time flow display, an analog computer will be utilized to compute mass flow from temperature and pressure measurements from the bellmouth or flow nozzles. A few pressure and temperature measurements from either the bellmouth or the flow nozzles will be routed to the analog computer for use in these real-time flow computations. These measurements plus several other similar measurements from both the bellmount and/or the flow nozzles will be routed to the digital system where they will be recorded as pressure and temperature data. The output reading of the analog computer will be digitized and recorded via the digital system. During data reduction or when time is available, the digital computer can use the pressure and temperature measurements to compute an accurate mass flow. The accuracy of the analog computer will be less than can be achieved with the more accurate digital computations. Therefore, it will be the digital computations which will be used in compressor evaluation and to provide test results during post-test data reduction.

Separate flowmeters will be used to measure stage bleed flows and seal leakage flows. Pressure and temperature data from each of these flowmeters will be routed to the digital acquisition system and in parallel routed to a small analog computer where flow will be computed for each flow path.

Figure 3-19 is a possible layout for a mass flow rate display panel which will be located on the test conductor's console. (This layout is not intended to represent the final design concept of the display panel but has been included to facilitate the functional discussions on operating philosophy associated with the flow measuring system.) At the top of this panel are two digital readouts, one for actual main flow and one for corrected main flow. Both of these values will be a direct output of the main flow analog computer. In the middle of the panel is a readout labeled SEAL - BLEED LEAKAGES. This indicator will read actual flow through the seal-bleed leakage flowmeter selected on the LEAKAGE SELECTOR switch. The mass flow rate display panel has been designed to accommodate up to 7 seal-bleed leakage flowmeters.

At the bottom of the mass flow rate display panel are digital indicators which read actual flow for each of the stage bleeds. Initially, three stage bleed flow paths will be provided, however, panel space will be provided to add 22 more of these digital readouts to make a total of 25 possible stage bleeds. Both the readouts from the seal-bleed leakage flowmeters and stage bleed flow meters are outputs from the analog computers associated with each of these flowmeters. The controls required for manual switching of the main flowmeter ranges are not shown on the mass flow rate display panel. For a more detailed discussion of the flow measurement system, see Volume V.

3.7.8 DATA REDUCTION

3.7.8.1 Digital Data

The digital computer furnished as a part of the data acquisition and process control system will have the capability to perform all digital data reduction and compressor test data evaluation for the Compressor Research Facility. The data reduction may be accomplished with the computer operating in a stand-alone batch processing mode (when it is not being used to support a compressor test) or in a background processing mode (when time is available) during a compressor test. Once the data reduction programs have been written and debugged, the operation required for data reduction is confined to just the operation of the digital computer and associated peripherals, including the video display, may be used with the CPU to provide the required off-line data reduction and data processing outputs. The video display can be used to view selected data and performance parameters in a graphic or alphanumeric format during data reduction. Hard-copy plots may be obtained from the X-Y plotter and hard-copy printouts may be provided by the line printer.

One step in data reduction will be to convert all test data on the "raw data" tapes to engineering units to create an "engineering units" tape for use as a test data record. During this step in data reduction, one or more data compression techniques may be employed to reduce the volume of meaningful test data for a given test. A data diagnostic program may also be employed to detect bad test data before further test vehicle evaluation is attempted. Other steps in data

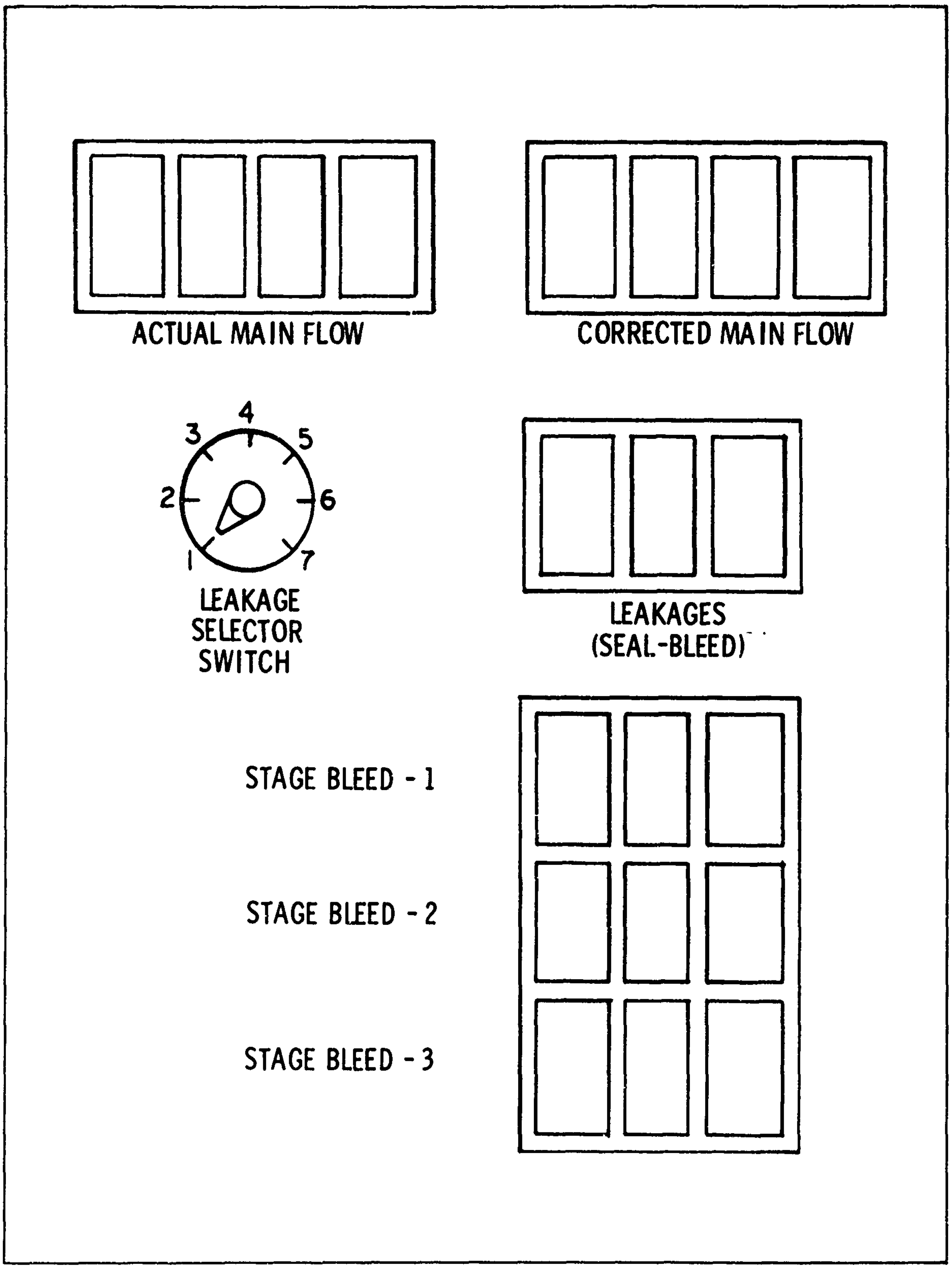


Figure 3-19. Mass Flow Rate Display Panel

reduction and evaluation of test results for the Compressor Research Facility may include but will not be limited to the following:

- Computation of compressor aerodynamic and aeroelastic performance parameters and characteristics
- Statistical analysis of compressor data
- Evaluation of compressor performance using test data in compressor simulation models or in compressor deterministic mathematical models
- Preparation of graphic hard-copy outputs

3.7.8.2 Analog Data

Off-line reduction of data recorded on the analog magnetic tape recorders may be accomplished by either playing the data back into an analog device such as a spectrum analyzer or an analog X-Y recorder or by digitizing the data using the digital system. For "quick look" purposes, the analog data may also be stripped out on an oscillograph or strip chart recorder.

To view the analog data on a spectrum analyzer, it is necessary to first route the output of the tape recorder playback electronics to the input of the spectrum analyzer. Then, through the use of the controls on the analog tape control panels or tape search/time reader (depending on whether a tape search is required), the recorder may be started allowing the data to be viewed on a spectrum analyzer. Likewise, the analog data may be used to create a plot on the X-Y plotter located on the vibration section of the dynamic data display/status panel. This is accomplished by routing one or more of the outputs of the playback electronics from an analog tape recorder to the X-Y plotter and then playing the appropriate portion of the tape back using controls on the computer and measurement systems console.

The more effective way to accomplish data reduction for the data recorded on the analog tapes is to digitize this data at a slowed down playback rate and then use conventional digital data reduction techniques. Depending on the data frequency and the record speed, several analog data channels may be digitized at one pass.

The first step in digitizing data recorded on the analog magnetic tapes is to patch the output of the analog recorder playback electronic for the channels selected for playback into the digital system input at patch panel number 4. The next step is to select the time slice to be digitized. This time slice will be entered into the START and STOP controls on the tape search/time code reader control panel. The RECORDER CONNECT switch is then used to connect the proper recorder to the tape search/time code reader controls. The MODE switch is positioned to the SEARCH TO READ position and the tape search is initiated by depressing the SEARCH pushbutton. The tape search/time code reader unit will search the tape until the start time is found at which time the back light on the SEARCH pushbutton will go out. At this time, the digitizing process may then be started from the computer and measurement systems console utilizing the control panel. The master acquisition OFF-ON switch will be moved to the ON position, the fast acquisition mode selected from one of three pre-stored fast acquisition programs using the MODE NUMBER switch, and the SCAN DURATION control will be adjusted for a time scan duration which is slightly longer than the time slice selected on the analog tape. Prior to starting the digitizing process, the appropriate playback speed will be selected using the speed control on the tape search/time code reader control panel and the MODE switch moved to the SEARCH AND READ position. All controls will now be in the proper position to start the digitizing process.

The digitizing process is started by depressing the INITIATE pushbutton on the acquisition control panel and depressing the SEARCH pushbutton on the tape search/time code reader control panel. The digitizing process will continue until the time reading on the time-of-day display on the tape search/time code reader control panel reaches the value set on the STOP control, thereby stopping playback of the analog tape automatically. The digital system can then be stopped by repositioning the master ON-OFF switch to the OFF position. During the playback process, the digital computer will digitize the data and store it on discs or on magnetic tape for further processing. When playback is completed, the computer may be used to reduce the data using appropriate disc-stored data reduction programs. Several tape units can be played back at the same time by using the tape search/time code reader to search each individual tape in the SEARCH TO START mode and then starting all recorders simultaneously.

3.8 PRETEST REQUIREMENTS

An extensive amount of preparation must be accomplished before a compressor test can take place in the Compressor Research Facility. Once it has been determined that a given vehicle will be tested in the CRF, this preparation must begin. The test item has to be fitted with internal instrumentation and "built up" with the proper adapters and fixtures for installation in the CRF. The test item instrumentation and buildup will not normally be accomplished at the Compressor Research Facility, but at another location prior to shipment of the vehicle to the CRF. Once the buildup and instrumentation of the test vehicle is completed, it will be transported to the CRF for further preinstallation preparation. A number of items must be installed on the test item after it reaches the CRF and before installation in the test section. The test item must be installed in the test section and the necessary post-installation preparation completed before test "setup" can begin.

Test "setup" will consist of the detailed "setup" of instrumentation and control systems. The proper torquemeter ranges and necessary gear installation to provide the proper gear ratio must be selected. After "setup" is complete, a comprehensive pretest safety checkout must be initiated prior to the start of any test activity. When the pretest safety checkout is completed, then the facility startup procedure may be initiated. The data acquisition and process control system and the facility control systems must be activated prior to starting the facility drive. A drive startup will be initiated from the electrical drive system panel (part of the facility annunciator/control panel). Once all systems are activated and the "setup" has been completed, the startup procedure is automatic, requiring only the manipulation of three switches.

3.8.1 TEST ITEM BUILDUP AND INSTRUMENTATION

Basic test vehicle buildup and installation of internal instrumentation will take place prior to the test vehicle being shipped to the CRF (whether it is a prototype specimen or a production compressor assembly). Test vehicle buildup and instrumentation is an expensive endeavor. When the test vehicle is a production compressor assembly, the buildup and instrumentation procedure generally will alter it to the extent that it will not be suitable for further use in a flight engine. There may be exceptions to this if a production compressor is adapted to the facility for a minimum test program not requiring excessive internal instrumentation resulting in extensive alterations of the compressor casing and/or blading. It is not anticipated that the manpower and/or fabrication facilities will be provided to build up and instrument a compressor at the CRF. However, a limited amount of buildup and other necessary pretest preparation will be accomplished at the CRF prior to installation of the test vehicle in the test chamber. This pretest preparation is discussed in more detail in paragraph 3.8.4 of this volume. The purpose of the test vehicle buildup and instrumentation is to provide:

- A discharge pressure control valve.
- A test vehicle with the proper adapters for mounting in the facility and connecting to the facility drive system. These adapters will include a facility mount and drive adapter, an air inlet bellmouth and bulletnose, and a discharge diffuser to the discharge valve if required.
- Auxiliary service adapters which allow connections to be made to the lubrication oil system, stator vane actuators, and if applicable, stage bleed and seal leakage outlets.
- Internal installation of instrumentation in the test vehicle. This will include installation of strain gages on rotor and stator blades, air temperature and pressure rakes in the inlet, discharge, and interstage sections of the vehicle, bearing temperature sensors, hot wire anemometers, static wall pressure sensors, and traversing probe mounting fixtures.

Each test vehicle will require some special considerations in adapting it to the Compressor Research Facility. The services of an engineering design group will be required to provide the detailed design for adapters and instrumentation prior to their fabrication and mating with the test vehicle. The actual installation of stator vane hydraulic actuators and bleed valve actuators will be accomplished at the CRF as part of the pretest preparation discussed in paragraph 3.8.3 of this volume.

Two types of vehicles, a prototype specimen and a production compressor assembly, may be candidates for tests in the CRF. The prototype is a relatively expensive vehicle unique in design and construction (designed especially as a test vehicle) and will be a heavy "battleship" type vehicle which has thrust takeout and rear frame adaption to the facility incorporated into the initial design. The production vehicle is normally a flight weight vehicle that must be adapted in total for installation in the CRF. It requires a rear frame adapter to adapt the rear frame of the compressor to the facility. This adapter also serves as a diffuser and limited plenum between the compressor and discharge valve. The diffuser is annular in section and guides the hot air discharged from the compressor around the rear radial and thrust bearings so that it does not hinder the lubrication of these bearings. Additionally the rear adapter provides sealing of air leakage to the entrance of the diffuser.

The test vehicle shafting must be modified to match the facility shafting. This is normally accomplished during buildup by splining an additional shaft to the compressor. This additional shaft will terminate in an end matching the facility shaft and also support the mechanism required to take out thrust. The thrust takeout is necessary as the test vehicle, unlike flight engine configurations, has no partial balancing force such as a turbine or as the J85, a balanced piston, to take the thrust out. During compressor buildup, the thrust takeout can be accomplished in two ways:

- Use production compressor bearings and a balance piston. This makes use of the shop air pressure working against a sealed differential area in a direction opposite the compressor rotor thrust. This method may be used on small high speed compressors.
- Use Kingsbury thrust bearings. Either a single or double bearing may be used. A single bearing takes up thrust in one direction only, however, it takes up less space and, consequently, rear adapting shafting may be made shorter. A double thrust bearing takes thrust up in both directions and has the advantage of operating in case of thrust reversal. However, this bearing is bigger and heavier and will add a little more length to the test vehicle. The cost of providing either type of bearing during the compressor buildup would be approximately the same. Use of Kingsbury bearings requires that the vehicle lubrication scavenging system be designed to provide the large quantities of oil required by such a bearing.

The inlet bellmouth is installed on the compressor to provide uniform inlet conditions. Standard bellmouths are typically available for production engine static tests and are probably good configurations for use in the CRF. Special tests may require modifications to the standard bellmouth design, or in some cases, may require a specially designed bellmouth for the particular application.

A discharge valve will be mounted to the rear of the test vehicle. This valve will be controlled by the pressure ratio/discharge valve position controls provided as part of the CRF facility control systems. It will control pressure ratio of the compressor by controlling the discharge pressure and must have the capability for fast opening. Two general approaches to the discharge valve design, i.e., radial flow discharge and axial flow discharge, are currently under consideration. It is very desirable to have the discharge valve as close as possible to the actual compressor discharge. If a large volume of air exists between the compressor discharge and discharge valve, it is difficult to rapidly unload the compressor.

The test results from a compressor test are no better than the sensing devices and other instrumentation used to acquire the data. For this reason, it is imperative that instrumentation installations be accomplished in a manner maximizing measurement system accuracy. In a typical compressor buildup, a large number of instruments will be installed inside the compressor. These will normally include rotor and stator strain gages, temperature and pressure rakes, clearanceometers, accelerometers, thermocouples, and in some cases, small pressure transducers (Kulites). The aerodynamic instrumentation installed inside a compressor normally includes the pressure and temperature rakes and hot wire anemometers.

Any instrumentation mounted upstream of rotating components has a high potential for major compressor damage in the event of mechanical failures. Therefore, a high priority should be allocated to the design and installation of instrumentation in the compressor. During the compressor buildup, the aerodynamic instrumentation (rakes and probes) will be installed in the inlet, discharge and interstage areas of a compressor. Pneumatic and electrical lines routed from these measurement points will be brought to either pneumatic or electrical connectors located on brackets mounted on the test vehicle. Leads from the strain gages mounted on the rotor will be brought through the compressor shaft and connected to slip rings during vehicle installation. Because of the damage that could result from internal instrumentation failure, an "infinite life" must be the design intent for all instrumentation hardware installed inside the compressor. The aerodynamic and aeroelastic instrumentation that go into the compressor may be designed by the engineering group responsible for compressor buildup or procured from a number of sources as off-the-shelf items. In any event, bench testing (vibratory stress and vibration) should be conducted on rakes, probes and other instrumentation to be mounted upstream of rotating components. The resonant or fundamental frequency of the rake or probe and the supporting structure must exceed the compressor frequency at 100 percent speed by 25 percent or more to provide a minimum safety margin at the operating temperatures which will be encountered. For inlet rakes on large compressors (fans), the resonant frequency must be below engine idle speed by at least 20 percent. Because the second flexual frequency of the low frequency rakes may be coincident with compressor speed at 80 percent speed and above, this mode of vibration must be thoroughly analyzed during the vibration bench test. The resonant frequency of all compressor mounted support bracketry should be at least 25 percent above the compressor frequency at 100 percent speed.

Unless a considerable amount of experience is available from the use of a given rake or probe, a good policy is to place strain gage instrumentation on the rake or probe when it is inserted in the air stream. The vibratory stress data acquired from the strain gages on the rakes and probes should be monitored in a manner similar to the vibratory stress data obtained from rotor and stator blades. In the cases where provisions are made for interstage traversing probes, the mounting fixtures should be installed during test vehicle buildup. Once the installation of the mounting fixtures is complete, the probes should be attached to the fixtures and traversed over their total travel paths while the rotor is slowly rotated to ensure that the probe does not touch any of the rotating components. Normally, the traversing probe, along with bracketry fitting the probe to the fixtures on the vehicle, will be removed for shipment to the CRF. These items will be reinstalled during the pretest activity at the Compressor Research Facility. After the pretest buildup is completed, the compressor is ready to be transported to the CRF. If the test vehicle buildup and instrumentation was performed at Wright-Patterson Air Force Base, then transportation from the buildup area to the CRF will probably consist of truck transportation. However, if the compressor buildup and instrumentation were implemented at a location other than at Wright-Patterson Air Force Base, shipment to the CRF may be by any means normally used by the Air Force to transport jet engine and jet engine components such as air, truck, or rail, using the packing procedures normally required by Air Force procedures.

3.8.2 TEST ITEM PREINSTALLATION PREPARATION

Upon arrival at the CRF, a certain amount of test item preinstallation preparation is required. The extent of this preparation depends upon the design of the test chamber, the method to be utilized in installing the compressor in the tank, and, to some extent, upon the individual test vehicle.

Particularly in the case of large test items where there will be a limited space between the chamber walls and the test vehicle, it is recommended that as much of the actuating and instrumentation hardware as possible be installed on the compressor prior to test chamber installation. For example, if a 10-foot diameter vehicle is to be installed in the 16-foot diameter chamber, then there is only three feet of clearance between the vehicle and the chamber walls for installation of vehicle hardware. Therefore, stator vane actuators, stator vane position sensors, stage bleed valve hardware, stage bleed valve position indicators, traversing probe hardware, and other transducers and instrumentation located externally on the compressor casing should be installed prior to vehicle installation in the chamber if at all possible.

3.8.3 TEST ITEM INSTALLATION

After compressor buildup and instrumentation, compressor shipment to the CRF, and the necessary preinstallation preparation at the CRF have been completed, the next step in preparing for a compressor test is to install the test vehicle in the test chamber. The test vehicle will be brought into the test chamber through a removable flanged section of the tank. The flanged section must be machined for a seal and installed perpendicularly within approximately 1/2-inch to permit sliding out from between two fixed tank sections. Inflatable seals will be utilized to achieve a leakproof joint. The slide-away section requires mounting on track and rollers to facilitate removal. A 17-foot long slide-away section is required to give sufficient access for the test vehicles; it will start approximately 15 feet from the test vehicle mounting bulkhead. The open area provided when the slide-away section is moved aside must be covered by grating supported on a retractable frame to provide a platform level with the floor of the test chamber. This method facilitates the application of the special inlet ducting required for special flight configuration inlet duct testing. A separate personnel door, is also required with the slide-away section configuration. It should be noted that in this configuration the slide-away section can be considered as part of the inlet ducting rather than the test chamber.

A handling system is required to facilitate moving the test vehicle into the test chamber and manipulating the vehicle onto the facility mounting flange. The handling system would consist of an overhead monorail in the test chamber with a load beam suspended from the monorail on trolleys as the test vehicle transporter. The load beam suspension would be provided with limited vertical movement and utilize motor operated actuators. The monorail would be precisely positioned in relation to the facility mounting flange to avoid a requirement for lateral position adjustment. A portable section of monorail with slings for attachment to the overhead crane is required to facilitate moving the test vehicle outside of the test chamber. To move a test vehicle into the test chamber, the portable monorail, load beam, and trolleys would be attached to the overhead crane and the trolleys locked to the portable monorail. The slide-away section of the test chamber would be moved aside and the test vehicle would be attached to the load beam using slings of a predetermined length to assure an approximately correct elevation of the test vehicle when suspended from the test chamber monorail. The portable monorail would then be positioned onto supports on the exterior of the test chamber, the fixed and portable monorail sections would be locked together, the trolleys would be unlocked, and the test vehicle moved into the test chamber along the monorail. Finally, the test vehicle would be manipulated onto the mounting flange using the vertical height adjusting mechanisms provided on the load beam suspension.

This method of handling does not conflict with space required for the location of permanent test vehicle instrumentation and service interfaces in the test chamber and requires relatively low headroom. Portable positioning devices such as hand-operated jacks can also be utilized to obtain lateral movement if an extremely heavy test vehicle is not properly centered in the test chamber. Electric hoist and trolley can be used on the monorail to handle other equipments that may be installed as part of the test setup.

Once a test vehicle has been moved into the test chamber, the next step is to align the vehicle with the facility and mount it to the chamber at the discharge end. This is accomplished using a large mounting flange which is an integral part of the test chamber discharge plenum. The flange will incorporate a rabbet and the mounting surfaces will be machined concentric with the drive jackshaft bearing mounting flange which is also a part of the test chamber discharge plenum, assuring good alignment. An adapter plate will be provided as part of the test vehicle buildup to accommodate various sizes of test vehicles. To maintain the structural integrity of the facility, the adapter plates will be designed to fail at or below the safe-loading level at the facility mounting flange. Continuous "Tee" slots will be provided on the walls of the test chamber to permit anchoring struts which would attach to the forward end of the test vehicle, thereby accommodating the requirement for support at the front of the test vehicle. In this approach, the test vehicle and jackshaft bearing housing mounting surfaces are part of an extremely massive and rigid test chamber structure. The test chamber will be aligned with the drive during installation on the foundation, then anchored and keyed to retain permanent alignment with the drive, assuring satisfactory alignment between the test vehicle and the drive provided proper tolerances are applied to the rabbet fits and test vehicle mounting surfaces are maintained in accurate alignment with the machine axis during test vehicle buildup.

3.8.4 TEST ITEM POST-INSTALLATION PREPARATION

Once the compressor is moved into the test chamber and mounted to the test chamber bulkhead, a number of post-installation preparations must be completed before a compressor test can start. The post-installation preparation depends to some extent on what has been accomplished prior to installing the compressor in the test chamber. Stator vane actuators and indicators, stage bleed valve and valve position indicators, traversing probe assemblies, lubrication oil scavenging manifold, and external transducers as well as other instrumentation must be installed if they have not been installed prior to moving the vehicle into the test chamber. As part of the pretest preparation, rotating screens or other devices used to generate (either discrete frequency or random frequency) turbulence at the compressor inlet must also be installed in the facility if they are required for the test program. All pneumatic pressure sensing lines, electrical, lubrication oil system, and hydraulic connections must be made between the test vehicle and the facility. The appropriate slip ring assemblies must be installed to enable rotor instrumentation connections to the slip rings. The appropriate gears must be selected and installed for achieving the proper speed range for the test vehicle. The appropriate flow measuring configuration must be selected and proper connections completed between flow measuring nozzles instrumentation and the signal conditioners in the signal conditioning room. Connections must be made between the bellmouth instrumentation (pressure and temperature measurements) and the facility. Once all necessary hardware has been installed on the vehicle and all necessary instrumentation connections, lube oil connections, hydraulic connections, and control system connections have been made between the facility and the vehicle, "test setup" may be initiated for instrumentation and control systems.

3.8.5 CONTROL SYSTEM SETUP

Every effort will be made in the design of the CRF control systems to minimize the effort required to set these controls up in preparation for a test. One of the first steps in setting up the control systems will be to calibrate the function generators included as a part of the stator/stage bleed controls and the pressure ratio/inlet valve position controls. These generators may be calibrated by first providing known input signals to simulate rotor speed and measuring the outputs to ensure expected correspondence to the table loaded into the generator. Span and zero adjustments may be made on each generator until the desired output is obtained. If some method other than function generators are selected (a dedicated digital computer) it is anticipated that the setup requirement will not change significantly.

The inlet pressure control will be set up initially in the position mode of operation. This will be accomplished by making the necessary zero and gain adjustments in electronic components until the readings and mechanical position indicators on the valve equal the setpoints loaded into the system at the inlet pressure/valve position control panel. To calibrate the control system for use in the inlet pressure control mode of operation, a voltage corresponding to the control system pressure transducer output would be substituted into the system at the appropriate point utilizing a control system calibrator and the necessary adjustments would be made until the INLET PRESSURE display on the inlet pressure/valve position control panel reads the engineering units value corresponding to the voltage being substituted into the system. The engineering units value corresponding to the transducer output may be obtained from the calibration curve of the control system transducers. With a given setpoint loaded into the system at the control panel, the control system output signal would be routed to the control system calibrator which would simulate the hardware being controlled and provide a simulated sensor reading to the inlet pressure controller. The same procedure would essentially be repeated to set up the pressure ratio/discharge valve position control system in the position and pressure ratio direct modes. Likewise, the stator vane/stage bleed control would be calibrated in the direct mode by making the necessary zero and gain adjustments in the control electronics until the mechanical angle indicators on the compressor casing equal the setpoints being entered into the system at the stator vane/stage bleed control panel.

To calibrate the pressure ratio/discharge valve position controls and the stator vane/bleed controls in the function mode of operation, the function generator must first be calibrated using the procedure described above. The output of this generator would be used to drive the remaining control electronics to position the stator vane/stage bleed valves or the discharge valve. With given simulated sp ed inputs, the stator angles and/or the bleed valve positions should correspond to the simulated input speed and the function loaded into the generator. Likewise, in the pressure ratio/function control, the output to the discharge value valve actuator should equal the value expected for the given simulated speed and table entered into the control system. The necessary adjustments must be made until the measured values are equal to the expected values.

To set up the speed control system, an input signal simulating the speed transducer output is provided to the speed control electronics and the speed control is measured to determine if the required error signal appears at the output. The necessary adjustments to the control electronics must be made until the output is correct for the setpoint and speed readouts on the speed control panels.

Since the aerodynamic instrumentation and backup speed measurement outputs are routed to the digital computer, they can be used to verify the speed and pressures provided by the control systems.

All other control systems will be set up in a similar manner prior to test start. To verify that the computer control is operating properly for those controls controlled by computer setpoint control, it is necessary to run a benchmark type program and observe the actual position of stator vane/stage bleed valves, and inlet and discharge valves, or measure the output speed and pressure references controlling speed, inlet pressure, or pressure ratio using the required control system calibrators. The benchmark program would cause the computer to supply several levels or setpoints to the control system to verify that the computer control is working over the total operating ranges.

3.8.6 DATA SYSTEM SETUP

A successful compressor test depends, to a great extent, on the accuracy of the data acquired during the test. A compressor evaluation, which is the primary purpose of the compressor test, can be no better than the results which are supplied by the data acquisition system. Therefore, it is absolutely necessary that good setup procedures be employed for both the analog and digital data acquisition systems in the pretest phase of test preparation. Once the compressor has been installed in the test chamber and all necessary instrumentation connections made between the facility and the test vehicle, data system setup may begin. The first step in the test setup will be to complete channelization of all measurement channels, using the "road map" which will be included as part of the measurement program's documentation. Channelization consists primarily of making all patches to route the data from the receptacle box in the test area to the proper signal conditioning modules in the signal conditioning room through the tunnels to patch panel number 4 in the control room, and then from patch panel number 4 into the appropriate data recording devices. Once these patches are made, it is necessary to verify continuity from a point as close as possible to the transducer end of the measurement channel back to the recording device. The method of verifying continuity may vary from measurement channel type to measurement channel type. For pressure channels requiring on-line calibration, a pressure can be applied to pressure transducers with the on-line cal system and the cables disconnected from each transducer (one at a time) while a voltage readout at the recording device is observed. For thermocouple temperature measurement channels, the front panel controls on the calibration modules can be depressed one at a time while observing the voltage readouts at the recording device. The continuity checks are necessary to ensure that there are no discontinuities in the measurement channel and to prevent the wrong transducer from being connected to the wrong channel.

Once channelization has been completed, the next step is to set up the signal conditioning modules. This is accomplished by breaking the channel at the output of the signal conditioner and making the necessary zero and span adjustments while the output of the signal conditioner is being monitored on a digital voltmeter. Once span adjustment has been completed, the output of the signal conditioners is repatched into the recording device. The span and zero adjustments are continued on a day-by-day basis until the complete setup is finished.

At the end of each day, the channels completed that day should undergo an on-line calibration and/or a reference check. Channels that have been completed should be reference checked on a daily basis until the setup is completed. This will provide a means for checking zero and gain drift on a day-by-day basis to identify unstable measurement channels or measurement channels where malfunctions occur. A calibration curve for each measurement channel in the form of a table containing counts (or voltage) versus engineering units will be loaded into the digital computer. Prior to the test, the necessary data acquisition programs must be entered into the computer to control acquisition and scan rates during the test.

Setup and calibration of the digital acquisition system is normally not necessary for each test but may be accomplished on a periodic basis. This would consist of calibrating the differential auto ranging amplifiers and the analog-to-digital converter and checking the multiplexer to ensure that the accuracy of the digital input system is within the specified tolerances. As opposed to the digital acquisition system, analog recorders must be set up for each individual test. The setup for the analog recorders consist primarily of providing an input voltage and making the necessary adjustments for recording the proper voltage levels on analog tapes. Prior to startup for a test, a total on-line calibration and reference check run should be made. Based on this run, a computer program may be used to "rotate" and "offset" the calibration curves to eliminate zero and/or gain drift inaccuracies. Immediately following test completion an additional complete calibration and/or reference check should be made. The "offset" and "rotate" corrections can be made based on a combination of the pretest and post-test on-line calibrations and/or referenc checks. The system also provides on-line calibrations or reference checking of certain channels while the test is in progress. The only requirement is that enough time be allocated in the test program to perform these calibration and/or reference checks without interfering with any other test function. No setup on an individual test basis, other than loading the necessary input acquisition and control programs, is required for the digital computer, display devices, and computer peripherals.

3.8.7 FACILITY INSTRUMENTATION SETUP

A number of instrumentation items are not included in the control systems or as part of the analog and digital data acquisition systems even though a par output from these items can be recorded on these acquisition systems. These items may be referred to as facility instrumentation. Examples of facility instrumentation would be drive system vibration measuring and recording devices, bearing temperature indicators, torquemeter readouts, etc. These devices must also be set up (span and zero adjustments) periodically or prior to the beginning of a test. This calibration or in some cases a reference check is required to provide the necessary data accuracies.

3.8.8 PRETEST SAFETY CHECKOUT

After all installation and setup procedures are completed, and before test start, a pretest safety checkout must be made. All aspects of the facility considered critical to facility, test vehicle, or personnel safety should undergo a thorough safety checkout prior to the start of a test; for example, a check of the traversing probes would be made by slowly rotating the compressor rotor while the probes traverse over their travel length to assure that no part of the probe comes in contact with the rotor. Also, a last minute check of inlet and discharge valves should be made. Position setpoints should be entered into the systems and the valve indicators physically observed to ensure that these setpoints are being obtained. The setpoints should then be moved to a greater or lesser value while the valves are being observed to ensure that the proper valve travel is obtained (either more open or closed) to correspond to the change in the setpoint. In other test facilities incidents have occurred where the valves have been connected backwards and an opening setpoint actually caused the valves to close. Human error in setup can cause severe damage to both the test vehicle and the facility. A last minute physical inspection by the test conductor and/or other senior personnel of the test vehicle, the inside of the test chamber, the drive system shafting and gearing, and any other rotating or critical components in the system should be made to ensure that no major discrepancies exist in the installation or setup for the test.

3.9 TORQUEMETER CALIBRATION AND OPERATING PHILOSOPHY

If a torquemeter system is furnished initially it will cover the range of 937 to 60,000 pound-feet. The torquemeters will be of the strain gage type and will be provided with an integral slip ring unit incorporating remotely controlled brush lifters. Each meter will have a rated accuracy of 0.25 percent of full scale and will withstand up to 50 percent torque overload without requiring recalibration. Overloads of 50 to 100 percent rated torque will require the meter to be recalibrated, overloads in excess of 100 percent rated torque will necessitate returning the meter to the manufacturer for repair.

The number and range of torquemeters to be furnishedare shown on Figure 3-20. The accuracy attainable with the system is shown on Figure 3-21. Digital readout of torque will be provided in the control room and the calibration room. Torque will also be recorded on a strip chart recorder.

3.9.1 OPERATIONAL CONSIDERATIONS

If torquemeters are used, a torquemeter must be installed to cover the desired torque range and accuracy prior to starting a test. Using the J79 compressor as an example and referring to Figure 3-20, TM 2 would be selected to accommodate full torque. Referring to Figure 3-21, if the accuracy desired is 0.5 percent of actual reading, then the meter should not be used to measure less than 20 percent of rated torque or 6000 pound-feet. Referring to the J79 speed versus torque curve on Figure 3-20, 6000 pound-feet represents a physical speed of approximately 520 rpm (70 percent). If torque measurement accuracy at 0.5 percent of reading is desired below this speed, then it will be necessary to shut down and change out torquemeters. In this case, TM 2 would be replaced by TM 4 to cover the rest of the speed range of interest (down to approximately 55 percent physical speed). The capability for precise measurement of torque is applicable only during steady state type testing. When speed transient testing is to be performed, a torquemeter must be selected that is rated for the expected accelerating torque, thus reducing the accuracy in terms of percent of actual reading. Also, though the magnitude of this effect has not been determined, torque measurement accuracy during a speed transient will be affected by system lags.

To protect the torquemeters during normal test operations, a torque limit feature is provided in the electrical drive controls. When the drive control system receives a signal from the torquemeter corresponding to full scale, it will automatically limit output torque of the drive system. In the event of a catastrophic failure such as freeze up of the test vehicle, a shear section in the facility shafting will fail at approximately twice the rated torque of the vehicle and provide protection to the torquemeter if it is rated for full compressor torque. If a reduced range meter has been installed to obtain precise torque measurement at low vehicle speeds, no protection is available and damage may occur in the event of a catastrophic failure. Gear torque limits will also be considered in designing the shear section.

If the range of the torquemeter must be changed during a test run, the following procedure would be required:

- Shut down the drive system.
- Turn off electrical power to the torquemeter system.
- Remove guards, uncouple torquemeter and lower onto storage dolly utilizing overhead crane.

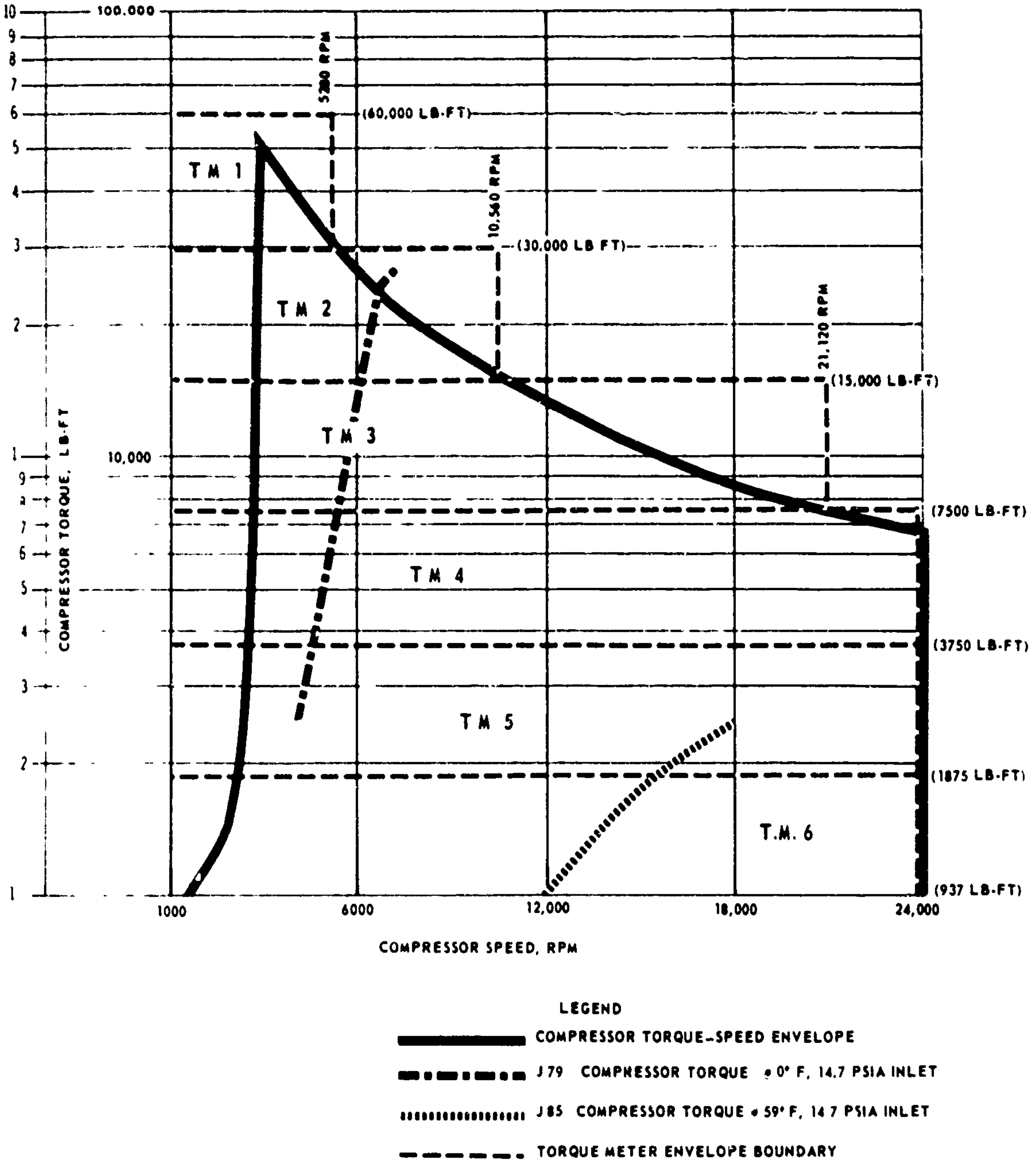


Figure 3-20. Compressor Speed Versus Torque

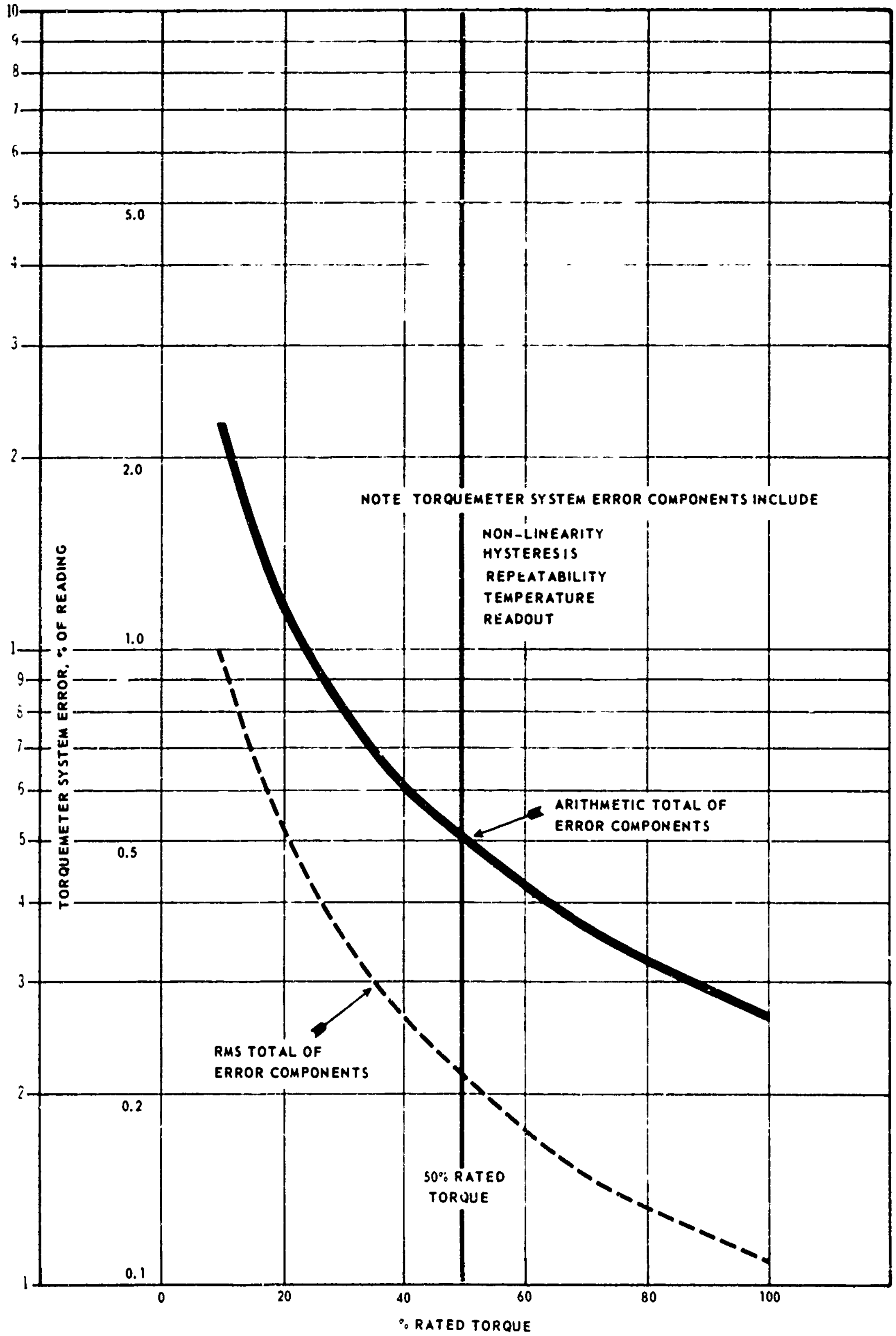


Figure 3-21. Torquemeter System Error Versus Percent Rated Torque

- Install torquemeter in drive shafting, utilizing overhead crane.
- Check electrical connections, verify operation at brush lifters, replace guards.
- Turn electrical power to torquemeter system on. Set full scale span and zero using trimming adjustments on signal conditioner and the digital readout in the calibration room.

It is estimated that it will take three technicians plus a crane operator four hours to accomplish this procedure.

An additional method for obtaining torque data utilizing aerodynamic data acquired and processed via the data acquisition and process control system has been considered and is discussed in Volume III.

No special periodic maintenance is recommended for the torquemeters; however, the slip ring unit will require service. (This can be accomplished during calibration of the meters.)

3.9.2 CALIBRATION

The existing torquemeter calibration stand will be used for calibration. This stand will require some modification to provide calibration accuracy compatible with the new torquemetering system. The main features of the calibration stand are shown on Figure 3-22.

The torquemeters required for a specific test program should be identified in the test plan. It is recommended that the meters to be used in a test program be calibrated in advance of the planned testing date. During the test, it would not be necessary to perform additional calibration (except for the zero and full scale setting during installation as identified in the torquemeter changing procedures) unless a torque in excess of 150 percent of rating has been applied.

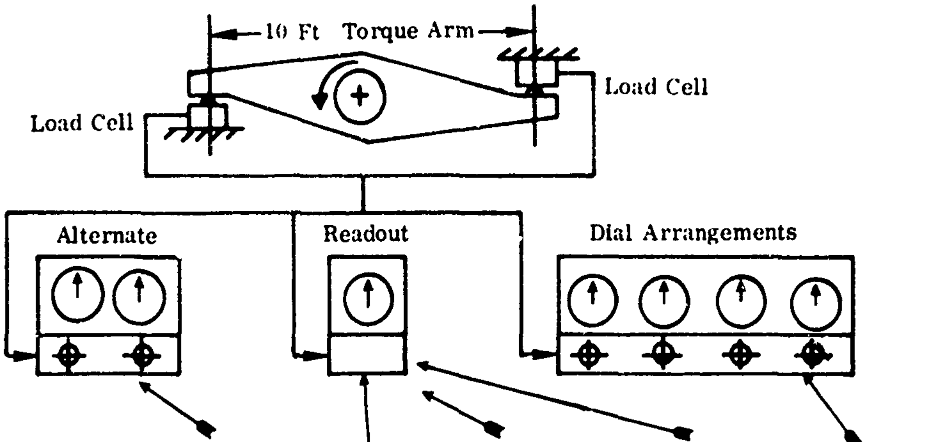
The following typical procedure would be followed for calibration:

- Remove the meter from storage, inspect the slip ring unit and service if required; inspect and clean up the coupling flanges.
- Install the meter in the calibration stand and connect to the signal conditioner.
- Utilizing the calibration stand torque readout and the local torquemeter digital readout, check span and zero settings using the shunt calibration technique.
- Return the torquemeter to storage or install in the drive shafting.

It is estimated that this procedure can be accomplished by two technicians in four hours. This does not include installation in the drive shafting.

3.10 DRIVE SYSTEM GEARING

The existing drive utilizes a double train speed-increasing gear box and two drive motors. Re-



Alternate Systems	1 (Existing)	2	3	4	5
Type Load Cell	Hydraulic	Strain Gage	Strain Gage	Hydraulic	Hydraulic
Sensitizing Method	Dual Range Dial	Multi-Range Dial	Change Load Cells	Multi-Range Dial	Multiple Dials
Number of T.M. Ranges Per Readout Dial Range	2	4		4	1
Torque Rdg. Error Due To Load Cell-Readout System					
%Rdg. at T.M. F.S.	.2	.1	.08	.2	.1
%Rdg. at T.M. 1/2F.S.	.4	.2	.16	.2	.2
Torque Rdg. Error Due to ± .001 Ft. (=.012 in.) Error in Torque Arm Length					
%Rdg. at T.M. F.S.	.01	.01	.01	.01	.01
%Rdg. at T.M. 1/2F.S.	.01	.01	.01	.01	.01
Total Torque Reading Error					
%Rdg. at T.M. F.S.	.21	.11	.09	.21	.11
%Rdg. at T.M. 1/2F.S.	.41	.21	.17	.21	.21

Figure 3-22. Torquemeter Calibration Stand Accuracy

motely controlled couplings are utilized to select the desired speed range. The existing drive provides 30,000 hp at speeds up to 12,000 rpm. To increase the maximum speed to 30,000 rpm, new gear units will be coupled to the output of the existing gear.

With the new gear units 30,000 hp may be provided over the speed range from 3000 to 16,000 rpm and 15,000 hp may be provided over the range from 16,000 to 30,000 rpm.

Speed range selection will be accomplished by coupling or uncoupling the low speed motor while the drive is stationary. When a new gear unit is installed, switches will be actuated to provide the switching logic required for the constant horsepower speed range display.

The new unit will be precisely positioned relative to the existing gear during the initial installation. Subsequent removal and reinstallation will be a relatively simple task. Changing of a gear unit would require the following steps:

- Remove hood section
- Uncouple lubrication and instrumentation
- Remove shaft couplings
- Unbolt and remove gear unit
- Install desired gear unit
- Install shaft and couplings
- Reinstall lubrication and instrumentation
- Replace hood section

It is estimated that three technicians can change a gear unit in eight hours. A crane operator would be required intermittently during this time and would be on standby throughout the e hour period.

3.11 FACILITY STARTUP

Before the electrical drive system is started, the other control systems must be moved to predetermined activation points to prevent damage to the compressor when the drive is started. Also, the computer and measurement system must be activated prior to the start of the facility drive. The actual startup of the drive system will be a semiautomatic process that may be accomplished with minimum manual effort.

3.11.1 COMPUTER AND MEASUREMENT SYSTEM ACTIVATION AND STARTUP

One of the first steps in activating the digital computer system is to load the necessary data acquisition and control programs prior to test start. The three monitor mode programs and three fast acquisition programs (operated manually from the acquisition control console) as well as the other scan formats and acquisition programs (operated under computer control) should be loaded into the system. It is assumed that all calibration curves for all measurements will have been loaded into the computer and reference levels established through on-line calibration or reference checking. If the test is to be conducted in the automatic mode of facility operation, a set of initial transfer control points should also be loaded into the computer. These points represent the point on the compressor performance map where control will be transferred from the manual to automatic mode. When a test is to be run in the automatic mode, the control programs necessary to supply required setpoints must be loaded into the computer prior to test start. Also, the display formats and display control programs required to operate the video display for a given test should be loaded at this time. After the required control and acquisition control programs have been loaded into the computation system and just prior to the electrical drive system startup, the timing system should be preset and started. Concurrently, magnetic tapes should be loaded on the tape units and paper rolls should be placed in the strip chart and oscillograph recorders.

Recorder speeds should be selected for the analog tape recorders and the strip chart recorders using the appropriate controls. Prior to electrical drive startup, the strip chart recorders should be started and the digital acquisition system should be started in the slow monitor mode. The analog tapes may be started after the electrical drive startup and prior to test data acquisition to minimize magnetic tape usage.

3.11.2 CONTROL SYSTEMS ACTIVATION

To prevent damage to the compressor during drive startup, the various control systems must be placed in prescribed initial conditions. In general, the stator/bleed valve controls will be placed in the function mode of control so that stator vanes will track compressor corrected speed while the inlet discharge valves will be placed on position mode of control and opened to a wide open position for electrical drive startup. The pneumatic (shop air) system, the test vehicle lubrication system, the hydraulic system, the electrical power system (including primary power, regulated power and backup power), and the cooling water system will be brought on-line and up to operating status prior to the electric drive system startup. Setpoints for speed control will be preset to an idle speed at the master speed control panel on the facility annunciator/control panel. After control systems and computer and measurement system activation has been completed and the test vehicle lubrication oil allowed to stabilize at the temperature and pressure setpoints, the facility is ready for electrical drive system startup.

3.11.3 ELECTRICAL DRIVE SYSTEM STARTUP

All controls necessary to start and operate the electrical drive system during a test will be located in the control room. The startup of the electrical drive will be initiated at the speed control section of the facility annunciator/control panel. An automatic startup sequencing device may be provided to activate the electrical drive system by operating three master switches. The automatic startup of the auxiliaries, the constant speed MG set, and the frequency converter set will be initiated using a master start switch at the START STOP control panel. The ability to start the auxiliaries and the constant speed MG set remotely from the balcony will be retained for maintenance purposes. Prior to initiating the automatic startup sequence, it is necessary to first start the drive lubrication system and allow it to stabilize at the proper lube oil pressures and temperatures. When lube oil is stabilized, the startup sequence may be initiated using the MASTER START SWITCH at the start-stop control panel. The sequence of automatic start will be:

- All auxiliary MG sets, blower motors, etc., will start.
- The constant speed set will start and synchronize on-line.
- The dc loop breaker will close and the frequency converter set will accelerate to the predetermined speed (approximately 50 Hz).
- A light will then come on indicating that the drive is now ready for start.

The procedure for operating the synchronous motor gear system will be as follows:

- Start the gear lube system and the synchronous motor auxiliaries.
- Select and couple in the synchronous motor to be run.
- Select direction of rotation.
- By manual control, bring the converter speed to 514 rpm (zero Hz). The ZERO Hz light will come on.
- Establish gear bearing oil film by running turning gear motor. The turning gear must be disengaged before the drive breakers can be closed. This step is recommended only when the drive has been standing for a prolonged period of time.
- Close synchronous motor start switch. The automatic sequence will then be:
    - Field will be applied to the synchronous drive motor.
    - The converter primary, secondary and synchronous motor running breakers will close.
    - The converter speed will be programmed to slowly decrease raising the voltage and frequency until sufficient stator current is produced to initiate synchronism and slow rotation. Once the motor is turning, a light will come on to indicate that the speed control may now be transferred.
- Transfer speed control to the master speed control panel by positioning the run switch.

Once the control has been transferred to the master control panel, the drive system can then be brought up to the speed at which the test is scheduled to start. At the direction of the test conductor, speed control will be transferred to the test conductor's console until the test is completed, when the speed control will be transferred back to the master speed control panel for normal shutdown.

3.12 COMMUNICATIONS SYSTEMS

A flexible communications system is essential to an efficient test facility. The communications system must be used in every phase of test setup, test operation and post-test activity. The CRF communications system basic station is a 20-channel, solid-state, pushbutton unit. The station has an integral speaker-microphone capable of a 3-watt output. A plug is furnished on the face of the unit for a microphone or microphone headset. Hands-free operation may be selected from the front panel switch. The set is equipped with a volume control for the integral speaker and each headset is equipped with its own volume control. Each station (except the test conductor's station) is identical and removal and replacement is accomplished by removal of front connected lock screws. The public address (PA) system which is a part of the communications system is powered by two 200-watt solid state amplifiers. The PA system may be selected at each station by a push button. A five-channel tape recorder is connected into the communications system for recording up to four communication channels during a test. A time-code signal is recorded on one channel of the recorder.

The test conductor's communication station is used as the master communication station during a test. Two channels (a primary and a backup) will be allocated as test conductor's channels for a test. The primary channel will be used by the test conductor to communicate all test information to test participants. Test participants' communication stations will be connected to this channel while the test is in progress. All routine test information will be relayed over the primary test conductor's channel. If a major problem arises, however, necessitating discussion of the problem on a channel other than on the primary test conductor's channel, a test participant can signal the test conductor on another channel, at which time the test conductor can switch to that particular channel to converse with the test participant. When the test conductor "comes up" on another channel, however, one half of his headset will remain on the primary test conductor's channel. The other half of his headset will be connected to the particular channel used to converse with the test participant. If an emergency occurs while the test conductor is talking to the test participant on the other channel, he may switch immediately back to the test conductor's channel to provide direction to test participants regarding the emergency. Because the test conductor's station is the master communications point, the overall philosophy of maintaining rigid test discipline during a test can be maintained. The test conductor, through the proper use of the communications system, can regulate all conversation among test participants and between test participants and the test conductor during a test.

All channels, including the test conductor's channels, can be utilized for communications links during test setup or test disassembly. During test setup, a number of independent channels must be established between the individuals performing the setup operation. The communications system allows for this mode of operation.

SECTION 4

COMPRESSOR TESTING PHILOSOPHY

This section outlines many of the tests that will be performed in the Compressor Research Facility. Although it is not possible to devise a test plan universally adequate for testing any compressor installed in the Compressor Research Facility, many of the tests performed on different test items are very similar. The intent of this section is to describe in general the proposed utilization of the Compressor Research Facility.

4.1 SINGLE SPOOL FAN AND COMPRESSOR TESTING

4.1.1 INITIAL MECHANICAL CHECKOUT OF A NEW COMPRESSOR

The purpose of the initial mechanical checkout is to determine if a compressor can be brought up to 100 percent of corrected design speed without problems. The first run on a new compressor will normally be conducted in the manual facility mode of operation. Since there is no test data available on the assembled test item, it is necessary to use the designer's compressor performance map as a guideline and an untried design stator schedule. Digital data will be acquired at an average rate of one sample per second per channel during the first run. Vibratory stress, vibration, and clearance data will be recorded on wideband analog tapes. Before test start, the stator schedule will be manually set in at the stator vane/stage bleed control panel. (Startup will be initiated per the procedure described in paragraph 3.11 of this volume.) The drive system will be brought to approximately 10 percent speed before speed control will be transferred to the test conductor's console, then increased slowly. Careful attention must be devoted to vibratory stress, vibration, tip clearance, and bearing temperatures. During this initial runup of the compressor, critical speeds will be identified using vibration data displayed on the vibration monitors. When critical speeds are encountered, they will be "probed" as necessary to prevent damage to the test item. Records will be made of the critical speeds for further observation because changes in critical speeds can be indicative of test item conditions.

The slow increase in speed will be continued to approximately 50 percent of corrected speed. The inlet and discharge valves will remain open or closed only as much as required to allow compressor operation. If unusual or excessive vibratory stresses are noted during the speed increase, it will be stopped momentarily and the stator vanes in the stages incurring the excessive stress will be adjusted to the point where the stress is minimized by holding speed constant and changing the stator vane control from the function to the direct control mode where the manual control will be utilized to adjust the stator vanes. When a new setting is attained, the controls on the function table controls corresponding to the speed will be adjusted to match the setpoints on the direct setpoint indicators. Stator control will then be reset to the function control mode and the speed increase continued to 50 percent (corrected), then slowly decreased toward zero.

Inlet and discharge valves will remain open until speed has been slowly decreased to the 10 percent point where a manual shutdown of the facility will be effected per the procedures described in paragraph 3.11. An automatic calibration will be initiated and a detailed inspection of instrumentation will be made. Particular attention will be devoted to strain gages used in measuring vibratory stress on rotor and stator blades, and a careful calibration check will be made of the stator position indicators. Any defective equipment should be repaired before the initiation of the next run.

The purpose of the second run will be a continued mechanical checkout to 100 percent speed. Although this is usually manual, it could be accomplished under the automatic mode. The acceleration to 100 percent speed must be made very slowly so the compressor is not subjected to excessive vibratory stresses, vibration, or tip rubs. Before the second run, a check will be made to assure that the proper stator schedule is set on the manual stator function control. The data acquisition and facility controls will be initialized per the startup procedure described in paragraph 3.11 and a data system automatic calibration/reference check will be conducted from the control console. Data acquired during the first test run will also be viewed using the video display to determine if any abnormalities exist in the data, and if an excessive vibratory stress was noted during the runup on run 1, it may be played back from the analog tape recorder and analyzed via the digital computer or a quick-look analysis using the spectrum analyzer or an oscillograph "strip out." When the pretest automatic calibration is completed, the startup procedures will be initiated.

After control is transferred to the test conductor's console, the drive will be brought to 50 percent corrected speed. A predetermined pressure ratio trajectory will be set using the function controls on the pressure ratio/discharge valve position panel. This trajectory will maintain pressure ratio just above the minimum limit for the compressor under test. Pressure ratio control will then be activated using the controls on the panel. After sufficient time for flow meter stabilization, a high speed data burst will be initiated from the acquisition control panel on the computer and measurement system console.

The speed then will be slowly increased toward 100 percent corrected speed. Careful monitoring of vibratory stress, bearing temperatures, and tip rubs will be necessary during this acceleration. Whenever an excessive vibratory stress is encountered on any given stage, the acceleration will be stopped and the stator vane control will be reverted to the direct control mode for individual stator adjustment until minimum vibratory stress is obtained. New setpoints will then be set into the function table via the manual control and stator vane controls will be reverted to the function control. At this time, the speed increase will be continued until the 60 percent point is reached at which time the acceleration will be stopped and the flow meter allowed to stabilize; then, a high speed data burst will be taken and recorded and the compressor will be slowly accelerated. If in the meantime excessive vibratory stress is encountered, the stators will be adjusted per the previous method described. Also, if excessive tip rubs or vibrations are encountered, the compressor will be shut down and the cause investigated. High speed data bursts will be taken every 10 percent corrected speed to 100 percent for the remainder of the acceleration. Upon arrival at 100 percent, the compressor will then be decelerated to 50 percent corrected speed, when the pressure ratio will be changed from function to direct control. While the pressure ratio is in a direct control mode, a new pressure ratio trajectory will be entered into the function controls. This pressure ratio versus speed trajectory will be one designed to cause pressure ratio to track speed along the design point operating line. Once the pressure ratio trajectory has entered into the system, pressure ratio control will be changed from direct to function control and the inlet pressure control will be changed from position to pressure control and an inlet pressure setpoint corresponding to the minimum possible inlet pressure with a given test vehicle under open loop cycle operation. After completion of a high speed data burst, a slow acceleration toward 100 percent speed will be initiated. At each 10 percent corrected speed increment, a high speed data burst will be taken. Whenever an excessive vibratory stress is encountered on the given stage, the acceleration will be stopped and the necessary adjustments to minimize stress levels made on stator vanes via the previously discussed method. Also during this acceleration, attention will be given to any excessive stator tip rubs or vibrations. After the 100 percent corrected speed point is reached, a deceleration will be started.

The deceleration steps will be similar to the acceleration steps with a planned trajectory along the same path as acceleration. Speed will be the only parameter changed on the deceleration path. When deceleration is completed, testing required for initial mechanical checkout and evaluation of the new compressor will have been completed.

4.1.2 STATOR VANE OPTIMIZATION

Stator vane optimization is one of the more critical series of tests that must be performed during the developmental testing of a compressor. The object of these tests is to arrive at an optimized stator schedule which:

- Gives best efficiency at cruise and takeoff conditions.
- Gives adequate stall margin over the entire operating range.
- Results in low blade vibratory stresses.
- Provides for ganging of stators to minimize operational control problems.
- Provides answers to unique design considerations which may otherwise go unanswered.

Stator vane optimization tests may be conducted in either the manual or the automatic mode; however, this series of tests can in general be better performed automatically because of the complexity of the optimum stator solution. In either mode, much of the same logic has to be applied by either the man or the computer. Initial discussions here will describe the tests and the method of arriving at optimum schedule in the automatic mode. This is a typical method of stator vane optimum schedule solution and not necessarily the only approach: there are many ways to obtain a solution for stator vane schedule. The best method of arriving at a stator angle solution will be that which produces the desired results in the shortest time. This method, called optimum programming in computer technology, is generally a result of systematic study of a particular problem. The following brief discussion of the stator optimization problem has been included to outline the basic elements involved in stator optimization.

Figure 4-1 is a modification of a conventional compressor map with nominal operating line drawn to facilitate the presentation. Three different regions, each considered to have constant compressor speed as a parameter,have been identified to indicate the three areas of usual interest. Thus, any point in Region 1 can be obtained at 100 percent speed by varying the stator vane angles: point (a) represents the maximum pressure ratio possible without stall; points (b) and (c) represent the points of maximum and minimum weight flow; point (d) represents the point of maximum efficiency; and point (e) represents any arbitrary starting point at 100 percent corrected speed with safe settings of stator vane angles. The problem which the computer must solve is to find point (f), representing that stator vane schedule which gives the best overall balance of all factors and results in a gangable stator vane schedule.

It has been assumed that the compressor has been brought up to 100 percent speed in the automatic mode with the specified inlet pressure and that the stator vane angles and the pressure ratio have been varied to achieve a point (e) in Figure 4-1. It has also been assumed that the boundary conditions of maximum permissable blade stress and vibration, desired stress and vibration operating level, minimum acceptable weight flow, maximum weight flow, minimum desired efficiency, minimum acceptable stall margin and gangability conditions have been entered into the computer system. The other necessary starting conditions will be that the predicted nominal operating line has been specified and that the relative importance of stage loading, stress and vibration, weight flow, pressure ratio, and efficiency has been specified when they are below their acceptable values.

Figure 4-2 is an elementary block diagram showing the initial solution sequence. Action will be initiated by the master programmer which instructs the computer to seek a solution by using a blade angle routine. It should be sufficient at this point to define the initial blade angle routine as an organized method for determining the blade angles resulting in the least stress and vibration while minimizing stage loading unbalance. After this condition has been achieved, the solution will be checked to determine that the resulting compressor efficiency is not acceptable; then, an efficiency improvement routine will be entered to determine how

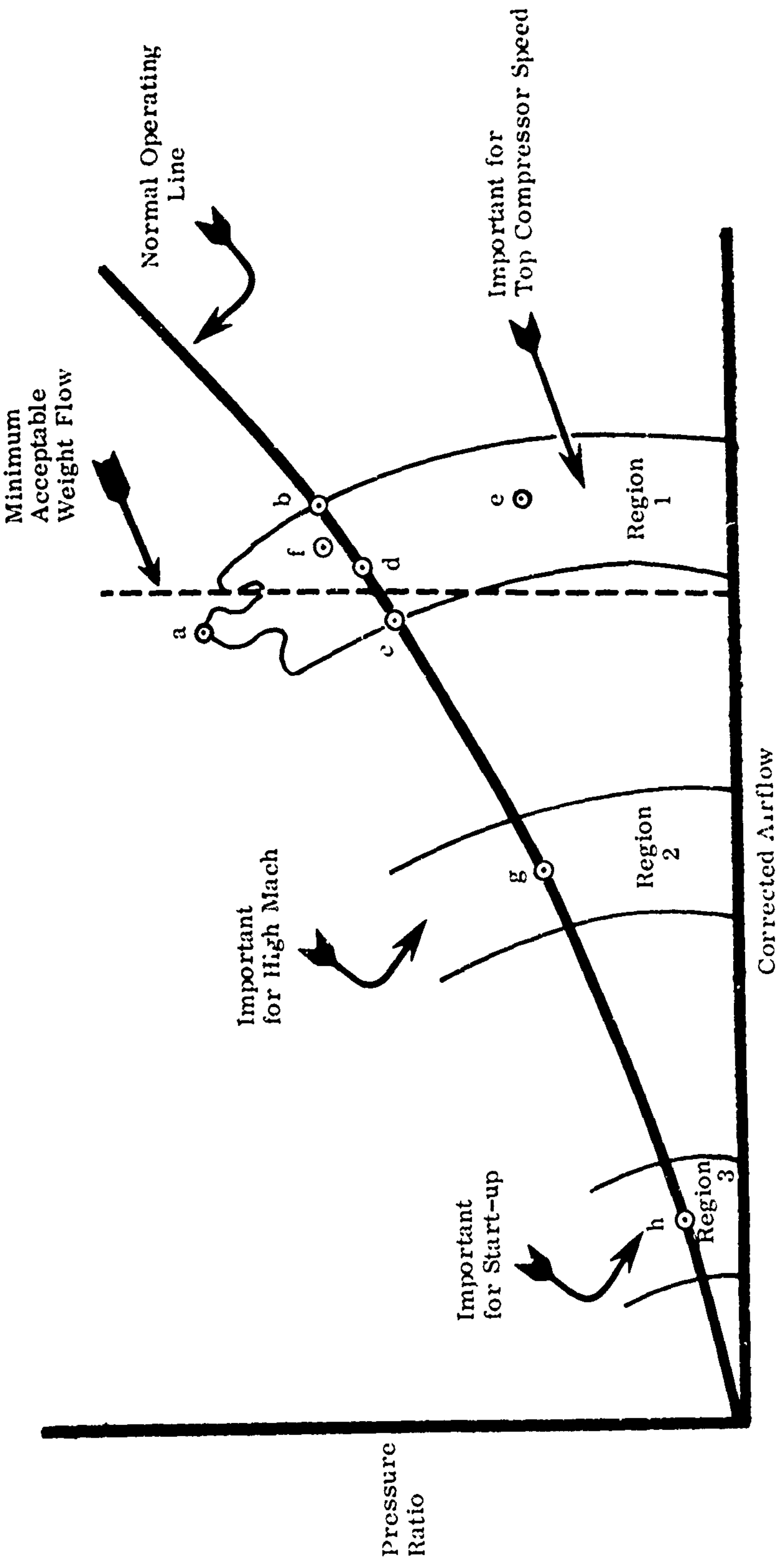


Figure 4-1. Compressor Map

The heart of the acquisition and control system for the Compressor Research Facility will be the digital computer which will serve as a valuable aid in compressor testing. Using the digital computer and associated peripherals, high speed data at rates up to 24,000 samples per second can be acquired and processed in real time or near-real time. The computer with its peripherals can convert this data to engineering units as necessary, display the data, print the data, and record it on discs or magnetic tape. Performance parameters can be computed in near-real time and displayed or recorded as necessary. Graphic plots of many of the compressor parameters can be constructed, updated, and displayed on command using video displays. These same plots can also be provided in hard-copy form using an X-Y plotter provided as a part of the computer peripherals. In the automatic mode, the computer will provide setpoint control for speed, inlet pressure, pressure ratio, compressor stator vanes, stage bleed, and test vehicle lubrication temperature. The computer will provide the computational capability necessary to perform all digital data reduction associated with compressor tests conducted in the CRF. The computer system will also have the capability to process general purpose scientific programs when it is not being utilized in compressor testing or data reduction.

Wideband analog tape recorders will be supplied as part of the computer and measurement system to record high frequency data. The wideband tape recorders will provide frequency responses up to 50 kHz for recording dynamic pressure, vibratory stress, and other high frequency data. Data recorded on analog tapes may be digitized at a "slowed-down" rate on an off-line basis utilizing the digital computer and its input peripheral equipment. Once digitized, this data can be processed by the more convenient digital techniques. A timing system will be furnished to supply a master time-of-day reference to all data records; this system will provide a digital code to the computer, an IRIG-B code to the analog tape recorders, and a slow time code to the strip chart recorders. The timing system will also have a translation mode enabling it to read the IRIG-B code from the analog tapes and translate to an equivalent digital code for the computer during the off-line conversion of analog data to digital data.

A flow measuring system will be provided to accurately measure steady state flow and (with some reduced accuracy) to measure transient flow up to the maximum response of the facility controls. The flow measuring system will be controlled from and displayed on the test conductor's console.

The Compressor Research Facility will be self contained insofar as data reduction is concerned. All foreseeable data reduction requirements associated with compressor testing may be satisfied using the hardware system provided for the CRF. The digital computer will be sized to provide the necessary resolution, storage capability, and speed to allow accomplishment of all digital data reduction. Reduction of analog data can be accomplished by digitizing it at a "slowed-down" rate and then performing the reduction using digital techniques. For "quick-look" purposes, a limited number of analog data channels can be "observed" using the spectrum analyzer or the oscillograph located on the dynamic data display status panel.

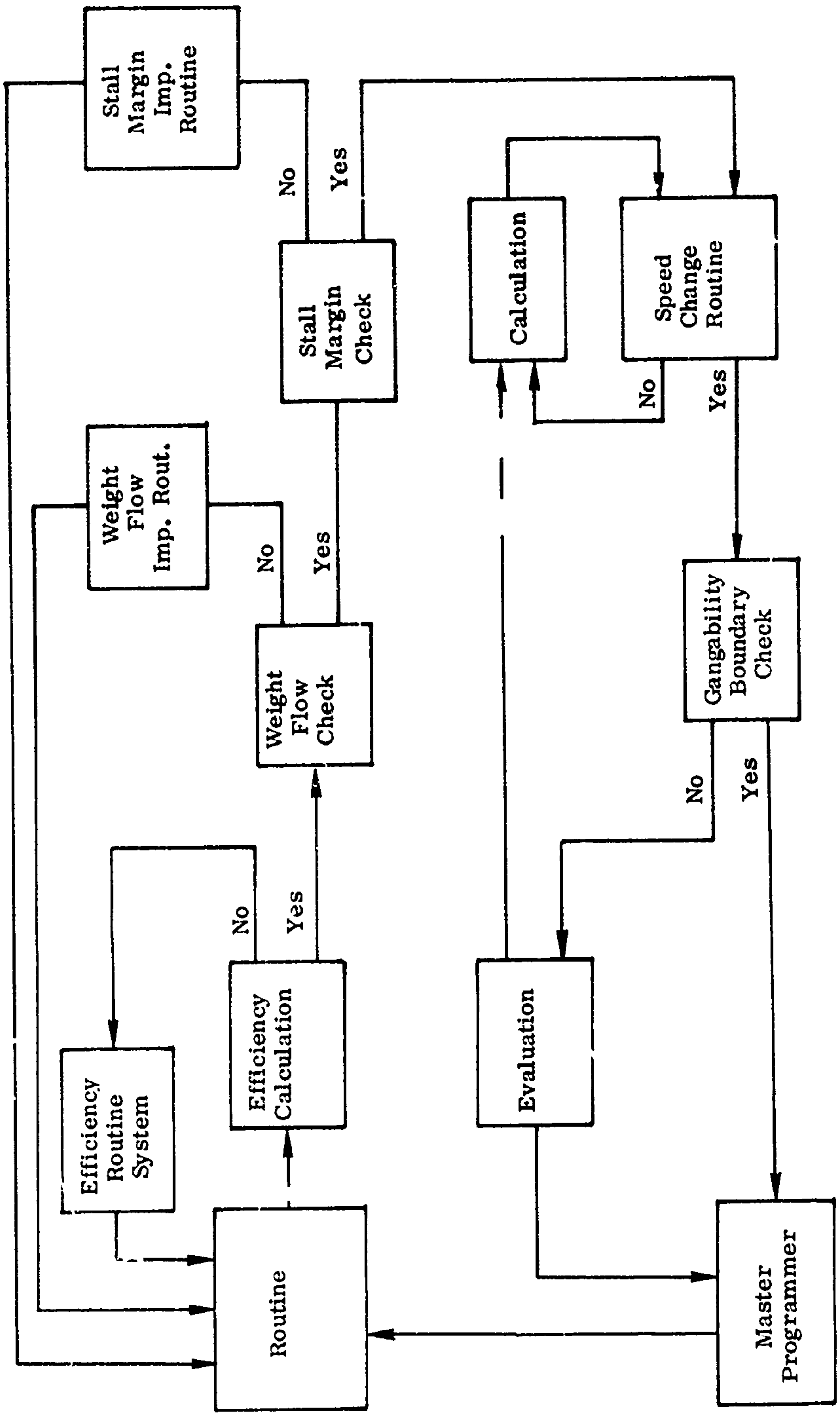


Figure 4-2. Initial Solution Sequence

the initial blade angle routine solution criteria must be modified to achieve satisfactory efficiency. This will define a blade schedule satisfying a modified initial criteria and also produce a satisfactory efficiency.

After this has been achieved, the blade solution will be checked against minimum desired weight flow. If weight flow is unsatisfactory, the modified initial solution criteria will be changed again until stress and vibration, stage loading, efficiency, and weight flow are within acceptable bounds. If the computer finds that no solution exists, it will signal the console of this condition. Assuming that a solution does exist, the computer will next check stall margin, iterating until an acceptable value is found.

At this point, the computer will have located a point (f) in Figure 4-1 within all specified boundaries; therefore, the blade angles associated with point (f) represent a possible solution.

After the blade schedule at point (f) has been established, the computer will attempt to reach point (g) in Figure 4-1 by varying speed and pressure ratio and holding a fixed blade schedule. Speed will be permitted to decrease until some specified boundary condition has been reached, then held constant. A minimum change of blade angle will be determined to permit the system to become unbounded and speed will be changed again. The various blade corrections will be checked for gangability and no gangability corrections will be accepted. The evaluation block will serve to specify the changes used in the blade calculations so that a gangable solution can be obtained. If no solution is found, the evaluation block will make recommendations to the master programmer block as to what course will probably yield a solution. If a solution is found, then the master programmer block will be signaled signifying that the next step in the routine can be made.

Because of the wide variation in the characteristics of the compressors which will be tested in the Compressor Research Facility, it is necessary that the computer solution technique be adaptable to effect maximum usage. While it may be possible to use one method of solution for all compressors, this approach may not result in the shortest cycle time. The ability of the computer to select the proper solution procedure for a particular compressor can add greatly to the overall savings. This ability of the computer to select the one solution procedure or combination of procedures giving the shortest time cycle based on its own experimentation is a form of machine learning. Of course, the computer will not devise its method of calculation, but it can be made to reorganize procedures introduced into its memory.

Some solution procedures which may be used are as follows:

- Greatest Gradient Method - The stage which exerts the greatest influence over the quantity to be varied is selected and changed until a boundary limit is approached or until some other stage becomes limiting.

- Linearizing - The effective initial change possible from each stage is determined by moving each stage a unit amount and noting the change in the dependent quantities. Each stage is returned to its initial position before another is checked. The per unit changes become coefficients in a set of linearized equations which can be solved by the computer.
- Higher Order Approximations - Equation coefficients are determined by methods similar to those used in linearizing but results are fitted to higher order equations.
- Emperical Equations - Equations used are determined from past experience on similar machines.

The computer may be programmed to solve the problem in any of the ways mentioned above as well as in other ways. For a particular machine and during a given portion of the solution cycle, it is probable that at least one of the methods available will result in the shortest cycle time. The ability of the computer to select the best solution method under the existing conditions is a necessary part of machine learning. The expansion capabilities are evident since as many solution methods as desired can be put at the disposal of the machine and may be added to the machine memory at any time without disrupting the previous solution program.

It should be recognized that the above example is but one isolated instance during one phase of the solution sequence. If similar freedom of choices are allowed to exist for all major points in the solution sequence, then, in reality, the computer is being allowed to determine its own optimum method of solution based on the information committed to memory. The first solution points will have the longest solution time while the machine is determining the best solution procedure.

4.1.3 STEADY STATE AERODYNAMIC TESTING

Many of the compressor tests required to evaluate an axial flow compressor including detail performance mapping, Reynold's number investigations, effect of stage bleed on compressor performance, stator schedule tolerance investigations, steady state temperature and pressure distortion, and stall line determination will fall in this category.

4.1.3.1 Detail Compressor Mapping

For this series of tests, the final gangable stator schedules and a partial compressor map will have been determined. The purpose of this testing will be to completely define a steady state compressor map. Typically, a compressor undergoing these tests can be stalled up to speeds of 75 percent but should not be intentionally stalled at higher speeds. Detailed mapping may either be accomplished in the automatic or manual mode. Because of the large number of data points recorded, however, and because enough data will have been acquired to at least partially determine the compressor characteristics by this stage of testing, the automatic mode of testing would appear to be more suitable. To perform detail mapping, data will normally be acquired along constant percent corrected speed lines. If more than one final gangable stator schedule has been determined, it may be necessary to develop the detail map with more than one stator schedule; however, any acquisition of data during detail mapping will be accomplished with an optimized stator schedule determined during earlier testing. Inlet pressure for the detail mapping tests will normally be maintained at atmospheric conditions. Deviations in this could result from an attempt to test a compressor which places the facility drive system in a horsepower limitation condition. If 100 percent speed cannot be obtained with the atmospheric inlet, the inlet pressure will be dropped to the point allowing detail mapping to approximately 108 percent of compressor corrected speed. The number of data points taken along each constant speed line will vary with the compressor under test. Also,the specified speed lines where data is being acquired may vary from test to test. In general, from 6 to 10 points will be taken along each constant speed line although this is not a fixed number and may vary as deemed necessary by the responsible design engineering personnel. The number of speed lines at which data will be acquired is also a variable. Normally, in detail mapping, data will be acquired at 30, 50, 60, 70, 75, 80, 85, 90, 95, 100, 105, and 107.5 percent corrected speed; however, this is only typical and not necessarily the number of points desired on each vehicle under test.

To illustrate the detail mapping procedure, a brief run through the actual operation will be described for a typical compressor.

Figure 4-3 is a modified performance map of the compressor. Assuming that all pretest preparation has been accomplished and an electrical drive has been started and brought to 50 percent corrected speed in the manual mode, the facility will be ready to be transferred to the automatic mode. The initial conditions for transfer preprogrammed into the computer system and set via the manual controls will be data point 1 as illustrated on the performance map. The data points are indicated by the numbers along the constant speed lines; thus data point 1 would appear as the data point on the operating line at the 50 percent corrected speed line. Prior to the test, a program will have been developed to direct the computer to traverse the paths shown on the constant speed lines in a predetermined manner.

In developing the computer program to perform the detail mapping tests described herein, it will be assumed that the decision was made that the machine would intentionally be stalled along constant speed lines up to and including 70 percent of corrected speed and above that data points will be acquired below the stall line and no attempt will be made to probe into the stall line. It will also be assumed that the decision was made that six points will be acquired along each constant speed line. At data point number 1, when the facility is transferred to the automatic mode, inlet pressure will be in the pressure control mode and set at ambient inlet pressure. Pressure ratio control will be in the pressure ratio direct mode be-

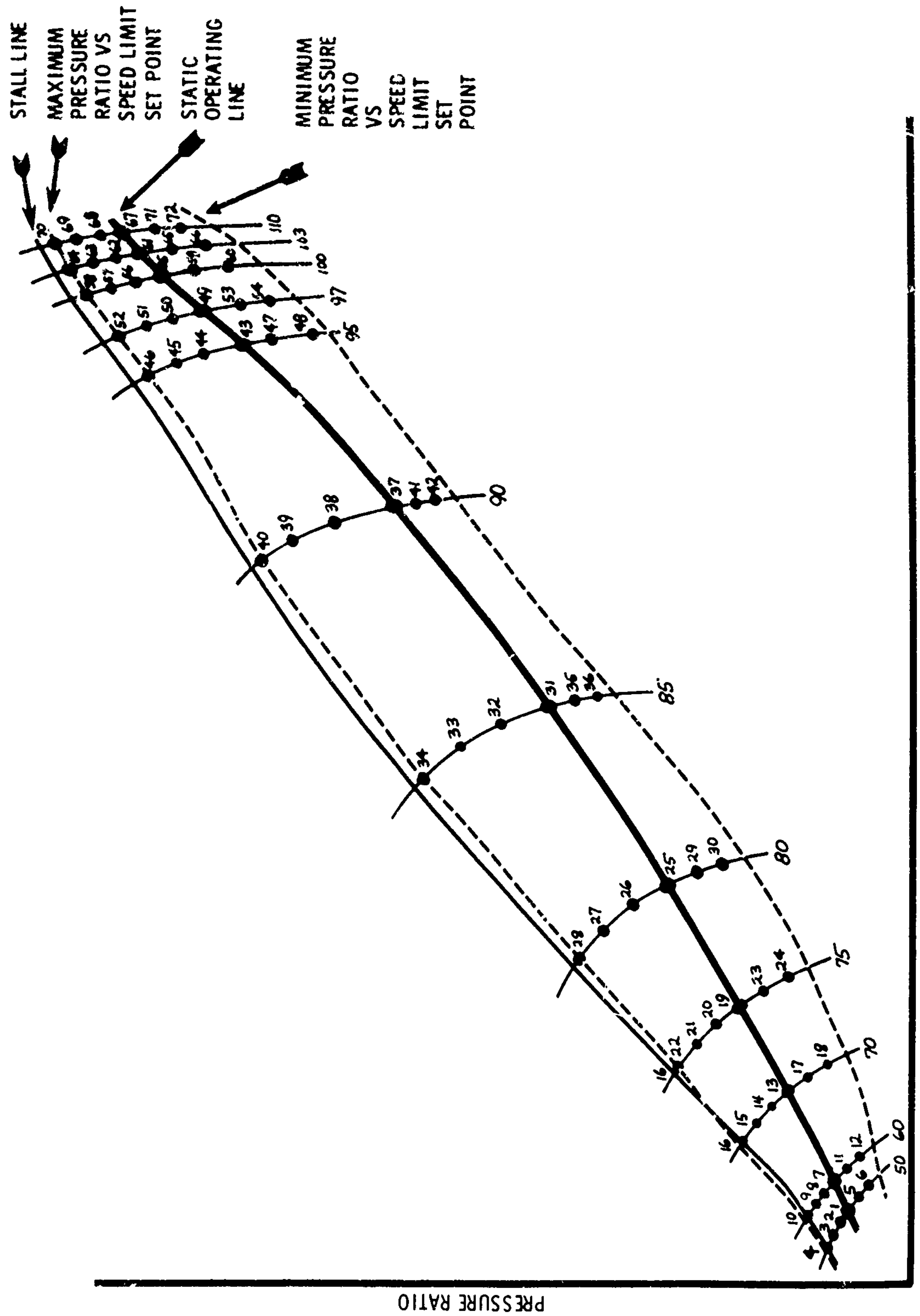


Figure 4-3. Typical Performance Map

cause pressure ratio will be controlled in steps along the constant speed line and not as a function of percent corrected speed. The minimum and maximum pressure ratio versus speed limit setpoints (represented by the dotted lines on the compressor performance map) will be set into the pressure ratio control system by the test conductor. The stator control and bleed control system will be in the function control mode; i.e., the function of bleed valve flow or stator angle versus speed will have been set by the computer to correspond to the desired stator schedule and bleed flow schedule. The test program already entered into the computer will also control data acquisition during the detail mapping tests. In this case, the high speed digital burst will be taken at each data point shown on the compressor performance map. The high speed burst will typically consist of a burst .5 seconds in duration with each measurement channel recorded on the digital system at an average rate of 50 times per second. Between high speed data bursts, data will be recorded on all channels at an average rate of 1 point per second per channel. This data is acquired primarily for monitoring, limit checking, and maintaining a status of all data channels between the high speed data bursts. All change of data scan rates will be accomplished by the computer per the preprogrammed plan. Analog data (vibratory stress, vibration and clearance measurements) will also be monitored on monitor scopes and recorded on analog tape recorders during the detailed mapping procedure. This data will be recorded at the slowest possible tape speed providing the required frequency response so that an excessive amount of magnetic tape will not be utilized during the test. Because of the large number of data points required, the detailed mapping tests are one of the more lengthy test series to be performed on a compressor.

After the facility is switched to the automatic mode, the computer will allow approximately one minute settling time before acquiring a high speed data burst. At the completion of a high speed data burst, the computer will issue a new pressure ratio setpoint, causing the pressure ratio to be set to data point number 2 along the constant speed line. After a one minute waiting time, another high speed data point will be acquired. As an option, in lieu of waiting a fixed length of time, i.e., 1 minute, to acquire a high speed data burst, the test can be programmed so the computer will monitor the flow meter output for a given stability criteria so that once the flow meter indicates stabilized, it will issue a command to acquire the high speed data burst. This procedure would minimize the time between data points and maximize data accuracy.

After the high speed data burst at data point 2 has been acquired, the computer will issue the necessary pressure ratio change in setpoint to move along a constant speed line to point 3 where a high speed data burst will be acquired.

Changing a pressure ratio from point 3 to point 4 and back to point 3 and acquiring data at point 4 will be accomplished differently because point 4 represents data at the stall line. Changing a pressure ratio from point 3 to the stall line will be accomplished as a series of pressure ratio iterations by the computer. The exact number of iterations and the methods of moving to the stall line will be predetermined and preprogrammed for a given vehicle when a performance mapping control program is devised. High speed data will be acquired (50 samples per second per channel average) continuously during iterations to the stall line. The change from point 3 to the stall line may be accomplished in ten or more iterations depending on the desired rate of approach to the stall line. If ten iterations are to be used, the computer will initiate the first pressure ratio iteration (the first tenth of the distance of the stall line), maintain a slight delay depending on the rate of traversing toward the stall line while it analyzes the data acquired during the first iteration, and make the decision to continue with the second iteration. The computer will issue the pressure ratio change for the second iteration and repeat the process. This will be continued until the stall line is reached. When the compressor goes into stall, the stall detection system will sense the stall and send appropriate signals to the pressure ratio control system, which in turn will cause the discharge valve to back off to a predetermined position at the maximum possible rate. When this discharge valve position is reached, the computer will move the pressure ratio back to the pressure ratio required to achieve data point number 3. The high speed data acquisition will be initiated prior to the iteration toward the stall line and continued through the stall and until the discharge valve backoff position is reached. When the backoff position has been reached and the computer has picked up pressure ratio control, the high speed data burst will be stopped and the one point per second per channel average data acquisition rate resumed. From point 3 the computer will issue the necessary command to move down the constant speed line to point 2 where another high speed data acquisition burst will be acquired. The computer will then move to point 1 and acquire a data burst and decrease pressure ratio down the 50 percent constant speed line to points 5 and 6 (where data points will be acquired). From point 6, the computer will issue the necessary command to move the pressure ratio back to point 5 for another data burst and then come back to the operating line (point 1). After returning to point 1, the computer will issue the necessary command to change pressure ratio control from the direct to the function mode.

Before test start, the pressure ratio versus speed curve representing the operating line will have been prestored in the computer and any speed change conducted while the pressure ratio control is in the function mode will cause the pressure ratio to track speed along the operating line. A speed change will be initiated to move the compressor from 50 percent corrected speed to 60 percent corrected speed. The pressure ratio will change in accordance with the function control and at 60 percent corrected speed; therefore, the pressure ratio setpoint would be at data point number 7 on the performance map.

At this time, the computer will issue the necessary command to change pressure ratio control from the function mode to the direct mode. Data will then be acquired at data points 7 through 12 by repeating the procedure used to acquire data at 50 percent corrected speed. In the same manner, data points 13 through 18 will be acquired at the 70 percent corrected speed point, and data will be acquired at the 80 percent through 110 percent corrected speed lines (except that the compressor will not be stalled at these percent corrected speeds). The computer will acquire data at all points to the last point which will be on the maximum pressure ratio versus speed limit setpoint and then traverse down so that two high speed data bursts will be acquired at each data point. In each case, the speed trajectory between corrected speed points will be traversed so that pressure ratio will track the operating line. At the speed where the drive system is no longer adequate to drive the compressor with an ambient inlet pressure, the inlet pressure setpoint will be changed to lower inlet pressure to where the drive system can continue the detail mapping process up to approximately 110 percent corrected speed.

4.1.3.2 Reynolds Number Investigation

One of the important considerations in axial flow compressor design is the ramifications of Reynolds number effect on compressor performance. In a typical two-dimensional performance map, the Reynolds number effect is not considered. Normally this map will reveal compressor characteristics with an ambient pressure inlet condition. To determine the effects on compressor performance of lower inlet pressure conditions, the tests described in this paragraph are required. The Reynolds number investigation consists of acquiring data along various constant speed lines at different inlet pressure conditions. This testing may be performed in the Compressor Research Facility either manually or automatically. Data is acquired in the same manner as in the detail mapping test and consists primarily of repeating the detail mapping procedure at selected constant percent corrected speed lines for several different inlet pressures.

An example of this type of test for the J79 would be to select the 100 percent corrected speed, the 95 percent corrected speed, and the 90 percent corrected speed as speed lines for which Reynolds number data will be acquired. Inlet pressures of 2, 4, 6, 9, and 12.5 psia and ambient inlet pressure are typical of those for which data may be acquired. The horsepower limitations of the drive system, however, may prohibit achieving ambient inlet pressure on many compressors. The procedure for acquiring data for Reynolds number investigations will be the same as used to acquire the data for the detail mapping test. First, the inlet will be set at ambient or as high as possible and data acquired along the constant speed lines. Then, the inlet pressure would be reduced to the next step and the procedure repeated until data has been acquired at all inlet pressures desired.

4.1.4 SPEED TRANSIENTS

The CRF will have the capability to run a controlled speed transient and acquire data during the speed transient in either the automatic or manual mode, although this capability does not exist in any current compressor test facilities. The maximum speed possible to attain in a speed transient for a given test vehicle is a function of the horsepower required to drive the vehicle which is in turn a function of the size of the vehicle with respect to pressure ratio and mass air flow. The maximum acceleration and deceleration rates for various loads are discussed in more detail in Volume III. During speed transients, virtually all facility controls must be modulated to maintain the desired setpoints. The inlet valve must be modulated to maintain a constant inlet pressure during a speed transient and the discharge valve must be modulated to maintain the desired pressure ratio which will generally be tracking speed through some functional relationship. During the speed transient, stator vanes must be moved as a function of speed in those compressors with movable stator vanes. Likewise, in some vehicles, stage bleed valves must be modulated as a function of compressor corrected speed.

To run a speed transient in the CRF, the facility will first be started and brought to the speed where the transient is scheduled to start. At this point, the speed transient may be run either under computer or manual control. The trajectory the pressure ratio is to follow with the change in speed will be entered into the main function generator on the pressure ratio/discharge valve position control panel. The required stator and bleed valve schedules will be entered on the function generators on the stator vane/stage bleed control panel, and the proper inlet pressure setpoint will be set on the inlet pressure/valve position control panel. It must be noted that horsepower limitations and/or pressure ratio limitations of the vehicle will permit only segments of the vehicle speed operating range to be covered during a single speed transient with one gear ratio or with one fixed inlet pressure. This must be considered when an inlet pressure is selected for a speed transient test. The termination point of the speed trajectory and the rate of change of speed for the speed ramp will be entered into the speed control system at the test conductor's speed control panel. Before the initiation of the speed ramp, pressure ratio and stator vane/bleed controls will be placed in the function control mode.

The speed ramp will be initiated by depressing either the ACTIVATE A or ACTIVATE B control on the test conductor's speed control panel. The speed ramp will continue until the termination point has been reached, then automatically terminate. The pressure ratio will automatically track the predetermined schedules and the inlet valve will be modulated during the speed transient (either an acceleration or a deceleration speed ramp depending on the purpose of the test) to maintain a constant inlet pressure. In some tests, it may be required that the compressor accelerate rapidly to some speed and then decelerate rapidly to the original starting point where both the acceleration and deceleration trajectories will be controlled from a pressure ratio standpoint. This may be accomplished in a manner similar to the speed ramp discussed above. In this case, the acceleration portion will be run with a given table loaded in the pressure ratio function generator and the deceleration portion with another if the trajectory used to go from the high speed back to the low speed is different from that traversed going from the low speed to the high speed. Stator vane schedules, however, would probably remain the same for both the acceleration and deceleration portions of the speed transient.

4.1.5 DYNAMIC TESTS

The dynamic tests referred to in this paragraph include tests associated with inlet stability investigations and other problems caused by high dynamic temperature, pressure, and velocity fluctuations at the compressor inlet. Both the effects from inlet distortion and turbulence are included in this type of test.

The adverse effects of inlet flow distortion on turbofan/turbojet compressors have long been recognized as important engine development considerations. Regions of flow separation and/or shock wave boundary layer interactions can cause nonuniform distribution or distortion of the total pressure and velocity entering the compressor. Engine operational problems, including [illegible]essor stall and structural failure, can result when compressor inlet distortion exi[illegible]s. [illegible]ens located forward of the compressor have been an acceptable method to produce steady state flow distortion for simulated altitude testing of jet engine compressors in compressor test facilities. At subsonic and low transonic flight speeds, satisfactory simulation of flight performance has been obtained; however, results of recent tests indicate that unsteady or turbulent flow characteristics of supersonic aircraft inlet ducts are equally important compressor design considerations. Based on the difficulties experienced with some current weapon systems, it is apparent that the Compressor Research Facility test techniques with controlled compressor-inlet flow conditions can be used to further understand compressor-inlet matching problems and to shorten compressor development cycle time requirements. As flight speed, maneuverability, and engine performance demands are increased, compressor - inlet compatibility problems become more critical.

Recent investigations in compressor test facilities have generally been limited to work with random frequency and amplitude flow disturbances characteristic of flow conditions in a high speed aircraft inlet duct. Representative of these investigations are those that have been conducted at the Arnold Engineering Development Center using engines rather than compressors. Considerable effort is required to define the flow characteristics which cause unacceptable degradation of compressor performance and stability. Statistical analysis methods are sometimes used to characterize inlet flow conditions at which compressor performance degradation and/or stall occurs. Complete testing of a turbofan/turbojet compressor requires that the sensitivity of the compressor to specific inlet flow properties be determined. For analytical purposes, inlet turbulence may be described by the use of combined random and discrete frequency wave forms. The sensitivity of compressor performance to random pressure fluctuation has been investigated to some success at Arnold Engineering Development Center by correlating time dependent inlet pressure distortion (turbulent flow conditions) with steady flow inlet pressure distortion. The results of these investigations indicate that the instantaneous inlet distortion of the turbulent flow may be considered to be essentially the same as steady state distortion when the instantaneous flow patterns exist for a finite length of time (on the order of the time period of one compressor revolution). Total pressure distortions which exist over this length of time (averaged to remove extreme peaks) are correlated using standard steady flow compressor inlet distortion parameters.

Another analysis method considers the effect of the compressor frequency response to the inlet pressure oscillations of the steady phase shift of a discrete frequency pressure fluctuation through the compressor. The results of this analysis indicate the probability of critical discrete frequencies which, as a result of the phase shift, may result in stage or stage group pressure ratios exceeding the stall limit. The sensitivity of compressor performance to discrete pressure fluctuations, however, has not yet been experimentally established over an extended frequency range. A discrete frequency pressure fluctuation generator which produces very low inlet pressure distortion and little random disturbance is needed as a tool to determine if jet engine compressors are sensitive to simple time variant pressure fields or are sensitive only to "steady state" total pressure distortion.

To accomplish the tests and experimentation required to determine the significance of random frequency and discrete frequency turbulence, it is necessary that certain provisions be made in the Compressor Research Facility. Hardware must be provided which can generate the necessary pressure fluctuations. This hardware will not be provided by the CRF contracter; however, provisions for installing this hardware in the CRF test section will be a consideration during the Phase II design of CRF hardware. A "clean inlet" will be provided to allow for turbulence generators to be installed in the facility. Basically, three types of turbulence generating devices are currently in use or being considered for this type of dynamic test, including a rotating screen, a random turbulence generator using a venturi with a movable centerbody, and a discrete frequency turbulence generator which utilizes a rotor and stator arrangement to generate discrete frequency pressure pulses. The rotating screen is a large screen with the appropriate mesh size which is placed in front of the compressor inlet. This screen is rotated 90 degrees at a time so that the required turbulence is distributed in an appropriate manner around the compressor inlet. The screen is rotated, then a data point is taken. The screen is rotated again and another data point is taken, etc., with the process continuing until the required data has been recorded. Figure 4-4 is a diagram of a random turbulence generator utilizing a venturi with a movable centerbody to create various random turbulence conditions at the compressor inlet (successfully used at the Arnold Engineering Development Center). This generator would be installed in the facility near the compressor inlet.

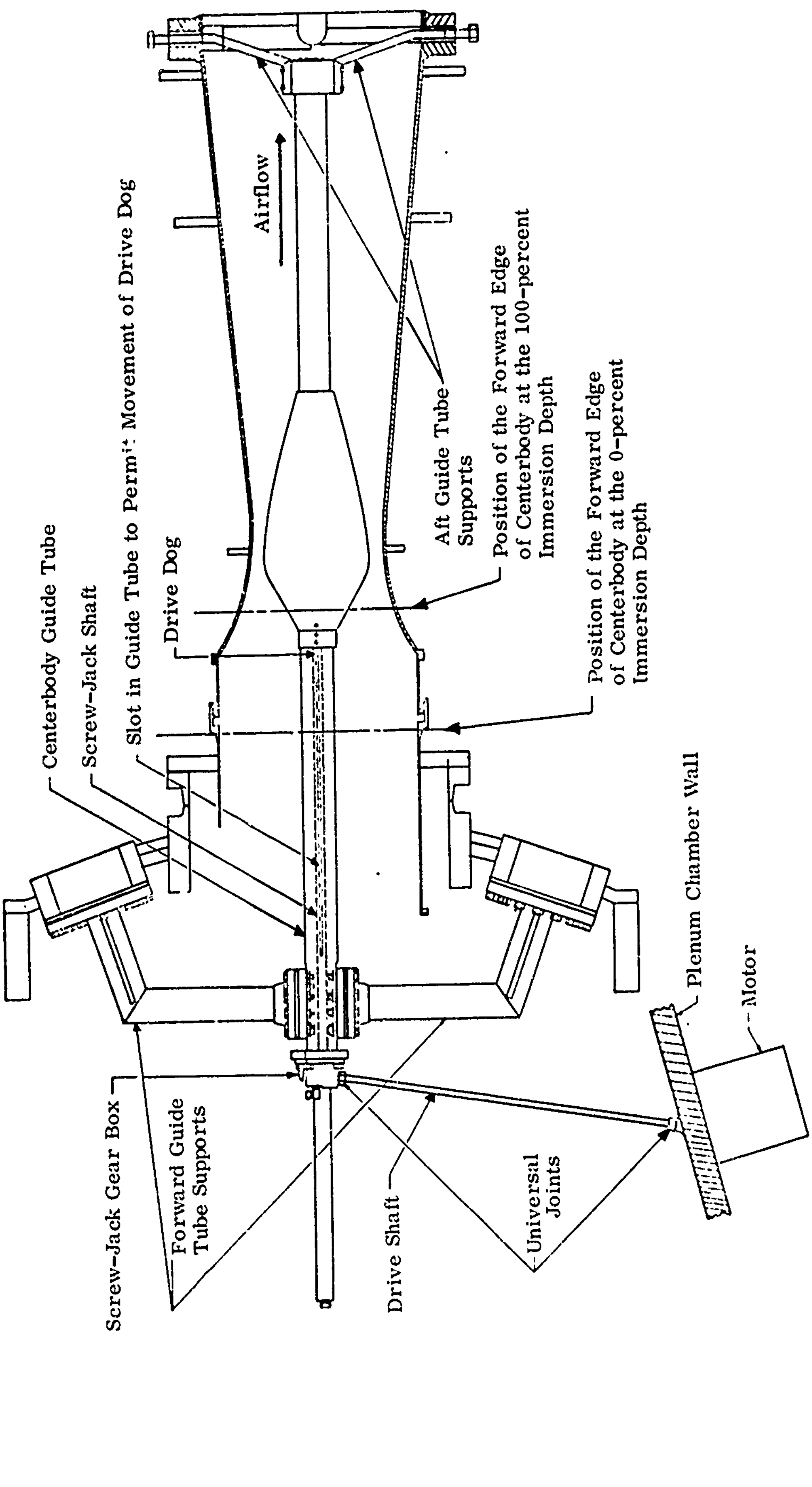


Figure 4-4. Turbulence Generator

The appropriate controls would be included in the installation to allow the centerbody to be moved forward or backward to generate the required random turbulence.

Figure 1-5 is a photograph of the discrete frequency generator currently under development at the Arnold Engineering Development Center. This generator is designed to provide discrete frequency pressure pulses at the inlet of the compressor. It is comprised of a rotor which rotates between two sets of stators. The rotor and stator arrangements are installed in ducting near the inlet to the compressor. The frequency of the pressure pulses are varied by varying the rotational speed of the discrete frequency generator rotor.

Other methods currently in use at some test facilities to generate pressure and temperature fluctuations at the compressor inlet and in some cases at the compressor discharge include:

- Injection of hot or cold gases at the compressor inlet
- Addition of liquid gas at the compressor inlet
- Ignition of an explosive charge either at the compressor inlet or at the compressor discharge

Conceivably in the future additional methods to generate pressure and temperature fluctuations at the compressor inlet and/or discharge will be developed. To provide for this, the compressor inlet section of the test chamber will be left as free of obstacles as possible to permit easy installation of pressure and temperature distortion generation devices.

A dynamic test will be run essentially at a facility steady state condition. The dynamic pressure fluctuation and temperature fluctuations at the inlet or discharge will be of a much higher frequency than the response of the control facility systems. Typically, to conduct a test where turbulence is generated at the inlet, the facility will be started and brought to some point on the compressor performance map. The turbulence generator hardware will then be set for the required conditions. A high speed data burst will be acquired to measure the steady state aerodynamic and aeroelastic parameters of the compressor and, at the same time, the dynamic pressure or temperature data will be acquired using wide band tape recorders.

The turbulence generating device will then be moved to a new condition (a new discrete frequency if the device is a discrete frequency turbulence generator or a new screen position if the device creating turbulence is a rotating screen). The facility controls will all remain with the same setpoints. At the new condition, another high speed data burst will be acquired using the digital acquisition and the wide band tape recorders will continue to record dynamic data. This procedure will be repeated until all conditions of turbulence have been investigated at the particular point on the compressor performance map. At that time, the facility will be adjusted to a new point on the compressor map and the procedure repeated to acquire the dynamic data at this point. This will be repeated until the test has been finished.

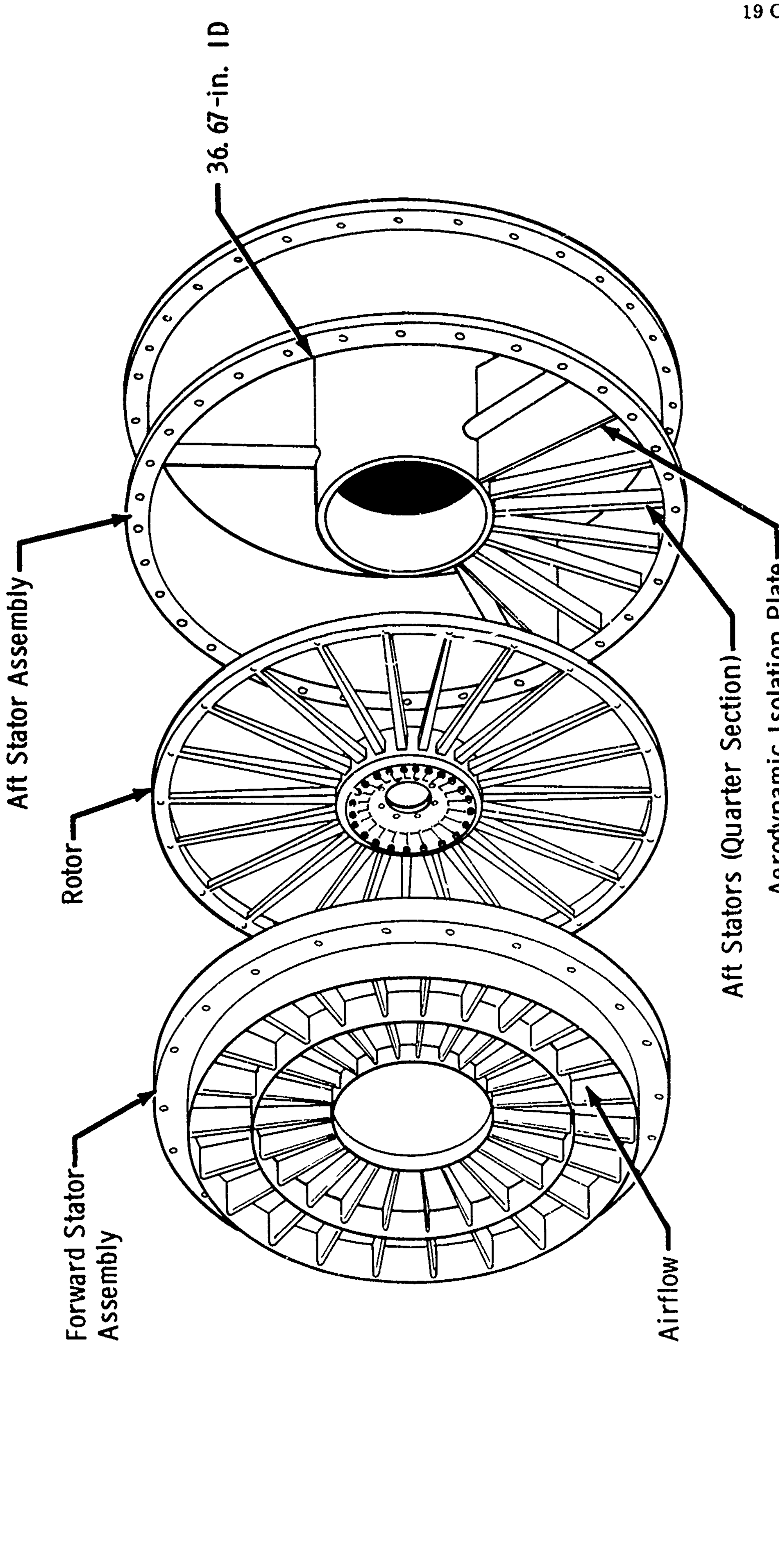


Figure 4-5. Discrete Frequency Generator

If, at some future date, it is required that a dynamic test be conducted under complete computer control, it would be necessary only to modify the system so the computer could provide the setpoint control to actuate the turbulence generating devices. Once this is accomplished, the automatic test may be conducted by preprogramming the conditions and the points of interest into a control program and then running this program under automatic control. The computer will then provide the necessary setpoints to move the facility controls to the proper setpoints and also provide the necessary setpoints to the turbulence generation devices to cycle through all conditions of interest at each point on the performance map preprogrammed into the control program. Computer steps will be similar to those discussed in conjunction with automatic control of steady state mapping in paragraph 4.1.3 of this volume. Once again, it should be pointed out that no turbulence or temperature fluctuation generating devices will be provided as a part of the hardware procurement under the initial CRF contract.

The acquisition of high frequency pressure data requires the use of high response pressure transducers. Currently, transducers are produced by Kulite which have the necessary frequency response, but the accuracy of these transducers is not as good as desirable to acquire data in this type of test. Typical accuracies associated with Kulites are ± 10 percent of full scale. Dynamic pressure data acquisition is discussed in detail in Volume V. The remote manual controls associated with turbulence and pressure distortion generating hardware as well as with temperature fluctuation generation hardware will be located on the test conductor's console, along with the display necessary for the test conductor to monitor the condition of these hardware items.

4.2 DUAL SPOOL COMPRESSOR TESTING

The capability to test a dual spool compressor in the CRF will not be provided with the initial CRF configuration (System I) even though the ability to conduct such tests is necessary in a state-of-the-art compressor research facility. The System III configuration under consideration will provide this capability. It is recommended in Volume I of this report that provisions be made to expand to the dual spool configuration (System III) in the initial CRF configuration, allowing expension to the dual spool testing capability at minimum cost at some later date. The development of the augmented turbo fan engine with dual spool compressors has revealed certain problems with respect to the maintenance of adequate engine stability across the operational spectrum required by current aircraft weapon systems concepts. These weapon systems concepts are generally structured to place a premium on excellent performance at other than a single point. The integration of the weapon system also requires that this performace be achieved in minimum weight. The requirements for adequate performance, absolute stability, and minimum weight are often not compatible, and particularly not when the requirement for transient excursions of the engines and for imposition of maldistribution of the flow field entering the engine are considered. The ultimate goal of the dual spool compressor test facility is to provide methods to predict and verify the performance and stability of dual spool compressors and compressor-fan combinations. Testing of the individual components of a dual spool compressor is not adequate in itself to determine the operating characteristics of the combination. Therefore, dual spool compressor tests which simulate as much as possible the operating environment anticipated when the compressor is operating in an engine configuration must be utilized. Several types of tests necessary to achieve the goals of a dual spool compressor test program are as follows:

- Steady state performance mapping of the tandem units with no externally or internally imposed constraints such as pressure distortion at the inlet, speed mismatch due to engine acceleration/deceleration, etc. Since these functions make the definition of the combined performance maps "with combined stall line" difficult, it is first necessary to generate steady state performance maps without the imposed constraints.
- Tests where mismatch of the speed ratio relationship is entered into the system intentionally to define the range of speed mismatch and bypass ratio change which can be tolerated by the compressor over its operating range and still retain the defined performance and stability criteria.
- Inlet distortion tests in a combined unit. These tests are the most difficult from which to segregate the test results because they can encompass rotating screens as well as time variant distortion at the face of the low pressure unit and discrete frequency and pure turbulence distortion conditions. The object of these tests is to derive an analytical method to account for and predict the performance and stability of the dual spool compressor under different flow turbulent and distortion conditions. Indications from operational advanced development experience are that past methods of stability/performance accountability within the dual spool compressor are inadequate for the dynamic performance of distorted inlet cases.

This implies that the testing and mapping procedures for the isolated units of a dual spool compressor tend to be misleading. Proper accountability of the interactions between the two spools is mandatory for proper definition of the stability of the dual spool compressor, hence, the requirements for a dual spool compressor test facility. The turbo fan engine presents a problem in compressor performance and stability accountability. The fact that the fan flow is exhausted into two separate throttling areas presents a situation requiring a different approach to compressor analysis and test procedures. These two separate throttle areas allow the detailed radial performance of the fan staging to differ radically from the performance of the staging when the flow is exhausted into a single throttle area. The existence in a mixed flow engine of a dynamic throttling area downstream of the core flow and bypass route of the fan discharge and the dynamic throttling downstream of the fan tip flow pass increases the complexity of the problem. The core compressor and the mixer region half of the turbulence section are the dynamic throttling areas. The core compressors downstream of the fan routes are contributory factors in a dynamic throttle area between the fan tip and mixer region. Because core compressors have stability limits associated with themselves, the problem is compounded. The dual spool testing of the compressor system with augmented mixed flow turbo fans is an order of magnitude more complex than the isolated unit testing of the individual components. Many permutations and combinations of tests can be conducted on a dual spool rig to determine the performance and stability characteristics of a dual spool compressor. The three basic types of tests outlined above are broad categories and can in turn be subdivided in many ways.

The dual spool compressor is a candidate then for all three broad categories of compressor tests within the capability of the CRF (steady state tests, speed transients, and dynamic tests). From an operational philosophy standpoint, the actual operating philosophy associated with a dual spool CRF configuration will be similar to that associated with the System I configuration. The speed control system must be expanded to include the capability to control speed of the dual drive system; functionally, however, both speed controls would be similar and require the same operating philosophy. Two discharge valves must be provided to account for the dual discharge flow paths The pressure ratio and bypass ratio will be maintained by modulating the discharge valves in both flow paths using control similar to those now found on the pressure ratio/discharge valve position control panel provided as part of System I. Stator vane and stage bleed controls for the dual spool configuration will not change from those required and provided as part of the System I configuration. Likewise, inlet pressure controls operating philosophy will be similar for both the dual spool and single spool closed cycle facilities.

SUPPLEMENTARY

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13. ABSTRACT

The Compressor Research Facility Rig 4 Project Analysis Report is contained in seven (7) parts, as follows:

Volume I	- Summary and Recommendations (Includes Abstract of Entire Report, and References)
Volume II	- Test and Operating Philosophy
Volume III, Part A	- Facility Systems and Services, Sections 1, 2, 3, and 4
Volume III, Part B(1)	- Facility Systems and Services, Section 5, and Appendixes A through I
Volume III, Part B(2)	- Facility Systems and Services, Appendixes J through M
Volume IV	- Facility Control System
Volume V	- Computer and Measurement System

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Computer Controlled Compressor Testing						
Steady State Tests						
Speed and Pressure Ratio Transients						
Dynamic Tests						
Operating Modes						
Open Cycle Compressor Testing Facility						
Closed Cycle Compressor Testing Facility						
CRF Personnel Requirements						
Test Planning & Documentation						
Off-Line Calibration and Maintenance Philosophy						
Facility Controls						
Pretest Requirements						
Facility Startup						
Single Spool Fan and Compressor Testing						
Dual Spool Compressor Testing						