ETS-1 CONTROL POINT GENERAL INDOCTRINATION COURSE

VOLUME TWO

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MASTER

NERVA Test Operations

Nuclear Rocket Development Station
Jackass Flats, Nevada

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ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION X
SYSTEM CONTROL HARDWARE

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A. REMOTE OPERATED VALVES

1. General. The ETS-1 facility is basically a vast complex of pipe, dewars and valves. Because of the hazards involved in handling some of the fluids, remote operated valves are used extensively. The original intention during design was to use pneumatic actuators for all of the remote operated process valves. During the facility activation phase it became obvious that the basic response of the cooldown control valves was insufficient. Modifications were initiated in late 1966 to convert these actuators from pneumatic to hydraulic.

This study guide covers only the remotely operated valves in a general sense and specific descriptions of individual valves are not included.

2. Valve Types. Two types of valves are in common use, the gate valve and the globe valve. The shutoff method is the basic difference between these two types. The gate valve uses a guillotine blade for shutoff, thus the flow impinges upon only one side of the blade. The globe valve uses a disk or plug that seals against the valve body, thus flow is around and under the disk or plug.

Globe valves are by far the most common, and are further classified by the valve body shape. Figure X-1 is a sketch of the more common patterns.

In general, globe valves require a higher pressure drop to produce the same flowrate as gate valves. Table X-1 lists the various types of valves and indicates the resistance factors that may be expected with each type.

Some of the advantages of the globe valves over the gate valves are:

- a. Manufacturing cost
- b. Shorter stroke
- c. Upstream pressure utilized to assist in sealing
- d. Flow characteristics easily altered by changing trim
- e. Low repair costs

TABLE X-1

RESISTANCE VALUES FOR VARIOUS TYPES OF VALVES

<u>VALVE TYPE</u>	<u>RESISTANCE FACTOR</u>
Gate Valves	1
Globe Valves	
Conventional	30
Y-Pattern 45°	11
Y-Pattern 60°	13
Angle	13

3. Valve Ratings. The ratings assigned to valve bodies are related to the valve pressure class, and the rating is generally formed into the valve forging. Two classes are in use in the valve industry: MSS, Manufacturers Standards Society, and ASA, American Standards Association. For all practical purposes the ratings are essentially the same. Table X-2 lists the common classes and the ASA ratings at 100°F, 900°F, and the recommended hydrostatic test pressure.

The class refers to the acceptable working pressure at 900°F steam. At lower temperatures the acceptable working pressure is much higher. Examples of this are the 1500 psi class valves used in the tank farm area. These valves actually have an acceptable working pressure of 3600 psi at ambient temperatures.

TABLE X-2

VALVE RATINGS

<u>CLASS</u>	<u>ASA RATING @ 100°F</u>	<u>ASA RATING @ 900°F</u>	<u>HYDROSTATIC TEST PRESSURE</u>
150	275	---	425
300	720	300	1100
400	960	400	1450
600	1440	600	2175
900	2160	900	3250
1500	3600	1500	5400
2500	6000	2500	----

4. Valve Trim. There are basically three types of valve trim used at ETS-1. They are: The Linear Plug, Percentage Plug and Semi-throttle Plug. Figure X-2 is a sketch of the plug trims. Figure X-3 compares the flow versus valve lift for these different plug trims.

a. Linear Plug. The linear plug is designed to provide equal flow area per increment of valve movement. Thus at 50% open the valve passes 50% flow. This is only true, of course, when the upstream and downstream conditions are held constant.

The linear plug valve is generally used where flow must be controlled over a broad region. This plug is particularly desirable for automatic control applications since the gain of the valve is essentially constant. Several of these plug forms are used, particularly for control purposes. PCV-471 is a typical example of this type plug.

b. Percentage Plug. The percentage plug is designed to provide a constantly increasing rate of flow per increment change of valve lift. The primary advantage of this type plug is the ability to control low flows with a high degree of precision while still maintaining the ability to control large flowrates.

An excellent example of a valve with a percentage plug is PCV-251 which is the control valve in the gaseous hydrogen cooldown system. This valve is used primarily to control very low flows that may range from .25 to 2 pps GH_2 or GN_2 equivalent flows. Upon occasion, however, this valve is required to produce massive flows ranging up to 25 pps GH_2 for short durations. The percentage plug valve is ideally suited to this application. Although the percentage plug valve has an increasing gain toward the full open position, this is overcome, to a certain extent, in most applications because of the decrease in pressure drop across the valve as the flow increases.

c. Semi-Throttle Plug. The semi-throttle plug is identical to the linear for the first 20 percent of its lift; at this point the flow increases very rapidly. The purpose of this type valve trim is to reduce the fluid hammer and shock when the valve is at the near-closed region.

Semi-throttle plugs are not used for flow or pressure control. Typical applications of this type valve are RSV-201 and RSV-78. These valves are the main shut-off valves for the GN_2 and He cooldown system, respectively. Since these valves have binary control, open or closed, and are used in some cases initiating or stopping flow, the semi-throttle plug form is chosen.

d. Quick-Opening Plug. The quick-opening plug allows essentially all of the flow to pass after the valve lift has moved only a very short distance. This plug form is desirable where high flows are required as soon as possible. Unfortunately, this plug form is undesirable for quick shut-off of flow since they are subject to excessive fluid hammer, particularly where flow is over the plug. The quick-opening plug is not used at ETS-1.

e. Valve Trim Applications. Most of the valves used at ETS-1 are capable of having both the form and basic size of the trim changed. The selection of the trim form is usually based upon the application.

For gas system control valves it is desirable to use a linear plug for control. Valves used to control gas normally operate in the sonic region, thus the rate of flow, assuming the temperature is constant, is directly

proportional to the flow area as shown by the following general equation:

$$\dot{w} = K A P$$

where:

$\dot{w}$ = Flowrate

K = Constant

A = Valve flow area

P = Upstream total pressure

From the above equation it is obvious that the linear plug will provide the widest range of uniform control.

Liquid systems generally use percentage type valves since the equation governing flow is:

$$\dot{w} = K (P_1 - P_2)^{\frac{1}{2}} A$$

where:

P_1 = Upstream pressure

P_2 = Downstream pressure

For liquids, the flow is still directly proportional to valve flow area; however, as flow increases the difference between P_1 and P_2 decreases. To achieve a linear relation between valve lift and flow it is desirable to increase the valve area exponentially rather than in a linear fashion.

5. Solenoid Valves (SV's). Solenoid valves are electrically actuated valves that are used for control of larger valves or for binary control where only low flowrates are required. All of the RSV's at ETS-1 are actuated through four-way solenoid valves. Figure X-4 is a sketch of a typical solenoid valve operating a double acting pneumatic actuator. Solenoid valves are particularly desirable from the safety standpoint since they always return to the SAFE position (open or closed) upon failure of power. Some of the applications of solenoid valves at ETS-1 are:

- a. RSV actuation using four-way solenoid valve
- b. Venting pressure transducers using three-way solenoid valve
- c. On/Off control of propane using two-way solenoid valve

6. Remote Shutoff Valves (RSV's). RSV's are the most common type of remote valve used at ETS-1. These valves utilize a binary control, i.e., they are either open or closed.

The majority of the RSV's are globe type valves utilizing semi-throttle trim. Figure X-5 is a typical balanced plug design which is used primarily in the cryogenic systems. Figure X-6 is a typical unbalanced plug which is used in the ambient gas systems.

7. Pressure Regulating Valves (PRV's). Pressure regulating valves are used extensively for breaking down high bottle pressure to the desired working level. Although most of the PRV's are preset, many are equipped with a remote loading feature.

Figure X-7 is a sketch of a typical PRV equipped with remote loaders. The regulator operates on a balance principle. The outlet pressure, which is then valve control pressure closely follows the pressure established in the dome volume between the regulating diaphragm and the relief diaphragm. As the dome pressure is increased, the main valve opens allowing only sufficient flow to raise the outlet pressure to a corresponding level. Conversely, a decrease in dome pressure will cause the then higher pressure in the outlet system to lift the relief diaphragm and vent off the excess pressure.

The dome pressure setting is established by manipulating two small poppet valves actuated by solenoids. The LOAD poppet valve receives its supply internally from the main inlet connection to the regulator. Gases discharged from the VENT poppet, as well as gas from the main outlet relief system, can be piped away. When both solenoids are energized, gas enters through load valve L to check valve C which unseats, admitting pressure to the dome. The loading rate is predetermined by fixed orifice 1. Orifice 2 allows a small bleed only during dome loading and serves to prevent momentary overpressure.

When the desired control pressure is reached, the load solenoid is de-energized and the dome pressure is "locked-in" and will remain so indefinitely or until a change in control pressure is desired.

De-energizing the VENT solenoid will reduce the dome pressure and hence the outlet or control pressure. When the vent solenoid remains

de-energized, the dome pressure and the outlet pressure drop to zero, shutting off the regulator as well as the larger dome regulator which it may be controlling. Thus, in case of electrical failure the regulator will fail safe in the closed position.

Should the outlet pressure tend to exceed the set pressure, the main regulating valve poppet will remain tightly closed and the pressure unbalance imposed on the control side of the relief diaphragm will unseat the relief valve and excess outlet pressure will be discharged through the vent connection.

Typical applications of these PRV's are the pressurization valves for the LOX dewar and LN_2 dewar. PRV's are also used extensively for reducing purge gas pressure.

8. Analog Valve (PCV's and FCV's). Analog valve utilizes the same valve bodies as the RSV's. The only difference between these valves is the plug trim and the actuator. The analog valves have the capability of being positioned anywhere between full open and full closed.

B. ACTUATORS

Actuators are the mechanical motor for positioning the valve plug. Three types of actuators are used at ETS-1: solenoid, pneumatic, and hydraulic. The solenoid actuators are basically electrically operated. The pneumatic and hydraulic are the same except for the working fluid. Pneumatic actuators use a compressible fluid while the hydraulic actuators use an incompressible fluid. The dynamic response of the pneumatic actuators is much slower than the hydraulic.

1. RSV Pneumatic Actuators. Figure X-8 is a typical pneumatic actuator. All of the RSV actuators are equipped with a bias spring. The purpose of this spring is to position the valve in the event of a pneumatic supply failure. The pneumatic actuators are rated at a working pressure of 500 psig.

2. PCV's and FCV's. The actuators for PCV's and FCV's are essentially the same as for the RSV's. The primary difference is in the auxiliary equipment for regulating the actuator. Two types of analog actuators are used; hydraulic and pneumatic.

a. Hydraulic. The hydraulic actuator is nothing more than a cylinder and piston for converting the hydraulic pressure into a mechanical movement. The servovalve is the component that makes the analog actuator unique. All of the analog hydraulic valves obtain their hydraulic supply through a servovalve. The servovalves can be thought of as variable four-way solenoids. These servovalves are controlled by current supplied by the servoamplifier. The block diagram is shown in Figure X-9. The servovalve senses both positive and negative current.

Figure X-10 is a sketch of a typical servovalve. The servovalve consists of an electric torque motor and a two-stage hydraulic power amplifier. Applying an electrical input signal to the coil produces a deflection of the armature and flapper. The flapper is connected to the spool through a feedback spring. As the flapper of the first stage hydraulic amplifier is deflected, it increases the size of one nozzle orifice and decreases the size of the other. This produces a differential pressure at the ends of the second hydraulic stage spool and results in displacement of the spool. The spool displacement causes a torque in the feedback spring. Spool movement continues until the feedback spring torque is equal to the torque produced by the electrical input signal. The servovalve output is proportional to spool displacement.

b. Pneumatically Operated Analog Control Valves. Several of the control valves are pneumatically operated. Typical examples of these valves are PCV-754, PCV-517 and the pressurization valves for V-3801 and V-5002. These valves differ in operation from hydraulic servovalves primarily in that the command to the valve is position rather than error signal.

Figure X-11 is a sketch of a typical pneumatic analog control valve. The command to the valve is a pot setting corresponding to a valve position. This command is converted to a pressure signal by the electro-pneumatic converter. The normal range of the converters is 0-5 ma input and 0-18 psi output. The converter is designed to be linear from 1 ma to 5 ma and 3-15 psi. The position signal is sent to the double bellows which positions the pilot valve to either increase or decrease the actuating pressure. The actuating pressure then drives the valve to a new position.

The valve is held in the new position by the balanced force of the actuating pressure and the compression of the feedback spring (positioner spring). Thus a balance or null is created at the new position.

The actuators used with these valves have a pre-set loading pressure and a variable actuating pressure. The actuating pressure and the mechanism for establishing the new valve position are controlled by the electropneumatic converter. The loading pressure establishes the stiffness of the valve and the maximum force that the valve can exert in any given direction.

C. CHECK VALVES (CHV's)

Check valves are used to prevent backflow and possible contamination of the various fluid systems. Swing, lift, and ball check valves (CHV's) are used at ETS-1. The swing type check valves are generally used in large lines where massive flowrates may exist. Lift check valves are also used in the larger lines. Ball check valves are generally confined to the smaller lines. Table X-3 lists the relative resistance of the various types of check valves.

TABLE X-3

RESISTANCE VALUES FOR VARIOUS CHECK VALVES

Conventional Swing	11
Clearway Swing	4
Globe Lift	13
Ball Check	11

Swing type check valves are classified according to the amount of clearance given the flapper. Figure X-12 illustrates the various types of check valves.

D. OPERATIONAL CHARACTERISTICS OF PNEUMATICALLY OPERATED VALVES

Because most of the valves at ETS-1 are pneumatically operated, it is important to understand some of the peculiarities that may restrict operational flexibility. Almost all of the RSV's are globe valves with flow over the plug, thus when the valve is closed the high pressure tends to hold the valve closed. Ninety-five percent of the time this is the most desirable way to operate these valves, however, situations exist where the downstream side of the valve may be at a higher pressure. When this occurs, backflow through the valve may exist contaminating the fluid on the upstream side. There are several methods for reducing this possibility. Among the more obvious solutions are: to increase the closing pressure of the pneumatic actuator, increase the effective area of the actuator, reduce the valve trim, or produce a buffer gas at a higher pressure upstream of the valve.

Pneumatic valves are very sensitive to the differential pressure across the valve. A valve that strokes evenly with a zero differential pressure behaves in a much different fashion with pressure across the valve. Figure X-13A indicates the difference in stroking that may be expected for different differential pressure across the valve. Indeed it is possible that the upstream to downstream pressure can become great enough to prohibit any movement of the valve.

Examination of the forces required to operate a typical RSV provides clearer insight into the dynamic operation of these valves. During operation of a typical valve without pressure across the plug, the valve lift will be a function of the pressure and vent characteristics of the actuator. Neglecting the weight of the plug, the stroking time can be shown as a function of the actuator volumes and flow allowed to pass into these volumes. Figure X-13B is a sketch of a typical pneumatically operated valve. When this valve is closed, P_1 is at 500 psig; P_2 is at 0 and the spring is tending to hold the valve closed. The valve cannot be moved until $P_2 A_2$ exceeds the sum of $P_1 A_1$ and the spring load. The time required to bring P_2 up to a value exceeding P_1 is dependent upon the supply characteristics of the four way solenoid and actuator piping.

In order for the valve to be positioned to any point between 0 - 100% lift, the following equation must be satisfied.

$$\text{LOAD} = P_1 A_1 - P_2 A_2$$

It is obvious from the above equation that initial movement of the valve is a function of the load on the stem. Neglecting the plug and stem weight the valve may be positioned at any location without a differential force. However, when a significant differential pressure load is present the movement of the valve is a function of the load on the stem.

All of the RSV's are setup to have P_1 and P_2 at either 0 or 100% of the supply pressure.

E. FAILURE MODES

1. Servovalve Failure Mode. Mechanically the servovalve can be set to fail in either direction, open or closed, upon loss of current. The failure direction is set by a mechanical bias within the valve.

Servovalves require clean hydraulic fluid, free from particles of any kind. The standard servovalve has an upstream 10 micron filter. Very few particles larger than 10 microns can be tolerated, and if such particles are numerous, the servovalve nozzle will usually become plugged, and the valve inoperative. Presence of such particles usually results in spool and sleeve wear, with increased null point leakage.

2. RSV Failure Modes. The failure of an RSV to respond to a command can usually be traced to one of the following causes:

- a. Power Failure
 - (1) Solenoid Valve Box Failure
 - (2) Command Failure
- b. Failure of pneumatic supply
- c. Valve freeze-up

The failure of the command or SVB, Solenoid Valve Box, power to an RSV will cause the valve to move to its de-energized position. The

de-energized positions have been carefully selected so that a catastrophic accident will not occur.

The failure of the pneumatic supply will also cause the valve to revert to the de-energized position. Correct positioning is insured by the bias spring in the actuator.

Freeze-up of a valve is highly unlikely except in the case of a cryogenic valve. Even when freeze-up occurs there is usually sufficient warning, and not until the freeze-up has progressed for some time will the valve be completely incapable of movement.

3. Pneumatic Analog Control Valves Failure Modes. Pneumatic operated analog control valve failure can usually be traced to one of the following causes:

- a. Command Failure
- b. Pneumatic Supply Failure
- c. Electropneumatic Converter Failure

Failure of the command will cause the valve to seek either the full open or the full closed position. The particular position desired can be selected based upon the electropneumatic converter.

The failure of the pneumatic supply will cause the valve to seek the position dictated by the direction of the loading pressure on the actuator. Eventually this pressure will also bleed down and the valve will be driven to the position dictated by the stem loading.

Most problems associated with the electropneumatic converter will result in erratic operation of the valve. These problems are usually caused by dirt in the bleed nozzle. If severe clogging of the nozzle occurs the valve will fail to the OPEN position.

Conventional Globe Valve

**Conventional Globe Valve
With Disc Guide**

Conventional Angle Valve

**Y-Pattern Globe Valve
With Stem 60 degrees from Run**

**Y-Pattern Globe Valve
With Stem 45 degrees from Run**

**GATE AND GLOBE VALVES
CUTAWAY VIEWS
FOR TRAINING USE ONLY**

FIGURE X-1

LINEAR PLUG

PERCENTAGE PLUG

SEMI-THROTTLE PLUG

QUICK-OPENING PLUG

VALVE PLUG CHARACTERISTICS
FOR TRAINING USE ONLY

FIGURE X-3

FIGURE X-4

TYPICAL FOURWAY SOLENOID OPERATING
DOUBLE ACTING CYLINDER
FOR TRAINING USE ONLY

FIGURE X-4

- 1 WASHER, BONNET
- 2 CAP SCREW, BONNET
- 3 GUIDE, STEM LOWER
- 4 TUBE, SEPARATOR
- 5 NAMEPLATE
- 6 SCREW, DRIVE, NAMEPLATE
- 7 GUIDE, STEM UPPER
- 8 NUT, GLAND FLANGE
- 9 BOLT GLAND FLANGE
- 10 FLANGE GLAND
- 11 GLAND PACKING
- 12 PACKING, "V" TYPE
- 13 PACKING, INTERMEDIATE
- 14 BONNET
- 15 GASKET BONNET
- 16 PLUG ASSEMBLY
- 17 BODY ASSEMBLY
- 18 FLOW ARROW (NOT SHOWN)

**TYPICAL REMOTE SHUTOFF VALVE
BALANCED PLUG DESIGN**
FOR TRAINING USE ONLY

1 BODY	14 FIN, NORMALIZING
2 GUIDE, STEM	15 PACKING
3 SPACER, SEPARATOR TUBE	16 FLANGE GLAND
4 HALF RING	17 BOLT, GLAND FLANGE
5 END FLANGE	18 NUT, GLAND FLANGE
6 WASHER, LOCK, BONNET	19 GLAND, PACKING
7 NUT, BONNET MTG	20 PLUG & STEM
8 STUD. BONNET MTG.	21 BONNET
9 BOLT, N F CLAMP	22 RETAINER, PACKING
10 NUT, N F CLAMP	23 GASKET BONNET
11 CLAMP, NORMALIZING FIN	24 SCREW, DRIVE NAMEPLATE
12 GASKET, NORMALIZING FIN	25 NAMEPLATE
13 TUBE, SEPARATOR	26 FLOW ARROW

TYPICAL REMOTE SHUTOFF VALVE
UNBALANCED PLUG DESIGN
 FOR TRAINING USE ONLY

FIGURE X - 6

SOL. LOAD

SOL. VENT

NOTE:

WITH DOME PRESSURE SET AND
LOCKED IN, SOLENOID "V" IS
ENERGIZED.

- 1 ROD PISTON
- 2 BUSHING PISTON ROD
- 3 PLATE, BASE A YOKE
- 4 O-RING, PISTON ROD
- 5 O-RING, BASE PLATE
- 6 SCREW, LOCKING, BASE PL
- 7 O-RING, PISTON
- 8 PLATE PISTON
- 9 SPRING, INNER
- 10 SPRING, OUTER
- 11 SCREW, TENSION
- 12 O-RING, TENSION SCREW
- 13 BUTTON, SPRING
- 14 CYLINDER
- 15 STOP, TRAVEL
- 16 NUT, PISTON ROD
- 17 PLATE, CAUTION (NOT SHOWN)
- 18 BOOT, STEM
- 19 WASHER

FIGURE X-9

**ELECTROHYDRAULIC ACTUATOR
& SERVO AMPLIFIER**
FOR TRAINING USE ONLY

FIGURE X-9

TYPICAL SERVO VALVE
FOR TRAINING USE ONLY

FIGURE X-10

FIGURE X-11

TYPICAL PNEUMATICALLY OPERATED
ANALOG CONTROL VALVE
AIR-TO-OPEN/SPRING-TO-CLOSE
FOR TRAINING USE ONLY

Conventional Swing Check Valve

Clearway Swing Check Valve

Globe Type Lift Check Valve

In-Line Ball Check Valve

A. VALVE STROKE CHARACTERISTIC

B. PNEUMATIC OPERATION

PNEUMATIC VALVE OPERATION
FOR TRAINING USE ONLY

FIGURE X-13

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION XI
DATA ACQUISITION SYSTEM

A. MAJOR DIVISIONS

The Data Acquisition System contains major systems which include Signal Conditioning, Analog Recording, Events Recording, and Digital Data Recording.

The principal function of the signal conditioning is to adapt and translate transducer variables into usable electrical signals for entry into the recording systems.

The Analog Recording System records wide band frequency data from dc to 20,000 hertz, displays selected critical parameters in real time, and records data for quick look purposes. The Events Recording System accepts on-off voltage signals which originate in limit switches of various sensing devices and remotely operated valves. These signals are recorded with respect to time. The Digital Data Recording System records analog data channels, binary events, and counter channels on the computer-compatible magnetic tape.

B. SUPPLEMENTARY MATERIAL

As supplementary material to this course, the following sections from the ETS-1 Instrumentation and Controls Introductory Course discuss the Data Acquisition System:

Section XII	Introduction to Data Acquisition
Section XIII	Signal Conditioning System
Section XIV	Analog Recording System
Section XV	Events Recording System
Section XVI	Digital Data System

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XII
INTRODUCTION TO THE DATA ACQUISITION SYSTEM

A. PURPOSE AND FUNCTION OF THE DATA ACQUISITION SYSTEM

1. Purpose. The purpose of the Data Acquisition System is to condition and record engine and facility test information during NERVA developmental tests conducted at ETS-1. This test information or data is utilized to evaluate engine performance and operation.

2. Function. The function of the Data Acquisition System is to accept electrical signals from various transducers within the ETS-1 complex, to condition those signals as required for both analog and digital recording, and finally to convert the recorded data into usable engineering units for analysis of test results.

Data signals from the ETS-1 complex are from three major sources, engine diagnostic transducers, Facility Control System (FC), and the Test Stand Control System (TSCS). The analog data channels from these sources total approximately 1500. It should be noted that not all of these channels will be recorded during an engine test inasmuch as some of the FC data channels have no direct effect on an engine test.

Due to the large number of measurements required, the Data Acquisition System is designed to handle large amounts of data very accurately through the use of modern digital conversion and processing techniques. In addition, the Data Acquisition System provides capability for directly recording analog data for quick look and wide band analysis.

B. GENERAL DESCRIPTION OF THE OVERALL SYSTEM

The Data Acquisition System consists of the following major subsystems:

1. Diagnostic Signal Conditioning
2. Digital Data System (DDS)
3. Analog Recording System (ARS)
4. Events Recording System
5. Patching Systems
6. Digital Data Processor

There are currently no overall accuracy figures available for the Data Acquisition System. However, the most recent state-of-the-art equipment has been procured for use and, assuming idealized transducers, it is presently estimated that the systems will be capable of 0.1% to 1.0% of full scale for narrow band variables (DC-10CPS) and from 1.0% to 5.0% of full scale for wide band variables depending on channel type, span, and recording device. The DDS is the most accurate subsystem within the Data Acquisition System and it has an overall measurement accuracy of 0.1% for high accuracy, high level channels; 0.15% for high accuracy, low level channels including amplifiers; and 0.5% for low accuracy channels.

Original design criteria established the philosophy that any failure or malfunction of the Data Acquisition System would not impair the operational integrity of any control system. Therefore, inasmuch as the engine diagnostic measurements are not utilized for operational control of hardware, these measurements are signal conditioned in the Data Acquisition System. Analog data emanating from the FC and the TSCS are actively isolated by amplifiers prior to entry into the Data Acquisition System to insure control integrity.

Figure XII-1, Sheets 1 through 4, comprise the block diagram of the Data Acquisition System. From this block diagram it can be seen that the equipment is located in three major areas, the Test Cell Building (TCB), the Forward Control Room (FCR), and the Control Point Building (CP).

The TCB contains the diagnostic signal conditioners and the Signal Conditioner Output Patch. The FCR contains data patchpanels, amplifiers,

filters, multiplexers and analog to digital conversion equipment for the DDS. The Recorder Room of the CP contains the data formation and control logic for the DDS, the Analog Recording System, and the Analog Record Patch. The Recorder Room of the CP also contains the DDS Master Control Console and the digital tape transports.

C. DISCUSSION OF BLOCK DIAGRAMS

1. XE Engine. The data flow within the XE engine is shown in Figure XII-2. Following the data flow from the engine diagnostic transducers, the cabling is routed from the engine to the connectors on the engine Upper Thrust Structure. The connectors on the Upper Thrust Structure mate with connectors on the Test Stand Adapter. This is the interface at which the engine is actually "Plugged" into the Test Stand. The cabling, then routed to connectors on the bottom of the Top Shield, continues from connectors on top of the Top Shield to the Test Stand Terminal Boxes which are located behind the Shadow Shield Wall (Figure XII-1, Sheet 1).

2. Test Stand and North Terminal Room. The cabling between the Test Stand and the North Terminal Room is included in Sheet 1 of Figure XII-1. The cabling continues from the test stand terminal boxes to terminal boxes in the North Terminal Room (NTR). The NTR also contains seven 96-channel thermocouple reference junction ovens (150°F reference) capable of referencing 384 channels of Chromel/Alumel and 288 channels of Copper/Constantan thermocouples. It should be noted that these reference ovens are also used for FC and TSCS thermocouples.

From the NTR signal cables are wired directly to the bins of the signal conditioners located in the TCB.

3. TCB Electronics Room. The signal conditioning equipment in the Electronics Room is depicted in Sheet 2 of Figure XII-1. The various signal conditioners provided for diagnostic measurements are as follows:

Passive:	STD STRAIN GAGE	99
	NON-STD STRAIN GAGE	213
	RTT's	69
	SWEPT POT	34
		<hr/> 415
	FUTURE	159
	TOTAL CAPABILITY	<hr/> 574

Active:	ANALOG	23
	C/C (T)	103
	C/A (K)	109
	W/W-Re	35
	SPEED/FLOW	<u>5</u>
		275
	FUTURE	<u>172</u>
	TOTAL CAPABILITY	447

The passive type signal conditioners contain power supplies and are used for transducers requiring external excitation. All transducer cabling to the passive signal conditioner bins is 6-conductor shielded (2 #16 and 4 #20).

The active type signal conditioners do not contain excitation power supplies but do contain bias cells for parameters such as thermocouples. Input wiring to active type signal conditioners is two-conductor shielded. The Master Calibration and Channelization Control Panel (MCCC) for all signal conditioners is located in the TCB. This unit controls the calibration and channelization function of the signal conditioners. The calibration function can be performed from Rack Calibration Control Panels, the MCCC or the Lead Instrumentation Engineers Console (LIE) located in the CP.

The output of the signal conditioners is wired directly to the Signal Conditioner Output Patch. This patch is divided into the High Level Data Patchboard and the Low Level Data patchboard. The High Level load also receives data signals from the FC and the TSCS. The actual data interface is at the terminal boxes located in the South Terminal Room (STR).

Layout of the Signal Conditioner Output Patchpanels is included in Figure XII-3 and 4. The Data Acquisition System, from the output of the Signal Conditioner Output Patch through the FCR, is divided into three identical subsystems. The primary purpose of the subdivision is to prevent a catastrophic loss of data with the Digital Data System in the event of a major equipment failure. The determination of which subsystem is utilized is determined at the Signal Conditioner Output Patch.

4. Forward Control Room. Figure XII-1, Sheet 3, illustrates the equipment in each subsystem. The high level signals are patched to one of

three High Level Data Patches located in the FCR. The low level data signals maintain their separation from the high level signals and are patched to one of three Low Level Data patchpanels also located in the FCR. The layout of the High Level Data Patch and the Low Level Data Patch are shown in Figures XII-5 and 6 respectively. The patchpanels include provisions for both ETS-1 and ETS-2; however, the ETS-2 facility will not be constructed.

Following the Data Flow through one of the subsystems the following should be noted:

- a. 160 low level signals can be patched directly to the ten sample per second (10 S/S) Low Level Differential Multiplexers of the DDS.
- b. 96 low level signals can be patched to the narrow band amplifiers.
- c. 60 low level signals can be patched to the wide band amplifiers.

One output of the narrow band amplifiers is directly wired to the input of the 10 S/S High Level Differential Multiplexer. The other output is wired to the input of the High Level Data Patch. The output of the wide band amplifiers is wired directly to the Magnetic Tape Recorder Patch located in the CP Recorder Room and a second paralleled output is wired to the input of the High Level Data Patch.

The high level data signals normally coming from the Signal Conditioner Output Patch are patched through the High Level Data Patch to the DDS via the Low Pass Pre-sampling Filters. These inputs can be recorded on the DDS as follows:

150 channels	-	10 S/S
40 channels	-	50 S/S
40 channels	-	100 S/S

It should be noted that DDS subsystem No. 3 is not currently provided. Eighty channels of any high level data may be patched to the Analog Record Patch located in the CP Recorder Room.

Overall it can be seen that there is a current capability of recording 960 channels of data on the DDS, routing 240 channels of data to the ARS and 112 channels of data to the magnetic tape recorders.

5. Control Point Building. Referring to Sheet 4 of Figure XII-1, high level signals designated for ARS recorders enter the Analog Record Patch. The ARS receives input signals from the following sources: (1) two-hundred and forty channels from High Level Data Patchpanels in the FCR, (2) twenty-five channels from TSCS interface terminal box, (3) forty event channels of the Event Recording System, and (4) forty-eight outputs from the wide band amplifiers. It should also be noted that 32 data channels can be routed to facility control recorders via the interface terminal box.

Details of the ARS will be covered in another section, but it should be noted that the following recording capability is provided:

- 48 channels on direct write recorders
- 150 channels on optical oscillographs
- 18 channels on single channel strip chart recorders
- 174 channels on analog magnetic tape recorders

The Event Recording System consists of system patching, relay divider chassis and two 120-channel event recorders. Inputs to the Event Recording System include 528 channels from the Facility Control System consoles, 20 channels of engine event, and 60 channels from the TSCS.

The Digital Data System is divided into two subsystems. Each DDS subsystem accepts 480 analog data channels and 52 event channels. The CP Recorder Room contains the following DDS equipment:

- a. Two Formatter Units
- b. Five digital magnetic tape recorders (two per subsystem and one for backup)
- c. One Tape Switching Unit that is common for all digital tape recorders and both digital subsystems
- d. One Master Control Console that is used to control both digital subsystems.

NOTES:

- "W/WRE" - TUNGSTEN/TUNGSTEN-RHENIUM THERMOCOUPLE, "KX" - CHROMEL/ALUMEL THERMOCOUPLE EXTENSION WIRE, "TX" - COPPER CONSTANTAN EXTENSION WIRE.
- FIGURES SHOWN ARE CHANNEL QUANTITIES. (LIST AND CONTINGENCY)
- DASHED LINES (-----) INDICATE TC & P EQUIPMENT.
- HEAVY DASHED LINES (-----) INDICATE AREAS OR SUB-DIVISIONS OF AREAS.
- NOMENCLATURE FOR CABLES:
EXAMPLE: 2-7 S/4 NO. 20(2SP)
EXPLANATION: 2 CABLES EACH CONTAINING 7 GROUPS OF 4 LEADS, WIRE SIZE NO. 20 AND EACH GROUP SHIELDED. SP DESIGNATION INDICATES NO. OF SPARE GROUPS.
- NERVA CABLE TYPES ARE AS FOLLOWS:
1A - 7 S/2 NO. 20
1E - 1 - 7S/6 NO. 20
1F - 1 - 7S/6 (2 NO. 16-4 NO. 20)
2G - 1 - 18PR NO. 20
3A - 1 - S/2 NO. 20
3B - 1 - S/2 NO. 16
3C - 1 - S/4 NO. 20
3D - 1 - S/6 NO. 16
3E - 1 - S/6 NO. 20
3F - 1 - S/6 (2 NO. 16 - 4 NO. 20)
4S - RG 58C/U
5X - 1 - 27PR NO. 22
5Y - 1 - 14 COND NO. 20
5W - 1 - 15 COND NO. 20
6B - 1 - 1 COND NO. 16
- THE SYMBOL INDICATES THAT THESE WIRES ARE TO BE INSTALLED, CONNECTORS ATTACHED AND THEN COILED OR HUNG IN THE APPROPRIATE RACK FOR FUTURE USE.

SHEET 3 OF 4
FIGURE XII-1
DATA ACQUISITION SYSTEM
BLOCK DIAGRAM
FOR TRAINING USE ONLY

XE ENGINE ASSEMBLY CONCEPTION
FOR TRAINING USE ONLY

FIGURE XII-2

RACK 20

RACK 21

SIGNAL CONDITIONER OUTPUT PATCH PANELS
FOR TRAINING USE ONLY

FIGURE XII-3

FIGURE XII-3

RACK 23

RACK 24

FIGURE XII-4
HIGH LEVEL SIGNAL CONDITIONER
OUTPUT PATCH
FOR TRAINING USE ONLY

DIGITAL DATA SYSTEM								NARROW BAND AMPLIFIERS															
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8								
9	10	11	12	13	14	15	16	9	10	11	12	13	14	15	16								
17	18	19	20	21	22	23	24	17	18	19	20	21	22	23	24								
25	26	27	28	29	30	31	32	25	26	27	28	29	30	31	32								
33	34	35	36	37	38	39	40	33	34	35	36	37	38	39	40								
41	42	43	44	45	46	47	48	41	42	43	44	45	46	47	48								
49	50	51	52	53	54	55	56	49	50	51	52	53	54	55	56								
57	58	59	60	61	62	63	64	57	58	59	60	61	62	63	64								
○ ETS - I LOW LEVEL DATA SYSTEM I ○																							
DIGITAL DATA SYSTEM								NARROW BAND AMPLIFIERS															
65	66	67	68	69	70	71	72	65	66	67	68	69	70	71	72								
73	74	75	76	77	78	79	80	73	74	75	76	77	78	79	80								
81	82	83	84	85	86	87	88	81	82	83	84	85	86	87	88								
89	90	91	92	93	94	95	96	89	90	91	92	93	94	95	96								
97	98	99	100	101	102	103	104	WIDE BAND AMPLIFIERS															
105	106	107	108	109	110	111	112									1	2	3	4	5	6	7	8
113	114	115	116	117	118	119	120									9	10	11	12	13	14	15	16
121	122	123	124	125	126	127	128									17	18	19	20	21	22	23	24
																25	26	27	28	29	30	31	32
○ ETS - I LOW LEVEL DATA SYSTEM I ○																							
DIGITAL DATA SYSTEM								WIDE BAND AMPLIFIERS															
129	130	131	132	133	134	135	136	33	34	35	36	37	38	39	40								
137	138	139	140	141	142	143	144	41	42	43	44	45	46	47	48								
145	146	147	148	149	150	151	152	49	50	51	52	53	54	55	56								
153	154	155	156	157	158	159	160	57	58	59	60												
161	162	163	164	165	166	167	168																
169	170	171	172	173	174	175	176																
177	178	179	180	181	182	183	184																
185	186	187	188	189	190	191	192																

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XIII
SIGNAL CONDITIONING SYSTEM

A. GENERAL

The principal function of the Signal Conditioning System is to adapt and translate transducer variables into usable electrical signals for entry into the recording system. This is accomplished through the use of specially designed signal conditioners, transducer excitation power supplies, signal amplifiers, and low pass pre-sampling filters. The requirements of the signal conditioning equipment depend upon the characteristics of the transducer and also upon the type of recording system used. The transducers are divided into two major classifications: (1) passive transducers, and (2) active transducers. Each of these classes requires a different signal conditioning approach. The passive transducer does not produce an electrical output by itself and must be connected to signal conditioning equipment that, in conjunction with the transducers, will produce an electrical output. The use of strain gages in a Wheatstone bridge circuit is a typical example of a passive transducer application. The block diagram below illustrates the major components of a passive transducer channel.

The active transducer is a self-generating transducer in that no external voltage source is required for the transducer to produce an output signal. Examples of active transducers include thermocouples and turbine flow meters. The signal conditioning system for an active transducer amplifies and prepares the signal for presentation to the recording system. The active transducer channel block diagram is shown below:

Another major function of the Signal Conditioning System is to provide a rapid means for calibrating the data channels and to verify their integrity. To accomplish this, the Signal Conditioning System provides circuits for electrical calibration of each individual channel, signal channelization checks, and leakage and continuity circuit tests.

B. BLOCK DIAGRAM

Signal conditioning equipment is required for the Facility Control System (FC), Test Stand Control System (TSCS), and the Data Acquisition System (DAS). Several types of plug-in equipment in the three systems are identical and can be used interchangeably. The primary purpose of the signal conditioner used with the FCS and the TSCS is to prepare transducer signals for use in control circuits or for visual display on the consoles at the Control Point. A secondary purpose is to supply signals to the DAS.

1. Facility Control System. The FC transducers are mounted on tanks, pipes, valves, and various other equipment. Thermal boxes are located near areas where groups of transducers are used. Cables are connected from the transducer to terminal boxes located in the field area to terminal boxes in the Test Cell Building Terminal Rooms. Six **different** signal conditioning circuit configurations are included in Figure XIII-1. The first three circuits are: (a) low level passive transducers, (b) low level active transducers, and (c) high level passive transducers.

a. The low level passive transducers include strain gages and resistance temperature transducers (RTT). The output from these transducers is less than 100 millivolts. The transducer signals are fed in sequence to passive signal conditioner equipment and narrow band amplifiers. Each narrow band amplifier has one input and two separate isolated outputs. One output of the amplifier connects the transducer signal to the FC. The second output isolates the DAS from the FC. This is done to prevent a failure in the DAS from causing a malfunction in the FC which could result in the termination of an engine test. A complete short circuit of the output connected to the DAS produces less than a 0.3% of full scale change in the amplifier output connected to the FC.

b. The thermocouple circuit uses thermocouple extension wire between the thermocouple and the thermocouple hot reference junction in the North Terminal Room. Copper leads connect the reference junction to the signal conditioner. The full scale thermocouple outputs range between 5 and 50 millivolts. Narrow band amplifiers are used to provide one output for the FC and a second output for the DAS.

c. The high level transducers produce signals up to ± 5 volts; therefore, additional amplification is not needed. The output from the transducer is connected to a signal conditioner input. The output from the signal conditioner is split. One signal is fed to the FC controller, recorder, or display. The second signal is connected to an isolation amplifier and then to the DAS. The isolation amplifier has a gain of one and is used only to isolate the FC from the DAS.

d. The last three circuits of Figure XIII-1 are specialized applications. The electronic vacuum gage is used with thermocouple signal conditioning equipment. The shield position LVDT is a passive transducer and requires additional equipment to supply a-c excitation. The level probe is a capacitance measuring transducer and also requires special signal conditioning equipment.

2. Test Stand Control System. Test Stand Control System transducers are mounted on the run tank, valves, pipes, and various equipment physically located on the test stand. Appropriate signal conditioners are used with each transducer. Amplifiers with two outputs are used with the

low level transducers that have signals fed to both the TSCS and the DAS. High level transducers do not require amplifiers unless the signal is fed to the DAS. All of the TSCS signals that are fed to the DAS terminate in the signal conditioner high level output patchpanel.

3. Data Acquisition System. Transducers on the engine which are not used for control purposes are fed through terminal boxes to the DAS signal conditioners. Isolation amplifiers are not needed with these transducers.

Figure XIII-2 is the Data Acquisition System signal conditioning block diagram. The DAS signal conditioning equipment includes a total of 574 passive signal conditioner channels and 447 active signal conditioner channels. The variable reluctance and speed flow transducers produce signal information in the form of a varying frequency. The signal conditioner output for these channels are fed to frequency-to-voltage converters before being connected to the signal conditioner output patchpanel. The outputs from the FC and TSCS signal conditioners that are fed to the DAS are connected directly to the DAS high level signal conditioner output patchpanel. This patchpanel contains terminations for 162 channels from the TSCS and 400 channels from the FC.

The signal conditioning system is divided into three subsystems to correspond with the three subsystems in the Digital Data System (DDS). At the present time two of the three DDS subsystems have been purchased and are installed. Signal conditioning equipment is installed in subsystems Nos. 1 and 2. Signal conditioning subsystem No. 3 is not completed; and only racks, patchpanels, and wiring are presently installed. Amplifiers and filters are to be installed only after the third DDS subsystem is purchased.

Figure XIII-2 also includes the block diagram of the equipment in subsystem No. 1. Signals from the signal conditioner high level output patchpanel are fed through terminal boxes to the three high level data patchpanels. Signals from the signal conditioner low level output patchboard are fed through terminal boxes to the three low level data patchpanels. Subsystem No. 1 includes 60 wideband amplifiers connected between the low level data patchboard and the high level data patchboard. Ninety-six narrow band amplifiers are connected to the low level data patchboard. One output from

each narrow band amplifier is connected to the high level data patchboard. The second output of each narrow band amplifier is connected directly to subsystem No. 1 of the DDS. One hundred and sixty channels are fed through the low level data patch directly to the DDS without being amplified. Outputs from the high level data patchpanel are connected to either the Analog Recording System or through low-pass presampling filters to the DDS.

C. EQUIPMENT LOCATION

The Signal Conditioning System has its signal input interfaces at the test stand shield wall terminal boxes and the Test Cell Building terminal rooms. The transducers are not a part of the Signal Conditioning System.

Seven 150°F thermocouple reference junctions for Chromel-Alumel and Copper Constantan thermocouples are mounted on the wall in the Test Cell Building North Terminal Room.

Signal conditioning equipment for the Data Acquisition System, Facility Control System, and Test Stand Control System, is located in the Test Cell Building Electronic Room. The rack layout in the Electronics Room is included in Figure XIII-3. The two rows of TSCS racks contain signal conditioners and amplifiers to prepare signals for control and display purposes in the TSCS and to isolate the signals fed to the DAS. The row of FC racks contains signal conditioners, wide band amplifiers, narrow band amplifiers, and isolation amplifiers. The two rows of DAS signal conditioning racks contain signal conditioners for 690 channels. Rack space is provided for a total of 1021 signal conditioner channels. All of the amplifiers for the DAS signal conditioning are located in the Forward Control Room. The rack layout of the Forward Control Room is shown in Figure XIII-4.

D. EQUIPMENT DESCRIPTION

1. Signal Conditioners. Two basic signal conditioner designs are used; one for passive transducers and a second for active transducers. Considerable flexibility is provided by the use of plug-in cards so that the signal conditioners can be readily adapted to the various transducer requirements. Each rack-mounted passive signal conditioner bin accepts six plug-in modules. The modules contain all of the front panel controls and the transducer excitation power supply. All of the modules are identical, but a

different plug-in card is placed within the module each time the module is used with a different type of passive transducer. Each rack-mounted active signal conditioner bin accepts ten plug-in modules. Transducer excitation power supplies are not needed with the active signal conditioners. Individual plug-in cards for each type of active transducer are used. The signals emanating from the signal conditioners are fed either directly to the recording systems or through amplifiers. Directly applied signals are either inherently high level (± 5 volts) or millivolt signals. The high level signals are fed directly to the analog recording system or through low pass presampling filters to the DDS. The directly applied millivolt signals are accepted by the differential low level multiplexers in the DDS. Only low accuracy (0.5% or greater) data are handled by the low level multiplexer. High accuracy (0.15% or less) low level data entering DDS are preamplified to 5 volt level by differential amplifiers. High accuracy (0.1% or less) high level data are handled by the high level multiplexers.

2. Narrow Band Amplifiers. The output signal from each signal conditioner that is connected to an amplifier is one of the following spans: 0 to ± 5 , 10, 20, 30, 40, 50, or 100 mv. The gain of the narrow band d-c differential amplifiers is set to provide a full scale output of ± 5 volts. Frequency response is down 3db at 100 cycles.

All of the narrow band amplifiers have two independent outputs. One output is used to drive remote recorders through integral or remote low pass filters. The other output is capable of driving an integral low pass filter and a remote analog recording input through a 600 foot line.

The time required for either output to settle to within $\pm 0.1\%$ full scale is less than 40 milliseconds. This settling time is measured in response to an applied step of sufficient amplitude to drive the output from zero to full scale. The time required for either output to recover and settle to within $\pm 0.1\%$ full scale after the removal of a 10 volt input overload is less than two seconds.

The amplifiers are of modular plug-in design and eight amplifiers are contained in each bin.

3. Wide Band Amplifiers. The input signal to each amplifier is one of the standard spans: 0 to ± 5 , 10, 20, 30, 40, 50, or 100 mv. As with the

narrow band amplifiers, the output of the wide-band d-c differential amplifier is adjusted to provide a full scale signal of ± 5 volts. Each amplifier contains one output to drive the analog data system magnetic tape recorders. Variation in amplifier gain from that at d-c is within 1% of full scale between d-c and 5 kc, and 10% of full scale between 5 kc to 20 kc. The time required for the output to settle to within 0.1% full scale is less than 100 microseconds. The time required for the output to recover and settle within 0.1% full scale, after the removal of 10 volts input overload of any duration, is less than 10 milliseconds.

The amplifiers are modular plug-in design and five amplifiers are contained in each bin. Both the narrow band amplifiers and the wide-band amplifiers contribute from 0.05% to 0.10% to the overall accuracy of 0.15%. The minimum common mode rejection at 60 cycles for the amplifiers is 120 db. Even though numerous patchpanels exist, the expected system isolation at 60 cycles per second is greater than 110 db.

4. Low-Pass Presampling Filters. Signals emanating from the high level data patchpanel are fed through low-pass presampling filters before entering the DDS multiplexers. These filters allow low frequencies to pass through the filter unattenuated, and prevent the transmission of high frequencies. Low-pass filters are internal to the narrow band amplifier construction.

Each signal is sampled by the multiplexer for a duration of less than 100 microseconds at a rate of 10, 50, or 100 samples per second. A periodically sampled signal can be exactly reconstructed only if the signal is zero above one half the sampling frequency. This frequency of one half the sampling frequency is called the folding frequency and is symbolized as f_n . Frequencies above f_n cannot be identified from certain frequencies below the f_n . A typical example is shown below. The dots indicate the points at which the data is sampled.

When an input signal with a frequency spectrum extending above f_n is sampled, the frequency spectrum above f_n is folded onto the frequency spectrum below f_n . Thus, not only is the frequency spectrum above f_n lost, but the frequency spectrum below f_n is contaminated. To prevent this, the frequencies above f_n are filtered out before sampling.

The filter cutoff frequency at which the output is reduced by 3db is given for each sampling rate.

<u>Sampling Frequency</u>	<u>Folding Frequency</u>	<u>Cut-off Frequency</u>
10 cps	5 cps	4 cps
50 cps	25 cps	20 cps
100 cps	50 cps	40 cps

Above the cutoff frequency, the attenuation of the filter is 12 db per octave. Each filter consists of a series inductance and a shunt capacitance.

E. CALIBRATION

All Data Acquisition System channels which contain a signal conditioner are capable of manual and automatic calibration. Local controls may be used on a unique channel-by-channel basis. Various local and remote controls may be used to actuate an automatic calibration sequence. These controls provide calibration signals on all applicable channels simultaneously. Channel calibration is accomplished at levels of 0, 25%, 50%, 75%, and 100% of the signal span for all channels except frequency which is calibrated at one point only. Selection of the calibration level and the actual initiation of calibration can be performed at a signal conditioner in the Test Cell Building Electronics Room, at a master calibration control point in the Test Cell, or from the Lead Instrument Engineer's (LIE) Console in the ETS-1 Control Room at the Control Point Building.

The calibration data is recorded on the Digital Data System. Immediately following the initiation of each step, the Digital Data System is commanded to scan all channels and record the data on digital tape. The calibration data are then fed into the Data Processor which stores and later uses the calibration information to correct the actual data obtained during a test firing. Prior to this, however, the Data Processor may be used to compare the

calibration data with pre-established limits to permit early detection of out-of-tolerance channels.

1. Calibration of One Data Channel. The ability to calibrate a particular data channel, either manually or automatically, is subject to the status of a calibration "inhibit-enable" circuit controlled from the LIE Console. Ten inhibit-enable circuits are provided: one for Data Acquisition System, one for Test Stand Control System, and eight for Facility Control System. The inhibit circuitry permits an operator to delete certain classes of channels from group calibration, and/or prevent the accidental calibration of certain critical FC and TSCS channels.

Each signal conditioner rack includes a calibration control panel. To select a calibration level for all signal conditioners within a rack, the operator sets the calibration level authority switch to the desired level. An extra "0" position is provided adjacent to the 100% position to facilitate rapid testing of channel zero and span.

To calibrate a particular data channel, the local calibrate switch on the appropriate signal conditioner module is actuated.

2. Calibration of all Data Channels in a Rack. To place all data channel signal conditioners in a rack into the calibrate mode, the operator places the operating mode switch on the Calibration Control Panel in the "calibrate" position.

Upon completion of all calibration activities controlled at a rack, the operator will relinquish calibration control to the Master Calibration and Channelization Control Panel (MCCC) by placing the calibration level authority switch in the "remote calibration authority" position.

Calibration control is transferred from individual calibration control panels to the MCCC panel and then to the LIE Console by switches at each location, thereby establishing a hierarchy of calibration control authority from the less general to the more general control location.

3. Calibration of all Data Channels Under Authority of MCCC Panel. The MCCC panel is located in rack 22 of the Test Cell Electronics Room. The MCCC panel can be placed in any of three calibration modes: manual, automatic, and remote. In the automatic mode, all data channels under the control

of the MCCC panel can be automatically sequenced through the five calibration levels. In the remote mode, the control is relinquished to the LIE Console.

4. Calibration of all Data Channels from the LIE Console. Either manual or automatic calibration can be conducted from the LIE Console. Upon initiation of the controls, all channels within the system are individually and simultaneously subjected to precise signals corresponding to one of the calibration levels. In the automatic mode, elapsed time between steps is approximately 10 seconds. This permits an entire calibration to be accomplished in less than one minute.

F. CHANNELIZATION

Because of the necessity of changing channel assignments to the recording system through patching techniques, it is essential to establish the integrity of a channel by channelization checks.

Several means are available to certify that a given channel is connected as desired. Test equipment in the Test Cell Building provides a means of checking the integrity of the circuit including the transducer through the signal conditioner without necessitating access to the remainder of the Data Acquisition System. Various means of exciting the passive transducers provide a check of the transducer, a check of the transducer and signal conditioner circuit, or a check of the entire instrumentation channel.

Channel connection integrity checks, from signal conditioners through recording devices, are performed by manually calibrating one channel at a time and observing the applicable recorder channels for expected response. Analog Recording System strip chart recorder channels are directly observable. Analog magnetic tape recorder channels are observable on built-in level meters. Digital Data System channels are observed on the digital word displays.

Channelization checking of the DDS is accomplished by a sequential automatic test signal which is developed in the Data Acquisition System signal conditioners. This test signal or "flag" is generated whether or not a transducer is connected and therefore is not a calibration signal. The "flag" is sequenced in a fixed order corresponding to the signal conditioner bin and module location. One channel at a time is "flagged." The calibra-

tion inhibit-enable circuits also serve to inhibit or enable channelization testing so that certain classes of channels may be deleted from a channelization test.

When the channelization test circuit causes the output of a particular data-channel signal conditioner to assume the flag level, it simultaneously directs the DDS to scan all channels. In the automatic mode the "flag" signal appears on each channel; one at a time. The elapsed time between channel steps is approximately 4 seconds, and the required time to automatically step through the entire system is between $1\frac{1}{2}$ and 2 hours. Upon completion of the channelization test, the records made by the DDS are compared with channel records by the on-site computer so that the integrity of channelization may be confirmed, or improperly patched channels may be identified. To accomplish this, the computer will be directed to examine the time slot of the Nth channel on the (N-1)th, Nth, and (N+1)th records made by the DDS during the channelization test. If three interrogations reveal a change in the level recorded in N slot, and if the level in N slot on the Nth record is indeed the flag level, the computer will indicate that channel N is properly patched. Those channels which the computer determines are improperly patched will be located by examining the entire DDS record made when the channel was caused to assume the flag level.

G. PASSIVE SIGNAL CONDITIONERS

1. Signal Conditioner Functions. The passive signal conditioners are used with two active arm strain gages, four active arm strain gage type transducers, one element RTT's, and potentiometer circuits. The functions provided by the passive signal conditioners depend upon the particular type of transducer used. Each function provided by any of the passive signal conditioners is listed and defined below.

a. Excitation. Excitation is the supply of power to a passive transducer. Each passive channel is provided with its own power supply integral with the signal conditioner. The excitation voltage is adjustable over a range of 1 to 15 volts.

b. Bridge Completion. Bridge completion describes the resistive networks which are connected to the transducer and excitation source in order to provide a standard voltage output over the desired measurement

range. With the exception of the plug-in signal conditioner cards used with the four active arm strain gage transducers, the plug-in cards have provisions for mounting bridge completion resistors. These networks include both single and multiple bridge configurations, as appropriate. Double or triple bridge circuits are used, for those one-element resistive transducers where lead wire errors must be minimized. Effects of lead resistance can also be minimized by using a constant current power supply for bridge excitation. For cryogenic applications using RTT's, circuits with constant current excitation replace the double and triple bridge RTT circuits.

c. Balance Adjustment. Balance adjustment is a control to change the balance point of a bridge circuit. This control is necessary for transducers which must be calibrated in place such as position potentiometers. Also included are transducers that have a high rate of drift, such as structural strain gages.

d. Sensitivity. Sensitivity adjustment is a change in the sensitivity of the span of a channel. Sensitivity is adjusted by changing the excitation voltage. Sensitivity adjustment is provided with all passive signal conditioners.

e. Passive Calibration. Passive calibration is the generation of an electric calibration signal by passive networks. For strain gage bridge channels, shunt calibration is used. The RTT circuits employ resistance substitution calibration, and the potentiometer circuits utilize voltage ratio calibration. Passive calibration is provided with all passive signal conditioners.

f. Output Test. Output test is the connection of a channel output to a voltmeter for measurement. Output test capability is provided with both active and passive signal conditioners.

g. Leakage Test. Leakage test is the measurement of leakage resistance from conductors to shield and from shield to ground within each channel. Leakage test points are available on all passive signal conditioners.

h. Continuity Test. Continuity test is the measurement of a transducer circuit loop resistance of less than 1000 ohms. Of the passive

signal conditioners, only the signal conditioners used with potentiometers require a continuity test. The continuity test is used to verify the integrity of the potentiometer stator.

2. Schematic Diagrams.

a. Four Active Arm Strain Gage. Both the schematic diagram and the conceptual circuit for the four active arm strain gage signal conditioner configurations are shown in Figure XIII-5. The transducer used with this configuration include strain gage type pressure transducers, strain gage type accelerometers, and load cells.

The signal conditioner power supply has provisions to provide either a constant voltage or a constant current. To provide a fixed output, resistor R12 is installed and SL3 is disconnected. By removing R12 and installing SL3, the span potentiometer is connected in the circuit and provides an adjustable output. The relays K1, K2, and K3, are the calibration step relays. The state of the calibration relays for each calibration value is listed below. The bar over a relay symbol indicates that the relay is not energized.

<u>Calibration Value</u>	<u>Calibration Step Relays</u>
0%	$\overline{K1}$, $\overline{K2}$, $\overline{K3}$
25%	K1, $\overline{K2}$, $\overline{K3}$
50%	$\overline{K1}$, K2, $\overline{K3}$
75%	$\overline{K1}$, K2, K3
100%	$\overline{K1}$, $\overline{K2}$, K3

Relay K5 is the channelization relay. When the K5 relay is energized, it disconnects the bridge circuit from the signal conditioner output and connects resistor R5 across the output. Additional K5 contacts are used to place the series combination of R5 and the calibration resistors across the power supply.

b. Two External Arm Strain Gage. The two external arm strain gage contains one strain gage element to measure strain and a second strain gage element for temperature compensation.

The signal conditioner configuration for the two external arm strain gage is shown in Figure XIII-6. By changing the values of R10, R13,

R14, and R15, the bridge circuit can be wired into the following configurations: (1) Wheatstone bridge, (2) three-wire bridge, (3) double bridge, or (4) triple bridge.

The plug-in card used with the two-arm strain gage circuits contains bridge completion resistors, shunt calibration resistors, calibration insertion relays, and channelization relay.

c. Resistance Temperature Transmitter RTT. The schematic diagram of the RTT signal conditioner is included in Figure XIII-7. A single temperature-sensitive element is connected in a triple-bridge circuit through lead resistances RL. The triple bridge effectively suppresses lead wire resistance even though none of the four lead wires have the same resistance. The double bridge can be obtained by changing the values of R15 and R16. This bridge configuration provides partial suppression of lead resistances.

The lead wires used with the temperature sensors have a resistance between three and six ohms. A typical RTT at 32°F has a resistance of 1380 ohms, but at -425°F the resistance is only 5.58 ohms. At cryogenic temperatures the suppression of lead wire resistance effects is essential.

A substitution method of calibration is used in which the RTT is disconnected from the bridge circuit and fixed resistance values are connected to complete the bridge circuit.

d. Swept Potentiometer. The swept potentiometer functions as two arms of a bridge circuit. See Figure XIII-8. The balance potentiometer R3 completes the bridge circuit. Potentiometer R4 is disconnected and R6 is connected to the power supply to provide a fixed power supply voltage during calibration. Relay K4 serves as both the calibration and the channelization relay. Calibration voltages are taken from the R5 voltage-divider network with the entire bridge circuit disconnected.

H. ACTIVE SIGNAL CONDITIONERS

1. Signal Conditioner Functions. The active signal conditioners are used with thermocouples, variable reluctance vibration pickups, analog voltages, and speed and flow transducers. The functions provided by the active signal conditioners are defined below.

a. Voltage Substitution Calibration. Voltage substitution calibration is the calibration of a channel by the substitution of an accurate voltage derived from a stable, well-regulated power supply. The thermocouple and analog voltage channels are calibrated in this manner.

b. Frequency Channel Calibration. Speed and flow channels are calibrated by a pulse train supplied from a Vidar frequency source and substituted in place of the transducer outputs. Nine calibration frequencies are available: 100, 200, 500, 1000, 2000, and 5000 pulses per second (pps) for flow channels and 10,000, 20,000 and 50,000 pps for speed channels.

c. Zero Offset. Zero offset is the insertion of a series voltage in an output lead of a signal conditioner, downstream from the calibration insertion. The purpose of zero offset is to shift a channel span into a standard range to suppress residual output. Zero offset is required on all thermocouple channels.

d. Output Test. All of the active signal conditioners have provisions for checking the output signal.

e. Continuity Tests. The continuity of the thermocouple and reference junction circuits, the speed transducers, and flow transducers is measured at the signal conditioners.

2. Schematic Diagrams.

a. Thermocouple Signal Conditioner. One thermocouple signal conditioner is used for all three types of thermocouples. The thermocouple circuits are shown in Figure XIII-9. The signal conditioner uses a mercury cell to provide zero offset. This source provides a "bucking potential" so that the output of the signal conditioner is zero when the measuring junction is at zero scale temperature.

Calibration is accomplished by electrically disconnecting the thermocouple reference junction output from the signal conditioner circuit and then substituting a fixed voltage across the signal conditioner output. The following relays are energized to provide the calibration voltages.

<u>Calibration</u>	<u>Relay</u>
0%	none
25%	K2
50%	K3
75%	K4
100%	K5

b. Moving Coil Vibration Transducer and Analog Voltage Signal Conditioners. Figure XIII-10 shows the signal conditioner circuit used with both variable reluctance vibration pickup and the analog voltage channels. The outputs from these transducers are passed through the signal conditioner without undergoing any conditioning. Calibration is provided by voltage substitution.

c. Speed and Flow Signal Conditioner. The frequency measurement channels originate in rotating speed and flow transducers. The signal conditioner for these transducers is shown in Figure XIII-11. Flow channel full-scale frequency range is typically less than 600 pps. Speed channel full-scale frequency range is less than 30,000 pps.

Calibration is accomplished by disconnecting the flow or speed transducer and substituting a fixed frequency signal. The schematic diagram shows frequencies of 200 cps and 20,000 cps delivered to the speed and flow signal conditioner via two separate leads. The selection of the frequency is made from the Vidar frequency source. A shorting element within the signal conditioner connects the desired frequency to the calibration circuit.

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FACILITY CONTROL SIGNAL CONDITIONING BLOCK DIAGRAM

FOR TRAINING USE ONLY

FIGURE XIII-3

TEST CELL BUILDING ELECTRONICS ROOM RACK LOCATION
FOR TRAINING USE ONLY

FIGURE XIII-5
FOUR ACTIVE ARM STRAIN GAGE
SIGNAL CONDITIONER

FOR TRAINING USE ONLY

NOTES:

1. FOR FIXED VOLTAGE OR CURRENT INSTALL R18 AND REMOVE SL3, $R18 \approx 300\Omega/V$
2. FOR VARIABLE VOLTAGE OR CURRENT INSTALL SHORTING LINK SL3 AND REMOVE R18
3. RDG = DUMMY STRAIN GAGE, RGA = ACTIVE STRAIN GAGE, RL = LEAD RESISTANCE
4. FOR ACTIVE GAGE, RGA, LOADED IN TENSION CONNECT B TO C, D TO E AND F TO G, FOR ACTIVE GAGE, RGA, LOADED IN COMPRESSION CONNECT B TO A, D TO G, AND E TO F.
5. THE CIRCUIT AS SHOWN PROVIDES MAXIMUM COMPENSATION FOR LEAD RESISTANCE ERRORS. IN SOME CASES A SIMPLER THREE WIRE BRIDGE MAY BE ADEQUATE, AND $R10$ AND $R14 = \infty$, $R13$ AND $R15 = 0$, LEADS L4 AND L5 NOT REQUIRED.

NOTES:

1. FOR FIXED VOLTAGE OR CURRENT INSTALL R19 AND REMOVE SL3. $R19 \approx 300 \Omega/V$
2. FOR VARIABLE VOLTAGE OR CURRENT INSTALL SHORTING LINK SL3 AND REMOVE R19
3. R13-R16 ARE REQUIRED FOR TRIPLE BRIDGE; FOR DOUBLE BRIDGE CIRCUIT $R16 = \infty$, $R15 = 0$, FOR SINGLE BRIDGE CIRCUIT $R15$ and $R13 = \infty$, $R16$ AND $R14 = 0$.

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RESISTANCE TEMPERATURE TRANSMITTER SIGNAL CONDITIONER

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FIGURE XIII-7

FIGURE XIII-9
THERMOCOUPLE SIGNAL CONDITIONER
FOR TRAINING USE ONLY

NOTE
ONLY BIN CIRCUITRY PERTINENT TO THE OPERATION OF THE
SIGNAL CONDITIONER SIGNAL CIRCUITS HAS BEEN SHOWN.

FIGURE XIII-10
MOVING COIL VIBRATION TRANSDUCER
AND
ANALOG VOLTAGE SIGNAL CONDITIONER
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NOTE

ONLY BIN CIRCUITRY PERTINENT TO THE OPERATION OF THE SIGNAL CONDITIONER SIGNAL CIRCUITS HAS BEEN SHOWN.

FIGURE XIII-11

VARIABLE RELUCTANCE

SPEED OR FLOW SIGNAL CONDITIONER

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ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XIV
ANALOG RECORDING SYSTEM

A. INTRODUCTION

Before discussing the Analog Recording System (ARS), it might be well to define what is meant by "analog." Analog means something that is analogous or similar to something else. As applied to a recording system, the voltage which the recorder "sees" (or records) is analogous to the changes in environment which are sensed by the transducer for that particular measurement. Therefore, by precise calibration of each channel for a specific voltage span at full range of the transducer, useful data can be obtained with a reasonable degree of accuracy on the order of 1.0% - exclusive of the transducer and human error.

B. GENERAL DESCRIPTION AND FUNCTION

The Analog Recording System (ARS) has the capability of recording high level (0 to ± 5 v.) analog signals in a frequency range from dc to 20,000 cps. Its purpose is to provide real-time data readout at the control center, and to serve as a backup for the Digital Data System (DDS). In addition to this, the system can be used in recording high frequency data in the range from 20,000 cps to 300,000 cps, if such a requirement should ever exist.

C. NARROW BAND RECORDING

Narrow band data is generally defined as that having a frequency range from dc to 100 cps. Generally speaking, this type of data will be

recorded on paper chart type recorders. Narrow band data can and will be recorded also on the DDS, but this discussion is limited to the ARS narrow band recorders. Two types of paper chart recorders are used for narrow band recording. Selection of the proper recorder is governed by the characteristics of the data to be recorded. Eighteen single-channel Leeds and Northrup strip charts are used for what is referred to as "red-line" parameters - usually a critical pressure or temperature which, if a certain limit is exceeded, can seriously damage or destroy the engine and/or facility, or endanger personnel. This type of recorder gives the test engineer a constant real-time readout of these critical parameters, but is limited in frequency response to approximately 1 cps. Therefore, any data which will be subject to fast-rise times and frequent changes could not be recorded on a strip chart. Photographs of the Leeds and Northrup single-channel recorder are shown in Figure XIV-1. Chart paper is 6 inches wide and trace is produced by an inking pen.

Moving upward in frequency, 6 eight-channel Offner (Beckman) recorders are available with a frequency response of 0-100 cps. Presentation is 4.0 centimeters in width for each channel, with the writing being accomplished by a heated stylus on heat-sensitive paper. A wide choice of push-button-selected chart speeds is available so that good data resolution is possible at all frequencies within the range of the instrument. The Offner eight-channel recorder is shown in Figure XIV-2. These recorders are used to record real-time data on which an immediate readout is required within a few minutes after completion of the test. In many instances selected data channel outputs will be paralleled to these recorders and the DDS. In the event of test malfunction immediate trend information is available from these recorders, whereas a certain time delay is involved in recovering the information from digital tape. In addition to this, the information thus recorded serves as a backup in the event of a failure in the DDS.

D. WIDE-BAND RECORDING

The major application of the ARS will be the recording of data in the range of 100 cps to 20,000 cps. To accomplish this, two different types of recorders will be used, light-beam oscillographs and magnetic tape recorders.

1. Oscillographs. The 3 oscillographs furnished are fifty-channel recorders made by Midwestern Instruments. Figure XIV-3 includes photographs of the Midwestern Oscillograph. These record by what is known as direct-write process. Up until a few years ago, all oscillographs which recorded on photo-sensitive paper required developing and drying of the paper in much the same manner as film, before the record was usable. This was a good process and produced a clear record. But as test programs got larger and larger, the test engineers demanded more and more measurements, and processing time approached the point where it was becoming unacceptable. The direct-write oscillograph was the result. Here a very high energy light source is used, together with a special paper, to produce a record which will develop itself when exposed to ambient light conditions. To accelerate the process, an ultra-violet lamp is provided which can be adjusted to focus on the paper and bring out the traces almost instantaneously. With the present selection of galvanometers and recording speed, a theoretical frequency response of 6000 cps can be obtained with these oscillographs. However, practical considerations such as test duration, recording speed, paper supply, etc., place this at approximately 250-500 cps. For a test duration of 10 minutes and a 450-foot roll of oscillograph paper the maximum recording speed is 45 feet per minute. This is equivalent to 0.75 ft/sec or 9 inches/sec. The figure of 250-500 cps maximum frequency to be recorded on the oscillograph is based on the assumption that data will be recorded continuously for the duration of the test. If it should prove feasible to record only certain portions of the test (start-up, shutdown, etc.) this maximum frequency could be extended considerably.

The recording galvanometer, which is the heart of the oscillograph, deflects proportionally to the amount of current which flows through its coil. Therefore, the current requirement for a galvanometer increases as its frequency response goes up. Since the signal source (signal conditioner, wide-band amplifier, or magnetic tape reproduce amplifier) is generally limited in the current it can supply, galvo driver amplifiers are used to drive high frequency galvanometers.

Forty-eight galvo driver amplifiers are supplied by Vidar Corporation. This provides a total of 16 amplifiers per oscillograph. The Vidar Model 410 is a high level dc amplifier designed to drive low impedance

loads requiring currents up to 100 ma. Input impedance is greater than 1 megohm and maximum input flexibility is provided by an eight-position attenuator with vernier control. Output impedance is less than 1 ohm and provision is made for mounting series and shunt resistors for proper matching to the load.

Other channels may be patched directly to more sensitive galvanometers through appropriate matching networks.

Recording speeds are push-button-selected and a wide range is available (0.16 ips to 160 ips). A reverse drive control permits rewinding the paper any desired distance for a second look, or to develop the traces under the latensifier lamp.

2. Magnetic Tape Recorders. To complete the wide-band recording capability, 5 magnetic tape recorders with a frequency response (when used in the FM mode) of 0 to 20,000 cps are available. These are of various configurations as shown below:

- a. One recorder with 14 tracks, full record and reproduce electronics.
- b. One recorder with 32 tracks, full record and reproduce electronics.
- c. Three recorders with 32 tracks, record-only electronics.

All recorders use 1-inch tape, and tape speed is servo controlled. All recorders have electrically switchable tape speed controls on the front panel, providing a choice of 60 ips, 30 ips, 15 ips, 7-1/2 ips, 3-3/4 ips, 1-7/8 ips, recording or playback speeds. An additional edge track is provided on each recorder for voice recording.

The Analog Recording System block diagram is shown in Figure XIV-4. All data recorded on analog magnetic tape is done in FM mode, with one assigned data parameter per track. With one track per recorder reserved for time correlation, there will be 137 tracks available for recording of wide band information. No multiplexing of carrier frequencies is contemplated at this time. In the FM record process the transducer voltage, after signal conditioning, amplification, and isolation, is patched to a VCO (voltage-controlled oscillator) which generates a specific center carrier

frequency (108 kc at 60 ips). The input voltage from the transducer deviates the carrier from center frequency by an amount proportional to the amplitude of the input voltage. Maximum deviation is +40% for full scale frequency modulation of the carrier. This is the signal that is recorded on the tape. In the reproduce mode, information is recovered from the tape by reversing the process. The electrical signal from the tape is "read" by the reproduce head, amplified, and the original data is reproduced by a discriminator. From this point the data is recorded on any recorder with necessary frequency response, or it is routed through an analog-to-digital converter for digitizing, and then to a computer for a print out in engineering units.

In most applications, the data is reproduced at the same tape speed at which it was recorded. However, in a case where it is necessary to reproduce very high frequency data, (5 kc to 20 kc), some problems arise, and a somewhat different method is used. For instance, suppose some vibration data which is calculated to peak out around 16 kcps is recorded. Using the galvos supplied with this system, the oscillograph has a frequency limitation of around 6 kcps, so, in order to make a record of this data, it becomes necessary to somehow reduce this to a frequency that can be handled, and at the same time, not degrade the data. The magnetic tape recorder, with servo-controlled tape speed, provides an ideal method of doing this by reducing the tape speed when reproducing the data. For example, if this 16 kcps data is recorded at 60 ips and reproduced at $7\frac{1}{2}$ ips, the original frequency will be effectively reduced by a factor of 8, or to 2 kcps. This can be recorded on an oscillograph with no problem. This is known as time base expansion. If required, the time base can also be contracted.

A tape search unit is also provided as part of the magnetic tape system. This provides a method for searching a reel of tape for a specific time, or time interval. The unit reads a pre-recorded time code from the tape and can be programmed to search out a start time at high speed, reproduce for a specific time interval to a stop time; rewind and repeat the cycle, or stop, depending on how it is programmed. It can also be programmed to remotely start and stop a recorder in synchronism with the programmed time interval. Programming is accomplished by selecting time of

interest on the control panel and initiating "Search Start." From there on, operation is automatic, but can be stopped with an override command at any time.

E. PATCHING

Referring again to Figure XIV-4, with the exception of the wide band inputs to magnetic tape, all signal inputs to the ARS are wired to the analog patchboard. At this point, all measurements are patched to their respective recorders. A separate patchboard is provided for the magnetic tape recorder inputs, and the 168 wide band amplifier outputs are hard-wired to this board. Forty-eight of these wide band outputs are also paralleled to the analog patchboard to provide a capability for real-time oscillograph recording of wide band data. Forty-six tape track outputs can also be patched back to the analog patchboard for making oscillograms of magnetic tape data.

F. OPERATION AND CONTROL

1. Non-Test Operation. During setup, checkout, and calibration of the system, all recording equipment will normally be operated in the manual mode to allow maximum flexibility.

2. Test Operation. After setup, checkout, and calibration of the system has been accomplished and the countdown is approaching firing time, at T-x minutes all recorders will be switched to "Remote" and control of the recorders will revert to a "Recorder Operations Master Controller" panel. This will provide control of all analog recorder functions from one central point. Status indications are also provided here, and at the Lead Instrumentation Engineer console. At this console the LIE can, at his discretion, switch recorders to "Jump Speed" and back. This increases recorder speed by a specific ratio. What that ratio is depends upon the recorder being switched. Quite often it is necessary to do this in order to record startup and shutdown transients.

Front Cover Closed

Front Cover Open

LEEDS and NORTHRUP SINGLE CHANNEL RECORDERS

FOR TRAINING USE ONLY

FIGURE XIV-1

WITH AMBIENT LIGHT SHIELD

WITH HEATED PLATEN EXPOSED

FIGURE XIV-3

NERVA
TRAINING

MIDWESTERN OSCILLOGRAPHS
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FIGURE XIV-3

FIGURE XIV-4

**ANALOG RECORDING SYSTEM
BLOCK DIAGRAM**
FOR TRAINING USE ONLY

FIGURE XIV-4

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XV
EVENTS RECORDING SYSTEM

A. INTRODUCTION

In an operational test activity certain functions occur which, when correlated with time, help to give meaning to all other test data. These are called events and are primarily recorded on special recorders known as Events Recorders.

B. GENERAL DESCRIPTION AND FUNCTION

The Events Recording System is designed for one specific purpose; to record the presence or absence of a signal. These event signals are derived from various sources such as pressure switches, limit switches, alarm circuits, and control circuits; and are strictly an on or off type function. All inputs to this system terminate at two events patchboards. At this point the signals can be patched to the Events Recording System, the Digital Data System, and the Analog Recording System.

C. BLOCK DIAGRAMS

Events signals are derived from different sources and can be divided into three main classifications.

1. RSV Event. The block diagram of a typical remote shutoff valve (RSV) event channel is shown in Figure XV-1. One command signal and two indicator signals are received at the events patchboard from the remote shutoff valve circuit. The command signal is initiated from a control point (CP) console by the closure of the switch that remotely operates the

shutoff valve. The indication signals are from OPEN or CLOSE limit switches mounted on the valve itself.

2. SV Event. The typical solenoid valve (SV) event channel block diagram is seen in Figure XV-2. One command signal is given by the closure of the switch that remotely operates the valve from the CP console. Indication signals are received from the power transfer relay OPEN or CLOSE contacts within the relay box. No indication signals are supplied directly from the solenoid valves.

3. Alarm Event. Figure XV-3 is the block diagram of a typical alarm event channel. A contact closure from the alarm circuit provides an indication to the event system of a hazardous condition.

D. PATCHING

As stated in the general description, all event type inputs are wired to two patchboards located in the Recorder Room. At this point, they can be patched as follows:

1. 240 inputs to Events Recorders.
2. 40 inputs, through appropriate voltage dividers, to the analog patchboard.
3. 160 inputs are provided to the Digital Data System. Parallel patching is provided where there is a requirement for recording the same event on more than one system.

E. EVENT RECORDERS

The two recorders supplied for the events system are Brush 150 channel recorders, but at present each recorder is wired for only 120 channel operation. A photograph of one of the event recorders is included as Figure XV-4. Each recorder is capable of recording up to 800 event changes per second per channel, and includes an individual solid state writing control for each channel. The recorder accepts on-off type data signals and each event is displayed in time relationship to other event channels, as well as to a time code recorded at the edge of the paper. Writing is accomplished on electro-sensitive paper through high-voltage, high-frequency pulses applied to a stationary stylus by the writing control units. The writing control unit is

a transistorized switch (one per channel) which is triggered by the incoming event signal. Threshold is set so that a 14 volt signal will positively produce a "write" condition. The chart paper (record) is 15 inches in width and a choice of 12 different chart speeds is available - ranging from .05 mm/second to 200 mm/second.

F. OPERATION AND CONTROL

1. Non-Test Operation. During setup, checkout, and calibration of the system, all recording equipment will normally be operated in the manual mode to allow maximum flexibility.

2. Test Operation. After setup, checkout, and calibration of the system has been accomplished and the countdown is approaching firing time, at T-x minutes all recorders will be switched to "Remote." In the remote mode the control of the recorders will revert to a "Recorder Operations Master Controller" panel. This will provide control of all analog and event recorder functions from one central point. Status indications are also provided here, and at the Lead Instrumentation Engineer's Console. At this console the LIE can, at his discretion, switch recorders to "Jump Speed" and back. This increases recorder speed by a specific ratio. What that ratio is depends upon the recorder being switched. Quite often it is necessary to do this in order to record startup and shutdown transients.

G. EVENT DATA ANALYSIS

Those events which will normally be analyzed on all tests will be paralleled to the DDS and the ARS for ease of correlation with other data recorded on these systems. Those which are recorded on the events recorders only, will normally be thoroughly analyzed only in the event of a test malfunction.

FIGURE XV-1

TYPICAL RSV EVENTS CHANNEL
BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XV-1

**TYPICAL SOLENOID VALVE EVENTS CHANNEL
BLOCK DIAGRAM**
FOR TRAINING USE ONLY

**TYPICAL ALARM EVENTS CHANNEL
BLOCK DIAGRAM**
(FOR TRAINING USE ONLY)

FIGURE XV-3

FIGURE XV-4

BRUSH EVENTS RECORDER
FOR TRAINING USE ONLY

FIGURE XV-4

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XVI
DIGITAL DATA SYSTEM

A. FUNCTION AND DESCRIPTION OF THE SYSTEM

The method used to record test data is dependent upon the program requirements. When only a few parameters are monitored and tests are conducted infrequently, the data reduction personnel may have time to make a detailed study directly from the strip charts and oscillograph records. When information is monitored on hundreds of channels and the test program cannot continue until the test data is analyzed, laborious and time consuming methods cannot be used. The solution in this case is to use a computer to compile and tabulate the test data.

In order to use the computer effectively, the test data is best recorded in such a manner that it can be used directly by the computer, without intermediate conversion processes. The purpose of the Digital Data System (DDS) is to accumulate pertinent test information in a form suitable for computer data reduction and test evaluation.

The DDS is capable of handling large volumes of data at high accuracies. It is the most significant and principal recording means within the Data Acquisition System.

Inputs to the DDS system include (1) both low level and high level analog signals, (2) binary event signals, (3) frequency data from speed and flow transducers, (4) range time, and (5) pre-selected identification words. The output of the DDS is recorded on digital magnetic tape. The tapes are

computer-compatible and will be temporarily stored for subsequent entry into the Control Data 3200 computer at the Administration and Engineering Building.

To prevent a catastrophic loss of data in the event of a major equipment failure, the DDS system is subdivided into two identical subsystems. Each subsystem contains its own power system, controls, instrumentation ground, and timing source. The data input to each subsystem consists of 480 analog data channels, 52 binary events and 3 counter channels. Under most operation conditions both subsystems will be operated in synchronism by the central timing system. However, either one of the subsystems may be operated at one time, or if desired, one subsystem may be assigned to the future ETS-2 Test Stand while the other operates with ETS-1.

B. LAYOUT OF EQUIPMENT

The DDS consists of the System Engineering Laboratory equipment shown in Figure XVI-1 and five model 604 Control Data digital tape recorders. Each subsystem includes one data acquisition unit, one formatter, and two tape recorders. A spare tape recorder is available for use with either one of the subsystems in the event of recorder malfunction. Rack space is provided and cables are installed for a third subsystem; however, the installation of the third subsystem is dependent upon additional funding and upon actual test requirements. The tape switching unit is common to all subsystems; also each console is designed to operate all three subsystems.

The data acquisition units are located in the Forward Control Room. Each unit accepts a total of 480 channels of analog data from the engine, test stand, and facility system. The data formatters are located in the Control Point Recorder Room. Each formatter accepts (1) serial coded analog data from one acquisition unit, (2) fifty-two open/closed or on/off external event signals, (3) frequency data from three rotary transducers, (4) range time and frame synchronization signals, (5) test and mode identification data from the master or forward control console.

The formatter combines and assembles the data in the correct makeup or format. The formatter presents all data through the tape switching unit to either of two digital tape recorders. Both the tape switching unit and the

tape recorders are located in the Control Point Recorder Room. The tape recorders are controlled by signals from the formatter and utilize load point and end-of-reel sensing. The load-point-sensing positions the tape prior to recording of data and the end-of-reel sensing is used to generate automatic transport interchange commands; this allows continuous recording of data. Tape interchange commands are also generated if excessive read parity errors are detected while recording data. A parity check is used to determine if the recorded data is identical to the data that was to be recorded.

The master control console is located in the Control Point Recorder Room. This console is the main control point for the DDS. The forward control console is located in the Forward Control Room. Both of these consoles contain system controls and indicators, subsystem controls and indicators, subsystem display select controls, and subsystem display indicators. The test cell console is located in the Test Cell Building. This console contains subsystem display select controls and subsystem display indicators. Complete control of the DDS system is always available at the master control console; however, system control can be granted to the forward control console. The subsystem display control can be granted to the forward control console or to the test cell console. The system controls are used to generate commands to all active subsystems simultaneously. The subsystem controls are used to generate commands to individual subsystems. The subsystem display controls are used to select specific channels of data for display on the digital readouts (word display) and event indicators at each console.

C. SUBSYSTEM DESCRIPTION

1. Analog Input. The analog signals entering the data patchboards emanate from the signal conditioners and are either high level (0 to ± 5 volts full scale) or low level (0 to ± 5 , ± 10 , ± 20 , ± 30 , ± 40 , ± 50 , or ± 100 millivolts full scale). The Digital Data Subsystem Block Diagram is shown in Figure XVI-2. High level signals are fed to high level time division multiplexers. These multiplexers are solid state switching devices that contain many inputs and only one output. Each input signal is connected in sequence to the multiplexer output circuit once during each sampling of the data. High level multiplexers are operated at rates of 10, 50, and 100 samples per second. Low level signals are segregated according to accuracy. Low accuracy

signals with accuracy within 0.5% of full scale, are fed directly into a low level multiplexer. The high accuracy data, with accuracy within less than 0.15% of full scale, are preamplified by narrow band amplifiers before entering a high level multiplexer. The sampling rate for all of the low level signals is 10 samples per second (10 S/S). If high sampling rates are desired for the low level data, the signals must be routed through wide band amplifiers shown in Figure XVI-3.

A total of seven input multiplexers are used in each subsystem.

<u>Input Multiplexer</u>	<u>Designation</u>	<u>Sampling Rates</u>
80-Channel L/L Multiplexer	A1	10 S/S
80-Channel L/L Multiplexer	A2	10 S/S
120-Channel H/L Multiplexer	B1	10 S/S
120-Channel H/L Multiplexer	B2	10 S/S
40-Channel H/L Multiplexer	C1	50 S/S
20-Channel H/L Multiplexer	D1	100 S/S
20-Channel H/L Multiplexer	E1	100 S/S

480 Total Input Channels

Multiplexers C1, D1, and E1 are programmable multiplexers and are connected to a digital patchboard. The sampling rates can be increased by decreasing the number of inputs. By forfeiting 40 channels of 50 S/S and 40 channels at 100 S/S any one of the following combinations can be achieved; 30 channels at 200 S/S, 12 channels at 500 S/S, or 3 channels at 2000 S/S. Multiplexers C1, D1, and E1 can be programmed to sample the inputs at any desired sequence but, caution must be used during complex programming schemes as it becomes difficult to determine the individual input sampling rate and to determine the location of the data on the tape. High sampling rates are highly desirable for limited recording of higher frequency data during test runs, or for post-test playback (at reduced speeds) of analog magnetic tape recordings.

A five channel multiplexer samples the output from each of the seven input multiplexers. Each signal from this five channel output multiplexer is stored in a sample hold circuit while it is applied to the analog-to-digital converter input circuit.

The analog converter generates a 17-bit, binary-coded decimal (BCD) word. Each BCD word consists of four 4-bit BCD characters and one sign bit. An even parity pulse is generated within the analog-to-digital converter for each of the four BCD characters. The BCD characters, sign bit, and parity pulses are serially transmitted to the formatter.

2. Formatter. The formatter receives input information from five different sources. A brief description of each input source is given.

Frequency data from the rotary transducers are fed to counters located in the DDS. Each counter output provides four-character BCD signals for the formatter unit.

Test identification information is provided by positioning selector switches on the Master Control Console or Forward Control Console. The operating mode switch indicates calibration, checkout, run data, cooldown, and other operating modes. Subsystem identification number indicates which of the three subsystems is connected to the formatter. The test number is four-character BCD number ranging from 0 through 9999. A recording mode indicator switch provides an indication of multiple, periodic, or continuous mode of operation.

Events are recorded as either fast or slow events. The fast events data is sampled at a rate of 100 times per second. The slow event data is sampled at a rate of 10 times per second. A total of 12 fast events and 40 slow events are fed to the formatter unit.

All of the analog channels from the multiplexer are fed to the formatter.

Range time data from an external timing system is supplied to the formatter as 6 BCD characters.

The formatter assembles all of the digital data for transmission to the digital tape recorder once during each 0.1 second. Each of these data presentations is called a frame. The frames are further divided into 1000 time slots or words. Each word consists of four 7-bit characters. The seven-bits comprising one character are presented simultaneously at the formatter output and the four characters are presented in sequence. The seven

bits in each character are designated 1, 2, 4, 8, A, B, and C, and correspond with the seven tracks on the tape. Format of a typical word is included.

Referring to the analog input signals, the inputs that are multiplexed at the rate of 10 samples per second are placed on the tape format once during each frame. Inputs sampled at rates of 50 or 100 samples per second are placed on the tape format five and ten times respectively during each frame. Four characters are required for each representation of an analog channel on the tape format. The total characters required for the analog data alone are tabulated below.

<u>Multiplexers</u>	<u>Analog Signals</u>	<u>Sampling Rate</u>	<u>Characters</u>
A1 & A2	160 Low Level Channels	1 S/frame	640
B1	120 High Level Channels	1 S/frame	480
B2	120 High Level (Narrow Band Channels)	1 S/frame	480
C1	40 High Level Channels	5 S/frame	800
D1 & E1	40 High Level Channels	10 S/frame	1600
Total			4000

To provide word space for the other data, twelve of the analog data channels connected to the formatter are not placed on the tape format. The channels eliminated include three from the A1, three from the B1, and three from the B2 multiplexers, two from the A2 multiplexers, and one from the D1 multiplexer. The D1 multiplexer channel is sampled 10 times per frame and the other eleven channels are sampled one time per frame. The elimination of these channels makes 21 words available for other use. Each complete frame format consists of the following information:

Range Time	6 Characters
Test Identification Number	4 Characters
Operating Mode	1 Character
Subsystem Number	1 Character
Events Data	52 Characters
Frequency-Counter Information	12 Characters
Data Samples (979 words)	3916 Characters
Start Frame Marker	4 Characters
End Frame Blank	4 Characters
Total:	<hr/> 4000 Characters

3. Digital Tape Recorders. The characters from the formatter unit are applied through the tape switching units to the tape recorder. Two tape recorders are used with each subsystem. Standard 10.5 inch tape reels are used and the operating speed is 75 inches per second.

During normal conditions the end of the tape on the operating unit is sensed and the operation is automatically switched to the standby unit. Continuous recording is possible in this manner. During abnormal conditions, more than three parity errors cause recorder crossover. One additional tape handler is provided for use with either one of the subsystems. This recorder is manually connected to the desired subsystem in the event of a simultaneous failure of both tape recorders in one subsystem.

The data are recorded in gapless format and, upon completion, each reel of tape is temporarily stored for subsequent entry into the Data Processor. On-line data processing is not presently planned; however, the present equipment can be used to achieve on-line operation.

Three recording modes are provided and the selected recording mode controls all active subsystems. In the continuous mode, a record command causes continuous frames of data to be recorded until a stop command is provided. In the periodic mode, a record command causes frames of data to be recorded at a rate determined by the position of a frame rate selector switch. Frame rates of one per second, one per 10 seconds or one per 100 seconds are available. Frames of data are recorded at the selected rate until a stop command is provided. In the multiple mode, 1, 4, 16 or 64 frames of data (one block)

are recorded in a continuous format when a record and manual command is provided. The subsystems stop recording data automatically upon completion of recording the block of data. Subsequent blocks of data can be recorded by providing externally generated start commands. The multiple mode is normally used in connection with system calibration or for any tests where only short runs of data are to be recorded.

D. TAPE FORMAT

The digital data is recorded on magnetic tape in blocks of at least one frame. A frame requires 7.5 inches of $\frac{1}{2}$ inch wide magnetic tape. Each frame consists of 1000 four-character words numbered 000 through 999. The format for one frame is shown in Figure XVI-4.

Word 000 is the start of frame code. It is identified by the presence of bits recorded in tracks 8 and 4 of all four characters.

Coded analog data from the data acquisition system is recorded in words 001, 003, 006-008, 011-013, 016-018, 021-023, and 025-998. All of this analog data is recorded in BCD format using data tracks 1, 2, 4, and 8. A bit is recorded in track B of the least significant character if the data is negative.

The twelve fast-events signals are recorded on tracks 1, 2, and 4 of words 002, 102, 202, 302, 402, 502, 602, 702, 802, and 902. No information is recorded in track 8 to prevent confusion with the start of frame code. The 40 slow event signals are recorded on tracks 1, 2, 4, 8, and B of words 010 and 014 and the first two characters of word 015. Track 8 contains the complement of the information in track 4. Thus one and only one signal will be present in tracks four and eight of each character.

Any one of ten operating modes, such as calibration, checkout, run data, or cooldown is recorded as the first character of word 004. A subsystem identification number (100, 200, 300) is recorded as the second character of word 004. Range time data in seconds and tenths-of-seconds in a 24-hour day is recorded in the last two characters of word 004 and as word 005.

The test number from zero through 9999 is recorded in BCD format as word 009.

Recording mode identification data (multiple frame mode, periodic mode, or continuous mode) is recorded as the last two characters of word 015.

Flow and speed data from the rotary transducers are recorded as BCD numbers in words 019, 020, and 024.

End-of-frame identification is recorded on the third character of track A or word 999. The last character of word 999 is used to record even longitudinal parity bits for the frame. Even lateral parity bits for each character are recorded in track C.

E. MASTER CONTROL CONSOLE OPERATION

The operation of the three control consoles are similar. Complete control of the system is always available at the Master Control Console. However, control of the system or display control can be relinquished to the Forward Control Console. Display control can only be relinquished from the Master Control Console to the Test Cell Console. Control of the DDS from the various consoles is illustrated in Figure XVI-5.

Major operating controls and indicators on the Master Control Console are discussed in conjunction with Figure XVI-6.

1. Subsystem Controls and Indicators. The upper two sections of the Master Control Console Panel is divided into three identical units - one for each subsystem. The function of each control and indicator of subsystem # 1 is defined.

- a. Address Select Switches. The Address Select Switches provide for the selection of a particular time slot from 000 to 999. The information of the selected time slot will be viewed on the Word Value Indicator or the Event Status Indicator depending upon the type of information recorded on the selected time slot.

- b. Word Address Indicator. The Word Address Indicator displays the time slot number of the word or event display on the Word Value or Event Status Indicators. The Word Address Indicator display corresponds with the setting of the Address Select Switches of the console that has display control of the subsystem and may not correspond with the setting on the Master Control Console.

c. Word Value Indicator. The Word Value Indicator displays the data recorded in the time slot corresponding with the number indicated on the Word Address Indicator. If the word address corresponds to an event time slot, the Word Value Indicator will be blank.

d. Event Status Indicators. The Event Status Indicators display the contents of the format register during the time slot selected on the Word Address Indicator. Each of these indicators function during any selected time slot from 000 to 999.

e. Subsystem Power Switches and Indicators. The Subsystem Power Switch controls the power to Data Acquisition Subsystem # 1 and Formatter # 1 when the Master Control Console has control of the subsystem. Regardless of which console has control of the subsystem, the lamps indicate the status of the subsystem power.

f. ETS-1 or ETS-2 Indicators. These indicators are provided for indicating that the subsystem is in use with either one of two test stands.

g. Subsystem Parity Indicator. This indicator provides a visual display when more than ten parity errors occur in one frame.

h. Activate Switches. The Reset Switch is used to reset the timing functions within the subsystem. This switch is operable only if the subsystem has not been started. The reset indicator light is on whenever the Reset Switch is operable and regardless of which console has control of the subsystem.

A Ready Indicator shows that the subsystem is ready for operation. The lamp is extinguished when the subsystem is in the record mode.

The Record Switch is used to place the subsystem in the record mode when the Master Control Console has control of the system. The Record Indicator shows the status of the subsystem regardless of which console has control.

The Stop Switch permits stopping the subsystem when the Master Control Console has control. The indicator lamp is on whenever the subsystem is not running.

i. Tape Status Indicator. One indicator is provided for each tape recorder. Both "Ready" and "In Service" indicator lamps are provided.

j. Tape Parity Error Switches and Indicators. A Nixie indicator shows the number of parity errors per frame that occur on the operating tape recorder. If tape recorder transfer occurs, the Nixie indicator holds the accumulated error count.

A Display Reset Switch allows resetting the parity counter and Nixie indicator to zero.

Error Transfer Reset Switch. This switch enables a retransfer of the tape units after tape has been changed on the initial tape recorder. The Error Transfer Reset Indicator becomes lighted when a transfer occurs and becomes extinguished when the retransfer is made.

k. Clock Status Switch and Indicators. The Master Indicator is on when the external timing system is running the subsystem.

The Internal Indicator is on when the external timing system fails and the system is operated from the internal subsystem timing system.

The Test Switch checks the internal timing system. The Internal Indicator is lighted when the Test Switch is depressed and if the internal timing system is operating.

2. Console Power Switch and Indicator. A separate "Power On" switch and indicator lamp and a separate "Power Off" switch and indicator lamp are provided for the Master Control Console, the Forward Control Console, and the Test Cell Console. The Master Control Console power is controlled from the Master Control Console only. The power to the other consoles can be controlled from the individual consoles as well as from the Master Control Console.

3. Control Request Switches and Indicators. A key switch is provided for each subsystem. The key switches are used to assign each subsystem to Engine Test Stand 1 or to Engine Test Stand 2.

A subsystem request indicator lamp is provided for each subsystem. When control of one of the subsystems is requested from the forward control

console, the FCR indicator lamp section of the corresponding subsystem switch flashes. Control is granted by depressing the switch. With control granted to the FCR the indicator lamp comes on steady. When control is no longer desired at the Forward Control Console, the CP indicator lamp section of the switch starts flashing. Control is obtained by depressing the subsystem switch a second time. The Master Control Console has control at all times except when the FCR light glows steady.

4. Display Request Switches and Indicators. The Control Selector Switch is used to grant control of the word value and event status display rates to the Forward Control Console or the Test Cell Console if a request has been received from one of those consoles. The switch returns the control to the Master Control Console when it is returned to the CP position.

A Display Rate Switch selects the rate at which the word value display or event status is updated on all three subsystems. This switch is operative only when the Master Control Console has control of the display function.

When a display request is made from a console other than the Master Control Console, the appropriate Request Indicator Lamp flashes. The lamp goes off when the Display Control Selector Switch is set to the corresponding position.

The Control Granted Indicator, is on steady when the Central Selector Switch is positioned to the requested position. When display control is no longer required at the particular control console the Control Granted Indicator flashes.

5. Recording Mode Switches. The Mode Selector Switch determines the recording mode of operation of the subsystems under control of the Master Control Console.

The Frame Rate Selector Switch determines the rate at which frames of data are recorded during the periodic mode of operation.

The Number-of-Frames Selector determines the run length during multiple mode operation. The Manual Switch is used in conjunction with the Number-of-Frames Selector. Each manual start command causes the selected number of frames to be recorded.

6. System Control Switches and Indicators.

a. Subsystem Operate/Standby Switches (SS-1, SS-2, SS-3). The Subsystem Operate/Standby Switches in the operate position allow the particular subsystem to be commanded by the system activate switches on either the Master Control Console or the Forward Control Console. In standby position, the subsystem can be commanded by the subsystem activate switches on the Master Control Console or the Forward Control Console.

b. Activate Switches. The four system activate switches have the same function for the entire system that the subsystem activate switches have for each individual subsystem. The system activate switches have control over the subsystems that have the operate/standby switches in the operate position and that are under the control of the Master Control Console.

c. Operating Mode Selector Switch. The number set on the Operating Mode Switch is used to give the identity of type of run data. The selected value is recorded once during each frame.

d. Test Number Switch. The four test number switches can be set to any number from 0 to 9999 to identify the test number. The selected value is recorded once during each frame.

e. Spare Tape Handler Indicator. This indicator is lighted when the spare tape recorder is available and ready for operation. The spare tape recorder is controlled from the Tape Switching Unit.

7. LIE Console System Status. A separate switch and indicator is provided for each subsystem. The Ready Switch for each subsystem, when momentarily energized, lights the corresponding subsystem Ready Indicator on the LIE Console if the subsystem is in a ready status. The indicator lights on both the Master Control Console and the LIE Console are extinguished if the subsystem returns to a "not ready" status.

F. FORWARD CONTROL CONSOLE AND TEST CELL CONSOLE

The front panel layout of the Forward Control Console and the Test Cell Console are shown in Figures XVI-7 and XVI-8. The Forward Control Console contains provisions for system control, subsystem control, and subsystem

display control. The Test Cell Console has provisions for subsystem display functions only. Comparison of the three console front panels gives an indication of the operations that can be conducted for each console location.

Master Control Console

Forward Control Console

Test Cell Console

Data Acquisition Units

Data Formatter

Tape Switching Unit

Figure XVI.1

TEST CELL
BUILDING

FORWARD CONTROL ROOM

RECORDER ROOM

DATA PROCESSING ROOM

CONTROL
ROOM

FIGURE XVI-2
DIGITAL DATA SUBSYSTEM
BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XVI-3

SUBSYSTEM NO.1
AMPLIFIERS & PATCHBOARD
 FOR TRAINING USE ONLY

FIGURE XVI-3

CONSOLE CONTROL BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XVI - 6

MASTER CONTROL CONSOLE
FOR TRAINING USE ONLY

FIGURE XVI - 6

FIGURE XVI-7

FORWARD CONTROL CONSOLE
FOR TRAINING USE ONLY

FIGURE XVI-7

FIGURE XVI - 8

TEST CELL CONSOLE FOR TRAINING USE ONLY

FIGURE XVI - 8

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION XII
NEUTRONICS SYSTEM

A. PURPOSE AND FUNCTION OF THE NEUTRONICS SYSTEM

1. Purpose. The Neutronics System has four functions: (1) to indicate reactor power level from source level to full power; (2) to furnish an analog signal which is the log of reactor power which can be used for reactor power control; (3) to provide fixed power, floating power and period scram signals to the safety system; and (4) to provide period and e-folding signals which can be used for reactor control and analysis.

2. Function. The function of the Neutronics System is to accept current levels and pulses from various types of neutron detectors located in the S-2 side shield and on the reactor dome; to condition the pulses from the start-up detectors for acceptance by scalars and count rate meters; to convert the log detector current into a voltage which is proportional to the log of the detector current; to convert the current from the linear detectors into ten decades of linear voltages with automatic range changing for each decade; to differentiate the log voltage resulting in a signal which represents the period of the reactor; to compare the log power with demanded and selected levels to develop a scram signal when a selected fixed or floating power difference is exceeded; to develop a period scram signal when the rate of change of log power per unit time exceeds a selected value; and to electronically analyze the linear power signal to develop e-folding times. All log and linear power is displayed by meter in terms of watts of power. All period indications are displayed by meter in terms of seconds. E-folding

times are displayed in seconds on a digital readout. A means of functionally checking all nine shield mounted detectors by a neutron source as an end-to-end system check is provided.

B. GENERAL DESCRIPTION OF THE OVERALL SYSTEM

The neutronics system is a part of the TSCS system and consists of the following major subsystems:

1. Neutron Detectors
2. Start-up System
3. Log System
4. Linear System
5. Reactor Safety System
6. Calibration System
7. Source Drive System
8. Fission Channel

The detailed description of each subsystem is covered in the order listed above.

C. NEUTRON DETECTORS

The Test Stand Nuclear Instrumentation and the Engine Nuclear Instrumentation systems use two different types of neutron detectors; BF-3 detectors and compensated ion chambers. The basic configuration of the BF-3 detector, the ion chamber, and the compensated ion chamber are shown in Figure XII-1.

1. WL-6307 BF₃ Detectors. These detectors are used in the start-up channels. The 6307 proportional counter is designed to detect neutrons of thermal energy in the range from 10^{-1} to 10^5 neutrons/cm²/sec. The use of boron trifluoride, BF₃, proportional counters for the detection of thermal neutrons depends upon the nuclear reaction $^{10}\text{B} (n, \alpha) ^7\text{Li}$. The ionization resulting from the energy loss of the alpha particle and lithium nucleus in boron trifluoride gas is collected and gives rise to a pulse charge at the collecting electrode for each boron disintegration occurring in the counter. This counter is extremely rugged, meeting military specifications for shock and vibration and will operate in any position at temperatures up to 250°F. The materials used have been selected for low activation properties. The thermal neutron sensitivity of the WL-6307 is approximately 4.5 counts/neutron/cm² at an operating voltage of 2000 volts.

2. Compensated Ion Chamber WX-5362. The compensated ionization chamber has two volumes. One volume is coated with ^{10}B which has a high thermal neutron cross section for the $^{10}\text{B} (n, \alpha) ^7\text{Li}$ reaction. The current from this volume is due to the neutron flux plus the gamma. The other volume is sensitive to gamma only. The neutron sensitive volume has a positive high voltage while the other volume has negative high voltage resulting in a net current due to neutrons only.

The WX-5362 is used for all log and linear channels. It is an electrically compensated ion chamber designed for operation with a fixed, applied compensating voltage. The chamber is of guard-ring construction utilizing high-purity alumina ceramics throughout. The outer shell and support structures are titanium; the electrodes and electrode support structures are beryllium to reduce low energy photon response and internal gamma heating. The gas fill is nitrogen to maximize the plateau length. The thermal neutron sensitivity with a 19.5 cm nitrogen fill is 5×10^{-15} amps/nv. The term nv is the number of neutrons falling on 1 cm^2 of target material. The uncompensated gamma sensitivity is about 2×10^{-13} amps/R/hr.

D. START-UP CHANNELS

Three independent start-up channels are utilized in the testing of the NERVA engines. Neutron detection is by BF-3 (WL-6307) proportional counters. These start-up channels incorporate a pulse amplifier, amplifier-discriminator, and scaler. The pulse outputs from the discriminator circuits are conditioned by pulse to log current converters. The log count rate is displayed on count rate meters. Block diagrams of the start-up channels are shown in Figure XII-2.

The start-up channels will monitor the reactor power levels from source level to five decades above source level. The total counts from all three channels are displayed on the Lead Reactor Engineer Console. The three log count rates are also displayed on the Lead Reactor Engineer Console, and any one of the log count rate channels can be selected for display on the Assistant Test Engineer Console.

E. TEST STAND LOG POWER CHANNELS

The three test stand log power channels utilize WX-5362 compensated ion chambers for neutron detection. The range is 7.5 decades below full power to 500 percent above full power. The log channels serve three functions:

(1) power level monitoring, (2) input to the safety system for malfunction detection, (3) power feedback signal for the Engine Control System.

The output currents from the log power detectors are fed to log microammeters. The output of each individual log channel is displayed on single range eight decade log meters. Figure XII-3 includes the log channels for the Test Stand Neutronics system. A more detailed block diagram of the log microammeter is included in Figure XII-4. A second output from each microammeter is connected to an averaging circuit. Normally all three log channels are averaged, but an automatic circuit rejects from the average any one signal outside of a predetermined span around the average. Controls at the Lead Reactor Engineer Console permit inhibiting of the automatic reject circuit for each log power channel. Additional switches provide manual rejection of any of the channels from the averaging circuit. There are two averaging amplifiers as a reliability redundancy. The output of the two average amplifiers is auctioneered. If either one fails high it will be rejected from the circuit. Because the outputs are auctioneered a low failure will not affect the control signal. When an amplifier is rejected it locks out until manually reset from the LRE console. The average reject circuit block diagram is shown in Figure XII-5.

The average log power as well as the three log power channels are displayed on the Lead Reactor Engineer Console and recorded in the Data Acquisition System.

The average log power signal is used to generate an average period signal. The average period is recorded in the Data Acquisition System and is displayed as a meter reading on the Lead Reactor Engineer Console.

F. ENGINE NUCLEAR INSTRUMENTATION

The Engine Nuclear Instrumentation consists of three log power channels. The detectors are located on the pressure vessel dome and are of the same type as the test stand log power channels. The electronics is identical with that used in the Test Stand log power instrumentation. Displays on the Lead Reactor Engineer Console are also identical for both neutronics systems.

In addition to the meter displays, the low nuclear power signal is displayed digitally on the Lead Reactor Engineer Console and recorded on a printer.

G. LINEAR CHANNELS

The three redundant linear channels use WX-5362 compensated ion chamber detectors. The linear channels are used to indicate and record power in watts and to measure power increase time. Linear system block diagram is shown in Figure XII-6. The current from the ion chamber is fed directly to an auto-ranging picoammeter. The linear power is monitored on multi-range displays which consist of a ten decade digital display and a linear power meter.

Linear channels monitor the power level over eleven decades. The first decade is 0 - 2 watts and the eleventh decade is 0 - 20,000 megawatts. All three linear channels are displayed on the Lead Reactor Engineer Console, and any one of the linear channels can be selected for display on the Chief Test Engineer Console.

The power increase time is monitored at the Lead Reactor Engineer Console. Any one of the linear channels can be selected for input to the power increase timer. Selected folding times of ϵ , $\epsilon/2$ or $\epsilon/4$ are displayed digitally.

The linear channel outputs from the picoammeters are fed to the Data Acquisition System, but the power increase time is not recorded.

H. ENGINE CONTROL SYSTEM

A power control switch on the Lead Reactor Engineer Console is used to select either the test stand average log power or the engine average log power. The test stand neutronics system average log power is hard wired to the input of the safety circuit. The average log power of the neutronics system that is selected for Engine System Control is then displayed on the Chief Test Engineer Console. The corresponding average period reading is displayed on the Assistant Test Engineer Console.

I. REACTOR SAFETY SYSTEM

The Lead Reactor Engineer Console provides controls for setting parameters for automatic reactor scram. These parameters include: (1) floating power, (2) fixed power, and (3) period. The average log signal from the

TSCS neutronic system is conditioned and compared with these three parameters. If an excessive power level is encountered or the period is short, the reactor will be automatically scrammed. The safety system block diagram is shown in Figure XII-7.

J. NEUTRONICS CALIBRATION SYSTEM

The Neutronics Calibration System includes: (1) range calibrator which provides signals for calibration and checkout of the log and linear channels, and (2) pulse calibration of the startup channels.

1. Range Calibrator. The Range Calibrator includes separate voltage references for the log system and the linear system. Common switching functions place various resistors in series with the voltage references and the amplifiers. The resulting calibrated currents delivered to the amplifiers simulate the detector current and serve for setup, calibration, and checkout of the log and linear systems. In the Local Calibrate mode the operator may select any current between 0.3×10^{-12} amperes and 1.0×10^{-2} amperes in steps of 1 or 3×10^{-n} amperes.

Other switching provides specified currents for use in data calibration. These current levels are 0, 25, 50, 75 and 100 percent of the full scale data channel. In the Data Calibrate Mode the calibration currents sent to the log systems are 10^{-10} , 10^{-8} , 10^{-6} , 10^{-4} and 10^{-2} amperes and to the linear systems are 0, 2×10^{-3} , 4×10^{-3} , 6×10^{-3} , 8×10^{-3} and 10×10^{-3} amperes.

A one point remote calibration of the log and linear systems can be initiated from the LRE Console. This results in a 1.0×10^{-2} amp current from the Range Calibrator and is used for a quick check on system calibration.

The Range Calibration is also used with the Test Simulation System. In this mode the reference voltage supplies are replaced with a simulate signal from the Test Simulation System and the signal is sent through the range calibrator to various log and linear amplifiers.

2. Pulse Calibrator. A pulse generator is located in the Test Cell Building Electronics Room in Rack 44 near the startup pulse amplifiers. Both the pulse amplitude and pulse rate are adjustable, with the pulse repetition rate controllable from .01 to 100,000 pulses per second. The meters for the startup system are scaled from 10^{-1} to 10^5 counts per second on a log scale for a six decade operation.

A Local/Remote switch allows the operator to select the mode of operation. In local operation the operator can select a calibration rate of 1, 10, 10^2 , 10^3 , 10^4 , 10^5 counts per second to check out the electronics system from end item to end item. In remote operation the pulse generator is set at 10^5 counts per second, and the LRE Console operator, by depressing the Neutronics Calibrate switch, obtains a single point full scale calibration check of the system.

K. SOURCE DRIVE SYSTEM

The electronics part of the log and linear start-up systems can be checked out end-to-end by means of the calibration system, but this does not provide a checkout of the neutron detectors. The source drive system enables end-to-end checkout of the S-2 shield mounted neutronics channels including the neutron detectors.

This checkout is accomplished by pneumatically positioning a separate ^{238}Pu -Be neutron source close to the start-up system neutron detectors located in each of three ports in the S-2 shield. The neutron flux increase produces an increase in the pulses from the W6307 BF_3 counter and an increase in the current from the WX5362 detectors. This action is displayed on the LRE console as an increase in count rate on the start-up channel, an increase in indicated power on the linear channels, and an increase in digital voltmeter reading on the log channels. The source drive system provides not only a continuity check of the systems but will also indicate troubles in the channels if an unexpected change in output level occurs.

When the source check is complete, the three sources are pneumatically driven to a position outside the S-2 shield where they are shielded from both the detectors and from personnel working in the area. With the sources in this shielded position, solenoid driven pins lock them in place so that they cannot be inadvertently driven to an exposed position.

The source drive control system consists of a panel located in the Test Cell Building Electronics Room and a panel on the LRE console in the control room. A key is required to operate the source drive system from either location. Each source can be commanded individually, or all sources can be commanded together from the panel in the Test Cell Building. Individual source control from the LRE console is not possible. The key switch

on the LRE console disables the control from the Test Cell Building and commands all sources simultaneously to the desired position. Limit switches in the exposed and shielded positions indicate the location of the sources by means of lights mounted on both panels.

A key and a special handling tool are required to insert or remove the ^{238}Pu - Be sources from the source drive system.

L. FISSION CHANNEL

A pre-calibrated Fast Flux Fission Chamber Neutronic Power Calibrator System for initial XE-1 startup is required to: (1) give a reasonably accurate indication of power level, (2) obtain an initial calibration of the TSCS detectors and safety circuits, and (3) insure sufficiently accurate power exposure of the low power dosimeters.

1. Fission Channel Description. The detector used with the fission channel is called a fission chamber and is a pulse chamber containing uranium 238. Fast neutrons entering the fission chamber cause fission of the uranium, and the resulting fission fragments cause ionization which is easily detected electronically.

One advantage of the fission chamber is that the pulse produced by the fission fragments is so large that easy discrimination between neutron and gamma radiation is possible. By using uranium 238 or depleted uranium the fission chamber is also made insensitive to slow neutrons.

2. Fission Channel Components. Block diagram of the Fission Channel is included as Figure XII-8.

The Fission Channel consists of the following components:

- a. Fast flux fission chamber installed at the nozzle throat of the XE-1 engine.
- b. Pre-amplifier close coupled to the detector.
- c. Amplifier/discriminator located in the Test Cell Building.
- d. Scaler and Timer located in the Test Cell Building.
- e. Amplifier/discriminator located in the Control Room.
- f. Scaler and Timer located in the Control Room.

The fast fission chamber produces pulses in a number proportional to the reactor power. The preamplifier amplifies the pulses and matches the impedance of the coax cable which connects to the amplifier/discriminator located in the Test Cell Building. The discriminator rejects any pulses with an amplitude less than the setting of the discriminator. The output of the amplifier/discriminator is a series of constant amplitude pulses which can be fed to either the scaler and timer at the Test Cell Building or at the Control Room. The scaler is a standard decade scaler which is turned on and off by means of settings on the timer unit. The total count displayed on the scaler is the counts per unit time as selected by the timer.

3. Fission Chamber Calibration. Calibration of the Fission Chamber requires portions of the calibration to be done at ETS-1 and portions accomplished at WANEF, Westinghouse Astronuclear Experimental Facility in Pittsburgh.

The Fission Chamber is first calibrated at NRDS using a ^{238}Pu - Be source. It is then shipped to WANEF where the source calibration is repeated to verify proper operation of the channel.

Next the detector is installed on the nozzle of a reactor mockup similar to the reactor which will be operated at ETS-1. The reactor is brought up to a known power level and the Fission Channel counts-per-minute per watt relationship is established.

Completion of the calibration procedure is accomplished by shipping the Fission Channel back to NRDS and repeating the source calibration to guarantee that the unit is still functioning properly.

4. Calibration of Neutronics to Reactor Power Level. Prior to use with the reactor, the source calibration checks of the Fission Chamber is again repeated at ETS-1.

The Fission Chamber detector is then installed on the nozzle in the same position as at WANEF. Next the reactor is brought up to a power level such that a statistically acceptable count rate is registered on the scaler. A series of timed counts are recorded to establish a counts-per-minute relationship. By correlation with the counts-per-minute per watt relationship established at WANEF the reactor power in watts is calculated.

The Neutronics channels are then electronically adjusted to agree with the calculated power determined from the fission channel. The log amplifiers used with the log channels are adjusted by means of an offset adjustment and the auto-ranging picoammeters used with the linear channels are adjusted by means of a gain adjustment. The accuracy of this preliminary power calibration is expected to be within a factor of 2. This is sufficient for the initial setting of the power for low power dosimetry and the settings for fixed and floating power scrams.

M. SUMMARY

The BF_3 proportional detectors are used for startup of the NERVA engine. These detectors give count rate data at very low power levels below the operating range of the linear channels. The neutronics power coverage for each channel type is included in Figure XII-9. The startup channels cover the range from approximately 0.1 milliwatt to 100 watts.

The linear channels detect the neutron level during the engine power run. These channels are used for display and data recording purposes and e-fold measurements. These channels cover the power range from approximately 100 milliwatts to 20,000 megawatts.

The log power channels are used by the Engine Control System to control the reactor power level and by the Reactor Safety System to limit a nuclear excursion. Either the Test Stand log power channels or the engine log power channels can be selected for control functions. Both log power systems cover the power range from 55 watts to 5500 megawatts. During the preliminary testing of NERVA engines the Test Stand log power channels will be used. As the program advances toward flight oriented hardware and controls, the engine log power channels will be used.

The Lead Reactor Engineer Console is primarily a neutronics console which consists of the displays and controls for both the Test Stand Neutronics System and the Engine Neutronics System.

The Assistant Test Engineer Console is used for reactor physics tests and includes reactor drum controls, period meter indication and startup log count rate.

The Chief Test Engineer Console contains the manual controls for engine operation; both linear and log power are displayed on this console to aid the operator during engine power runs.

BASIC DETECTORS
FOR TRAINING USE ONLY

FIGURE XII-1

NOTES:

- BUFFER AMPLIFIER TO DATA SYSTEM
- LOCATED ON LRE CONSOLE
- DIGITAL DISPLAY
- METER DISPLAY
- TSS INTERFACE

START-UP SYSTEM
FOR TRAINING USE ONLY

FIGURE XII-2

FIGURE XII - 3

LOG SYSTEM
FOR TRAINING USE ONLY

FIGURE XII-4

LOG MICROAMMETER
FUNCTIONAL BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XII-4

FIGURE XII-5

AVERAGE AND REJECT CIRCUIT
FUNCTION BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XII-6

LINEAR SYSTEM
FOR TRAINING USE ONLY

FIGURE XII-6

FIGURE XII-7

REACTOR SAFETY SYSTEM
FOR TRAINING USE ONLY

FISSION CHANNEL BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XII-8

APPROXIMATELY
0.1 Milliwatt

100 Watts

START - UP

APPROXIMATELY
100 Milliwatts

20 KMW

LINEAR SYSTEM

55 Watts

5.5 KMW

LOG - TSCS

55 Watts

5.5 KMW

LOG - ECS

XE-1 NEUTRONICS POWER COVERAGE
FOR TRAINING USE ONLY

FIGURE XII-9

FIGURE XII-9

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION XIII
TEST STAND CONTROL SYSTEM

A. GENERAL

The purpose of the Test Stand Control System (TSCS) is to operate those facilities that interface directly with the engine in order to provide the operating controls for the test stand and engine. Examples of such facilities are: run tank control system, malfunction detection, warning and emergency shutdown, and engine cooldown systems. Operation of these facilities cannot be completely independent of the engine or other facilities, so the TSCS must provide for proper sequencing and interlocking. In most cases, sequencing will be done by an operator from an operating console. In others, where operator reflex time may be too slow, as in the emergency cooldown initiation, the sequencing may be automatic.

The TSCS provides the ability to check out test stand operation and thereby minimize the danger of damaging either the test article or the facility. It also provides enough simulation of the test item and the test stand to allow check out of programs, sequences, and system compatibility. The simulation is extensive enough to allow a particular test to be "dry run" from the operating consoles. This not only increases competence, but helps uncover awkward or unworkable test sequences.

Test stand maintenance and calibration has been considered in the design of the simulation and checkout equipment. Provision has been made to simulate those functions which are controlled from the Chief Test Engineer Console. The checkout equipment must be considered both as a pretest quick-check device, and as an aid to troubleshooting and maintenance. Local control of the checkout equipment and easy connection with other equipment are provided.

Variable engine requirements are anticipated in the design of the TSCS, and minor engine changes do not require major control systems changes, but can be accommodated by adjustment, minor circuit or sequence change.

B. DESCRIPTION OF TEST STAND CONTROL SYSTEM

The TSCS consists of the electronic equipment and interconnections required to control those vital test stand functions most closely allied to engine operation and to display important parameters. The TSCS interfaces with other electronic equipment, with the test item and its associated equipment, and with the process systems required to operate the test article. The equipment supplied by the TSCS does not include any valves, transducers, or other items within the process system. The TSCS consists of the following arbitrarily grouped items: test stand controllers, engine control system, test simulation system, checkout system, and control consoles.

1. Test Stand Controllers. Figure XIII-1 is a simple block diagram of the TSCS. Figure XIII-2 is a functional block diagram of the grouping and the major interfaces of the TSCS. The test stand controllers are the electronic packages required to control such process systems as the LH₂ run tank pressurization system, the cooldown system, and the other process systems which directly interface with the test article. Typically, such a controller will receive the output of a transducer measuring the controlled variable. On demand from an operating console, the controller will provide the driving voltage or current required to adjust the controlled variable to the value demanded by the operator. Thus, a valve is opened or closed in order to adjust a pressure or flow rate. The controller is the point at which the

comparison of demand to actual value is made, and the appropriate voltage or current is generated to drive the valve towards the open or close position.

Most demands are set by the operator at his console. Where other than quasi-steady state demands are required, they will come from function generators. At the present, no such requirement is known.

While it is apparent that the greatest amount of sequencing is done manually by operating personnel, certain items must be sequenced automatically. As an example, the emergency engine cooldown requirements are so stringent as to require at least automatic initiation, if not automatic sequencing. In this sequence, if the turbopump or other failure in the LH_2 supply halts flow to the engine from the run tank, the LH_2 required for cooldown must be obtained from the high pressure LH_2 run tank. Full flow must be obtained in about 300 milliseconds. Assuming that the facility is capable of responding this quickly, the initiation of the flow must be accomplished faster than human reaction time could allow.

Sequencing, as used here, does not necessarily imply clocked sequence, but more often is event sequencing, as when a certain temperature is attained, etc.

2. Engine Control System. The engine control system controls all of the engine functions required for engine operation. Two basic controls are provided; reactor drum control, and turbine pump control. The controllers for these controls are provided by the engine control system. Several engine operating modes have been anticipated and the controls provided for them.

Malfunction detection and emergency shutdown are two of the functions of the TSCS. Certain malfunctions detected by the TSCS result in either a warning signal to the operator, or emergency action initiated, or both. Engine shutdown and the emergency cooldown initiation are examples of emergency action that may originate in the malfunction detection system.

3. Test Simulation System (TSS). The test simulation system consists of two separate groups of simulators: an engine simulator, and

a process system simulator. The engine simulator simulates reactor kinetics, control drum dynamics, turbopump dynamics, etc. The process system simulator simulates the run tanks, cooldown systems, etc. Process system simulation is designed not only as a checkout and operator training tool, but as an aid to maintenance and trouble shooting.

4. Checkout System. The checkout system is a stimuli and status generating system. It contains function generating equipment and measurement reading and recording devices. It has the capability of injecting stimuli into various systems and measuring the response.

The local reactor control panel, although used for checkout, is not an integral part of the checkout system, but consists of those controls required to perform control drum response tests. For those checkouts, the system will be able to utilize the function generator and recording devices of the checkout system.

5. Control Consoles. The control consoles operate and monitor the reactor, engine, and facility systems that interface directly with the engine. In addition, the consoles are connected to an analog simulation of the TSCS and engine for the purposes of: (1) studying operator procedures, (2) checkout of control loops, (3) providing operator training, and (4) evaluating hazards. The consoles display to the operator such things as the controlled variable status, demand, indication of abnormal or unusual conditions or operation, and all other data necessary for a complete manual operation. The division of the consoles and/or readouts between the various operating consoles is made on the basis of system. There are five operating consoles in the TSCS: Test Stand Engineer (TSE), Assistant Stand Engineer (ASE), Chief Test Engineer (CTE), Assistant Test Engineer (ATE), and Lead Reactor Engineer (LRE).

a. The TSE and ASE control consoles contain all of the controls and readouts related to test stand operation.

b. CTE console is the "master control" console containing all of the controls and readouts necessary for engine operation. Such controls as engine start, stop, emergency shutdown, power demand, PSV control and turbine control valve control are on this console. This

console has the ability to override the engine programmer and have manual control over those functions normally controlled by the engine programmer.

c. The ATE console contains those controls required for physics tests and displays many run parameters for monitoring during engine testing. The CTE will man this console during physics tests or whenever individual drum control is required.

d. The IRE console contains controls and readouts required for readying the reactor for test and for control of the neutronics instrumentation.

C. INTERFACE REQUIREMENTS

The Test Stand Control System interfaces with equipment on the test stand, with the Facilities System, and with the Data Acquisition System. The Test Stand Control System is the last of the major systems. The criteria used for the Facilities System and the Data Acquisition System furnished important guidelines in the design of the Test Stand Control System. The TSCS signal levels and impedances are compatible with the Instrumentation and Controls System. In fact, identical signal conditioners are used for both TSCS and the I & C system. The grounding techniques for all systems are compatible. Five of the fourteen Control Point consoles are a part of the TSCS system. All of the consoles are integrated to provide complete control for operation of the ETS-1 facility.

D. SUPPLEMENTARY MATERIAL

Three sections of the ETS-1 Instrumentation and Controls Introductory Course expand upon the main subdivisions of the Test Stand Control System.

Section XXI, Process Systems Control, includes descriptions of:

- (1) Propellant Feed System, (2) Cooldown System, (3) Purge System, and
- (4) Actuation Gas Supply System.

Section XXIII, Engine Control System, expands upon: (1) Function of the Engine Control System, (2) Description of the Engine, (3) Reactor Drum Control, (4) Turbopump Control Valve Control, and (5) Engine Operation.

Section XXVI, Test Simulation System, describes: (1) Function of the Simulator, (2) Operator Training Application, and (3) Simulator Operation.

These three study guides follow as supplementary material to Section XIII of the ETS-1 Control Point Operator General Indoctrination Course.

FIGURE XIII-1

TSCS BLOCK DIAGRAM

FOR TRAINING USE ONLY

FIGURE XIII-1

FIGURE XIII-2

TSCS FUNCTIONAL BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XIII-2

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XXI
PROCESS SYSTEMS CONTROL

A. GENERAL

In addition to engine control, one of the prime functions of the Test Stand Control System is to control those process systems that interface directly with the engine. These systems are the propellant feed system, cooldown systems, purge systems, and actuation gas supply system. A simplified flow diagram of the process systems is shown in Figure XXI-1.

B. PROPELLANT FEED SYSTEM

The propellant feed system consists of the run tank controls, the feed line to the engine and its controls, and the fill line and controls. Functionally, these controls can be separated into three systems: (1) run tank pressure control system, (2) run tank fill control system, and (3) propellant feed line control system.

1. Run Tank Pressure Control System. Figure XXI-2 is a Functional Diagram of the Run Tank Pressure Control System. In order to provide a positive inlet pressure to the engine turbine pump, and to maintain this pressure under varying flow conditions, the run tank is pressurized to whatever pressure is required to maintain the pressure at the engine inlet. It also maintains a constant pressure under static conditions; that is, when the tank is filled with no outflow except the hydrogen that is boiling off. It also provides a safety circuit to relieve pressure in the tank whenever it exceeds a preset amount. Pressure in the run tank is controlled by either bleeding GH_2 into the tank or by bleeding GH_2 off into the vent system.

To control the run tank pressure, two pressure control valves are provided; pressure control valve 50PCV165, and vent control valve 50PCV180. In the automatic pressure control mode, these valves operate to maintain the preset pressure. If the pressure is too low, 50PCV165 will be opened and allow GH_2 to bleed in until the pressure rises to the desired value. If the pressure is too high, 50PCV180 will open, allowing the gas to vent off into the vent system, thereby lowering the pressure. One demand potentiometer controls both valves. A second mode of operation is manual position control of 50PCV165 and 50PCV180. One position control potentiometer operates both valves alternately, so that only one valve can be operated at a time. This prevents the operator from bleeding gaseous hydrogen into the system and venting it into the flare stack system at the same time.

The operating controls and indications for the run tank pressure control system are located on the Assistant Stand Engineer (ASE) console. To operate the pressure control system, the following procedure is typical. After the run tank has been filled, the pressure control system is placed in manual position control. That is, 50PCV165 and 50PCV180 positions are controlled manually. The position demand potentiometer is placed in its center position. This closes both control valves. The GH_2 shutoff valves 50RSV186 and 50RSV283 are then opened. The run tank pressure demand potentiometer is set to the desired value. The MANUAL/AUTOMATIC switch on the ASE console is placed in the AUTOMATIC position. This puts the run tank pressure control system in pressure control. Valve 50PCV165 will be opened, allowing GH_2 to flow into the tank, raising the pressure until the desired value is obtained. As the pressure approaches the preset value, 50PCV165 will begin to close. If the preset pressure is exceeded, valve 50PCV180 will begin to open, allowing the pressure to relieve into the vent system. The pressure feedback parameter is 50PT99, the run tank ullage pressure. As flow out of the run tank increases, 50PCV165 will open, supplying a volume of gaseous hydrogen equivalent to the volume of LH_2 being fed into the engine.

The run tank pressure control system also has the capability of maintaining engine inlet pressure while the run tank is being topped. This will allow for extended runs beyond the capacity of the run tank storage. If the topping flow exceeds the engine flow, 50PCV180 will open to vent the added

pressure into the vent system. If the inflow is less than the outflow, the volume difference will be supplied through 50PCV165. The run tank pressure control system will also be used to drain the run tank at the conclusion of a test. The run tank pressure will be raised to some value greater than the storage dewar pressure and the fill valves opened, allowing the run tank to drain back through the fill system into the storage dewar.

The run tank pressure control system also has over-pressure protection. A comparator compares the output of 50PT99 to a preset value. If 50PT99 exceeds this value, 50PCV180 is opened, no matter what mode of operation has been established by the operator.

The storage dewar pressure control system operates in the same manner but with different compensation.

2. Run Tank Fill Control System. Topping of the run tank during a run can be accomplished either manually or by using a topping controller. The controller is not a part of the existing system but may be added in the future. This controller is a pressure demand generator for the LH₂ Storage Dewar Pressure Control. It does not directly control any valves. Final design of this controller is not complete, but one scheme which would generate the pressure demand is shown in Figure XXI-3.

During non-topping periods of operation, Switch S-1 is in the position shown in Figure XXI-3. In this mode, the storage dewar pressure is controlled in the same manner as the run tank pressure is controlled (see para. XXI-B-1) according to the demand established by the LH₂ Dewar Pressure Demand Potentiometer.

To begin topping the LH₂, dewar pressure is set to the same value as the run tank pressure. The level demand will be tracking the run tank level and is therefore preset. S-1 is activated. The input to the Dewar pressure controller is switched to the run tank level controller and the follow-up motor for the level demand potentiometer is disconnected.

In the topping mode, the run tank level and run tank level demand signals are compared and a pressure demand proportional to the difference generated. This signal is added to the run tank ullage pressure signal. The sum then becomes the input to LH₂ Dewar Pressure Controller. The run tank

pressure signal acts as a biasing signal to hold the Dewar pressure at the same pressure as the run tank under static or no-flow conditions. As flow out of the run tank begins, the measured level begins to decrease and the error between the demand and measured signals increases. This error signal adds to the run tank pressure signal, raising the dewar pressure demand proportionately.

As the flow rate increases the run tank pressure will increase in order to maintain a constant engine inlet pressure. This increase in pressure will cause a like increase in the demand to the Dewar Pressure Controller. Therefore, the flow rate is proportional to the level error and is not affected by run tank pressure except that the Dewar pressure limit cannot be exceeded. If the run tank pressure is too high, limited flow rates can be obtained.

3. Propellant Feed Line Control System. The propellant feed line is that section of line between the run tank, V-5001, and the engine (see Figure XXI-1). Included in the line are the tank shutoff valves, line vent valves, chilldown valves, propellant flow meters and pressure and temperature transducers. Control of the feed system is limited to opening and closing of shutoff valves and analog vent valve 50PCV579. Prior to opening the pump shutoff valve, PSV, the propellant feed line will be chilled by venting through 50PCV579.

C. COOLDOWN SYSTEM

In order to better understand the operation and control of the cooldown system, a brief description of the several modes of engine cooldown is given. Engine cooldown can be accomplished in any of the following modes: (1) normal cooldown, (2) flow shutdown, and (3) emergency cooldown. In order to understand better the operation of the cooldown system, a brief and rough description of the cooldown modes is included. The X-E Engine Flow Diagram is shown in Figure XXI-4.

1. Normal Cooldown. Normal cooldown is the mode of operation, wherein engine power and temperature are reduced at a programmed rate. The initial coolant LH_2 , is obtained from the run tank through the normal propellant flow path. After the engine temperature has been reduced sufficiently, liquid hydrogen is replaced with gaseous hydrogen by opening the

CSV and closing the propellant shutoff valve (PSOV). GH_2 is used long enough to warm up the propellant lines and the reactor so that the next coolant, liquid nitrogen, can be introduced into the system without freezing. After the gaseous hydrogen warm-up, liquid nitrogen is then introduced to the system and is continued at a decaying flow rate until the gamma heating of the reactor is low enough so that pulsed flow can be used. The cooldown is then completed, using "pulsed" liquid nitrogen.

2. Flow Shutdown. Flow shutdown is similar to normal cooldown, except the engine is scrammed from full power and the initial LH_2 coolant is obtained from the run tank through the tail off of the turbine pump. After LH_2 , GH_2 is introduced and from this point on the cooldown sequence is the same as the normal cooldown.

3. Emergency Cooldown. This is the mode of cooldown, wherein loss of propellant flow necessitates using the high pressure run tank for the initial coolant supply. The normal cooldown valve is opened or may already be open and the LH_2 from the high pressure tank is introduced into the normal propellant path downstream of the pump. From this point on, cooldown is similar to the above two cooldown modes; that is, LH_2 is followed by GH_2 and then by LN_2 .

4. Emergency Cooldown with GHe. Emergency cooldown with GHe begins in the same manner as emergency cooldown. Liquid hydrogen already in the cooldown line is introduced into the propellant feed system downstream of the pump. However, after a short period of time, liquid hydrogen is replaced with gaseous helium through PCV471 and RSV78. Gaseous helium is continued until the reactor temperature is low enough to use liquid nitrogen. From this point, the cooldown is the same as the others.

5. Cooldown Systems Control. The major part of the control of the cooldown system will be a manual operation. The Test Stand Engineer, serving as cooldown operator, will manually control flow rates or pressures from his console. However, due to the requirement for rapid initiation of emergency cooldown in case of loss of flow, it is necessary to automatically initiate liquid hydrogen or some other coolant into the system upon propellant flow loss. This means that both emergency cooldowns will be automatically started.

Normal cooldown will be controlled by the Engine Programmer until the LH_2 cooldown phase is complete. Then control of the cooldown will be taken over by the Test Stand Engineer. He will introduce the gaseous hydrogen, followed by the liquid nitrogen. The TSE will control the flow rate and the pulsing of the LN_2 flow.

Fast shutdown will be controlled by both the Chief Test Engineer and the Test Stand Engineer. The Chief Test Engineer will control the flow rate of LH_2 by controlling the turbine power control valve position. Then the Test Stand Engineer will take over in the same manner as in the normal cooldown mode; that is, at the time when GH_2 is introduced into the system.

Emergency cooldown will be controlled by the TSE. He will control LH_2 flow as well as GH_2 and LN_2 . Emergency GHe cooldown will also be controlled by the TSE. At the end of the LH_2 cooldown, he will open the GHe valve, replacing LH_2 with GHe. He will then control the flow of GHe until the reactor temperature is low enough to switch to GH_2 .

A cooldown fluid controller using a hydraulic analog control valve is shown in Figure XXI-5. The controller operates in either of two modes; (a) valve position control or, (b) parameter control such as pressure, temperature, or flow.

a. Valve Position Control. In the position control mode, a valve position is demanded by the position demand potentiometer. The position demand is connected directly to the servo amplifier which controls the servo valve. When one polarity signal is supplied to the servo valve, it opens one side of the hydraulic actuator of the analog control valve to the hydraulic supply and vents the other side to the hydraulic return. As the signal amplitude decreases, the servo valve opening decreases, reducing the flow rate of oil into and out of the analog control valve. The valve moves until the output of the valve position potentiometer equals the demand. The signal to the servo valve is then zero and it centers, trapping the hydraulic oil on both sides of the piston in the analog control valve actuator. The valve is then held stationary. The servo amplifiers used on PCV-471, 472 and 251 all have gains in the range of about ten. This means that a position error of approximately 5% results in the servo valve being fully open. The analog control valve then travels at its limit or maximum velocity.

b. Parameter Control. In parameter control the position demand or servo amplifier input is supplied from the automatic control amplifier. In this mode the automatic demand is set on a potentiometer. This input is compared to the measured parameter and the difference amplified and compensated in the automatic control amplifier. The output of the amplifier then becomes the position demand. When in the automatic control mode, this output is also compared to the manual demand potentiometer output. The difference is amplified, then fed into a servo motor which drives the manual demand potentiometer until the difference is zero. This allows the operator to switch to manual from auto without causing system transients.

c. A third mode of control has been contemplated in the design of these controllers. The console mode switches all have a third position labeled PROGRAM. This position has been provided for the possibility that some type of cooldown programmer would be required. The exact system is undetermined at the present time.

FIGURE XXI-1
PROCESS SYSTEMS
SIMPLIFIED FLOW DIAGRAM
 FOR TRAINING USE ONLY

FIGURE XXI-2
 RUN TANK PRESSURE CONTROL
 FUNCTIONAL DIAGRAM
 FOR TRAINING USE ONLY

FIGURE XXI-3

FIGURE XXI-5

PROCESS SYSTEM TYPICAL CONTROLS
SCHEMATIC DIAGRAM

FIGURE XXI-5

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XXIII
ENGINE CONTROL SYSTEM

A. FUNCTION OF THE ENGINE CONTROL SYSTEM

The XE Engine Control System, ECS, has been designed to provide safe and stable startup, steady-state operation, and shutdown of the engine within the operating constraints. Basically, the ECS controls the reactor period by positioning the control drums, and the chamber pressure by controlling the position of the turbine power control valve. Figure XXIII-1 is the Engine Control System functional diagram.

B. REACTOR DRUM CONTROL

The control drum position is controlled by any one of the following modes: (1) position control, (2) auto-start, (3) power control, (4) temperature control, (5) programmed temperature control, or (6) scram control.

1. Position Control Mode. In position control, the drum position signal comes from the ganged position pot. Selected drums can be placed in individual control and positioned by the associated individual position pot.

2. Auto-Start Control Mode. In the auto-start mode, the drum position signal is the sum of an exponential voltage and a ramp voltage. The asymptote of the exponential voltage and the ramp rate are set with two pots on the IRE console designated EXPONENTIAL and RAMP. At the earliest point that a measured log power signal exists, adjustable between 100 and 1000 watts within the engine programmer, a comparator will automatically close the power control loop on measured log power. The reactor will proceed on a preselected

period to a preselected power level. When this power level is reached, the auto-start is completed and the ECS awaits further instructions. Hold circuitry within the ECS allows the Chief Test Engineer to terminate the power rise at any point after the flux loop is closed.

3. Power Control Mode. The power control loop is closed through the nuclear feedback signal, $\ln N_m$, which is the voltage analog of the natural logarithm of the neutron population. The log power signal covers eight decades from 0 volts equals 55 watts to 10 volts equals 5,500 megawatts. The scale is 1.25 volts per decade. The power compensation amplifier generates a drum velocity signal as a function of the demanded log power minus the measured log power. A final integrator in the power controller generates a ganged drum position demand.

4. Temperature Control Mode. In the temperature control mode of reactor operation, the temperature compensation amplifier generates a drum velocity signal as a function of the difference between the demanded and measured chamber temperature. A final integrator, identical to the power control loop, generates a ganged drum position demand.

The chamber temperature analog signal is the average of five measurements obtained from individual thermocouples spaced about the thrust chamber. The averaging is performed by an average and reject circuit. The output of the averager is linearized. Zero volts equals 500°R and 10 volts equals 5000°R . Rejection of a single channel of measurement from the average is provided if an individual input to the circuit exhibits a deviation of $\pm 10\%$ from the average. A maximum of three channels may be automatically rejected. The circuit contains automatic provisions for individually weighing the inputs. As a channel deviates from the average by more than $\pm 5\%$, the relative contribution of that channel is decreased. Provision is also made to allow manual rejection of any input signal, with the result that up to four channels may be rejected before manual lockout occurs.

5. Programmed Temperature Control Mode. In the programmed temperature control mode the system behaves the same as in the manual temperature mode, except the temperature demand is a ramp of 12.5, 25, 50, or $100^{\circ}\text{R}/\text{second}$. The ramp rate is selectable with pushbuttons on the CTE console and the temperature demand is furnished by the engine programmer. When both temperature

and pressure are operated in the programmed mode, only the 50 and 100°R/second ramp rates are used.

6. Scram Control Mode. When a scram signal is received from the engine safety system, 24 vdc battery supply is applied to the individual drum driver amplifiers causing the drums to rotate inward at the maximum rate. When the drums are full in, the manual locking pins are automatically engaged and the drums cannot be rotated outward.

C. CHAMBER PRESSURE CONTROL

The chamber pressure loop controls the turbopump through positioning of the turbine power control valve, TPCV. The turbine flow through the TPCV is provided from a mixture of hot chamber gas and the cooler diluent nozzle bleed from the reflector. The XE engine flow diagram is shown in Figure XXIII-2. At full power the conditions are nominally: hot bleed 1.65 lbs/sec at 4090°R and 563 psia; diluent bleed 5.54 lbs/sec at 210°R and 694 psia; turbine inlet 7.19 lbs/sec at 1143°R and 419 psia.

The methods of controlling the turbine power control valve are: (1) position control, (2) engine startup, (3) pressure control, (4) programmed control, (5) scram control, (6) shutdown control, and (7) flow shutdown control.

1. Position Control Mode. In the position control mode the position demand from the CTE console is summed with the measured position in the TPCV driver amplifier.

2. Engine Startup Control Mode. Engine startup is initiated by depressing the engine start button on the CTE console. Necessary interlocking is provided to preclude engine startup under conditions which could result in damage or undue hazard to the test article. An automatic engine start command is inhibited unless the temperature demand and pressure demand mode selection have been placed in the programmed mode.

Upon receipt of an engine start command, the engine programmer commands the pump shutoff valve open. The TPCV is held closed until the programmer signals that the chilldown is complete, or until the CTE depresses a manual chilldown complete switch. The engine programmer determines that chilldown is complete when the average of three reflector inlet temperatures reach a preset temperature.

At the completion of chilldown, the engine programmer signals the reactor to increase power on a preselected period, and initiates the bootstrap operation. The bootstrap is accomplished either in closed loop pressure control or in programmed position control. In the programmed position control mode, the TPCV position demand is an exponential asymptotic to an angle preset within the engine programmer. When coincidence is achieved between the measured pressure and an operator inserted pressure demand, the pressure loop is closed. Similarly, when the chamber temperature equals the operator inserted temperature level, the temperature loop is closed.

3. Pressure Control Mode. In the pressure control mode of operation, the position demand to the TPCV driver amplifier is the compensated error signal between the demanded and measured pressure.

The measured chamber pressure is obtained by averaging the signal conditioned outputs of three strain gage pressure transducers. The averaging is performed by an average and reject circuit. With all three measurement channels functioning, automatic rejection of one of the channels occurs if an individual channel deviates in excess of $\pm 10\%$ from the average. Manual reset can be accomplished only if the offending channel returns within $\pm 10\%$ deviation. In addition, with all three channels functioning, the average and reject circuitry contains automatic provisions for weighting the pressure input signals. As an input deviates from the average by more than approximately 5 percent, the relative contribution from that input is decreased. This feature prevents a sharp pulse in the measured pressure signal, which could lead to an automatic flow shutdown in the event of a sudden change in one of the input signals. With only two measurement channels functioning, neither automatic rejection nor signal weighting occurs; however, manual reject provisions have been provided to allow for rejection of as many as two of the three input signals.

4. Programmed Control Mode. In the programmed control mode of operation the pressure demand signal is supplied by the engine programmer. Four pressure ramps of 5, 10, 25 and 50 psi/second are available. These are selectable by push buttons on the CTE console. With both pressure and temperature in programmed control, the temperature ramp is manually selected and the compatible pressure ramp is automatically selected. Since only four

pressure ramp rates exist, and two are required for each temperature ramp rate to rise to power on the operating line, only the 50 and 100°R/second temperature ramp rates are used in program control.

5. Scram Control Mode. When the engine control system receives a scram signal from the engine safety system, the drums are inserted at their maximum rate and the TPCV is automatically transferred to a temperature mode of control. The temperature demand decays from the value just prior to the scram to 1000°R on a 20 second time constant. Then the temperature demand holds at 1000°R until the TPCV is fully closed. At that time the engine control system is automatically reset.

6. Shutdown Control Mode. When the CTE manually inserts a normal shutdown demand, the pressure and temperature decay on the selected ramps until 1600°R is reached. At that point a scram is initiated and the sequence of events is identical to the scram control mode.

7. Flow Shutdown Mode. Malfunction detection circuits monitor critical parameters within the engine and determine when the continued use of the propellant supply would create a hazardous condition. When this situation exists, a flow shutdown and a scram signal is automatically generated.

Upon receipt of a flow shutdown signal the TPCV is commanded closed at the maximum rate, TBV is commanded closed, and after a time delay the PSV is commanded closed. This time delay is provided to assure continuous LH₂ supply to the turbopump until rotation has ceased. Reactor coolant is then provided through the emergency cooldown line, shown in Figure XXIII-2.

D. INHIBIT AND OVERRIDE CIRCUITS

The power/temperature controller contains inhibit circuits that provide protection against transients in the engine control system.

1. Power Mode Inhibit. If the difference between demanded and measured power exceeds a permissible preset threshold, the power mode inhibit prevents entry into the power control mode from either manual drum control or temperature control. If a large power error signal should occur while operating in power control, the power mode inhibit will be activated.

This will cause an automatic mode switch to temperature control if there is no temperature mode inhibit. If the temperature loop is also inhibited, the system will transfer to position control.

2. Temperature Mode Inhibit. The temperature mode inhibit provides similar protection against entry into the temperature control mode, if a large error exists between demanded and measured temperature. Automatic transfer out of temperature control is provided if the inhibit occurs while in temperature control. Transfer is attempted first to power control and, if unsuccessful, to position control.

3. Log Power and Temperature Override Circuit. Log power and temperature override circuits are provided to protect the reactor in the event of failure of the power or temperature control loops. The override circuits generate a negative drum demand signal proportional to the amount that the preset power or temperature override set points are exceeded.

4. Pressure Error Override. A pressure error override is provided to reduce the temperature or power demand and pressure demand, if the demanded pressure exceeds the measured pressure by a preset amount. The three override set point pots are located in rack 01L at the front of the Control Point Building Control Room.

E. FOLLOWUP SYSTEM

Automatic followup of manual demand pots is provided whenever the manual mode of operation for a given parameter is not in use. The followup accuracy is sufficient to permit mode switching from the automatic to the manual mode of operation without excessive system transients. Re-entry into the programmed temperature and pressure modes without transients is dependent upon the test operator, since no followup of the program mode is possible. The test operator is guided by error meter indication.

**ENGINE CONTROL SYSTEM
FUNCTIONAL DIAGRAM**
FOR TRAINING USE ONLY

FIGURE XXIII-1

NOTES.

- △ EACH OF THE SOLENOID VALVES (12 TOTAL) SUPPLY GN₂ GAS TO 12 COUPLING DRIVE MOTORS
- △ SOLENOID VALVES SUPPLIES GN₂ GAS TO THE PUMP INLET LINE, TO COOLDOWN LINE AND TO COMMON LH₂ VENT LINE

LEGEND

SYMBOL	DESCRIPTION
	REMOTE SHUTOFF VALVE
	CONTROL VALVE
	PRESSURE CONTROL REGULATION
	CHECK VALVE
	SOLENOID VALVE - THREE WAY
	RESTRICTION ORIFICE
	FILTER
	RELIEF VALVE

VALVE DESIGNATIONS
PSV — PROPELLANT SHUTOFF VALVE
TPCV — TURBINE POWER CONTROL VALVE
PDSV — PUMP DISCHARGE SHUTOFF VALVE
PDKV — PUMP DISCHARGE CHECK VALVE
PDVV — PUMP DISCHARGE VENT VALVE
CSV — COOLDOWN SHUTOFF VALVE
CKV — COOLDOWN CHECK VALVE
SFV — SHIELD FILL VALVE
CVV — COOLDOWN LINE VENT VALVE
HPSV — HELIUM PNEUMATIC SUPPLY VALVE
PKV — PNEUMATIC VENT CHECK VALVE
TPA — TURBOPUMP ASSEMBLY
N.O. — NORMALLY OPEN
N.C. — NORMALLY CLOSED
TBV — TURBINE BLOCK VALVE

FIGURE XXIII-2
XE ENGINE
FLOW AND INTERFACE
FOR TRAINING USE ONLY

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION XXVI
TEST SIMULATION SYSTEM

A. FUNCTION

The Test Simulation System, TSS, provides simulation of the engine and critical test stand functions. It serves three major tasks: (1) checkout of the control circuitry operation, (2) aid in establishing the readiness of the control systems and console to perform engine test operations, (3) malfunction simulation for operator training with corrective procedures as well as normal test run procedures.

To provide these functions the Test Simulation System shown in Figure XXVI-1 includes subsystems for simulating:

- a. Engine Kinetics and Thermodynamics
- b. Control Drum Actuation System
- c. Engine and Test Stand Nuclear Detectors
- d. Propellant Feed System
- e. Turbine Power Control Valve (TPCV)
- f. Pump Shutoff Valve (PSV)
- g. LH_2 Cooldown System
- h. GH_2 Cooldown System
- i. LN_2 Cooldown System
- j. GHe Cooldown System

B. OPERATOR TRAINING APPLICATION

Operator training is one of the prime uses of the simulator. To provide meaningful operator training all of the major functions of the test stand control system must be simulated. Through the simulator the operator should experience the conditions of an actual engine run. The valve indicator lights should give the conditions of the simulated valves. Pressure and temperature meters should provide indications of the simulated engine and test stand conditions.

The limitation on the extent of simulation is accuracy of the math model for the actual system. Since the primary concern is operator training, the simulator requirements can be limited to those functions which are needed to provide realism for the operator.

C. ANALOG COMPUTER MODEL

There is a big difference between an analog computer model of the system and the simulation of the system. The analog computer model at REON is used to check various control schemes. As an example, a controller is designed to be compatible with the math model, and then is tried out in conjunction with the analog computer model to determine the performance characteristics of the system. If the analog model is a good representation, the control system can be optimized using the analog model itself.

The analog computer model requires an accurate representation of all of the transfer functions of the actual system. The transfer function is a mathematical expression giving the complete description of the dynamic properties of a system.

The TSS at ETS-1 is used primarily for operator training and the operator himself cannot appreciate the dynamics of the system. The operator is aware that when he goes into a certain mode of control and starts increasing the engine pressure, the temperatures and pressures behave in some relation to one another. The dynamics of the system must be simulated well enough to provide the operator with a realistic indication of TSCS operation, but the dynamics need not be an exact analog model of the system.

D. EQUIPMENT LOCATION

The simulator is contained in racks 58 through 62 in the test cell building. Rack layout is shown in figure XXVI-2. The TSS enters into the system as close as practicable to the last control component in order to permit exercising the maximum possible control and monitoring functions in the TSS. Inputs and outputs to the TSS are programmable from a patch board. Since the simulator is designed to perform one specific function, the simulator equations are generated in a specific manner and the individual computing elements are hardwired.

Malfunctions are inserted into the TSS for the purpose of operator training. Trim potentiometers are adjusted to produce out of normal limits of the TSS. Signals available at the patch board are used to introduce abnormal dynamic responses.

E. SIMULATOR DYNAMIC LOOPS

The simulator has three basic loops: engine temperature, neutron flux, and chamber pressure, figure XXVI-3.

As a closed loop system, the engine temperature is controlled by the error between the measured and demand temperature signals. To increase the engine temperature a preset linear voltage ramp is introduced as the temperature demand. The temperature loop is closed when the chamber temperature reaches 1000° R.

As a closed loop system, the flux loop is controlled by the error between the measured and demanded Ln signals. The flux loop is closed at 1% of full power.

The pressure loop is controlled by the difference between pressure demand and measured chamber pressure. The pressure loop is closed at 100 psia chamber pressure.

F. SIMULATOR OPERATION

The operating mode of the simulator is controlled from the Chief Test Engineer Console. Three modes are provided through the key switch on the console: OPERATE, SIMULATE, and OPERATE/SIMULATE. In all three modes the actual controllers of the system are used.

In the OPERATE mode the outputs of the controllers are connected to either drum actuators or valve actuators.

In the SIMULATE mode the outputs of the controllers are connected to the simulator and the valve position is simulated. Feedback from the simulated valve positions are derived mathematically and fed back into the controller to give the effect of an actual power, temperature, or pressure.

In the SIMULATE/OPERATE mode the output of the controllers go to the TSCS Simulation Panel located in the Control Room. The TSCS Simulator Panel layout is shown in figure XXVI-4. The switches on the Simulation Panel permit the controller output to be connected to the actuator or to simulator. Regardless of which position is selected, the feedback signals representing pressure, temperatures or other parameters are derived within the simulator. In this mode, a simulator run can be conducted while actually driving the system valves. This mode is not used when there is pressure immediately upstream of a valve that will be operated.

SYMBOLS	DESCRIPTION
$\dot{W}$	FLOWRATE
P	PRESSURE
T	TEMPERATURE
$-\theta_d$	CONTROL DRUM POSITION DEMAND
(PSOV)d	PUMP SHUT-OFF VALVE POSITION DEMAND
(TSCV)d	TURBINE POWER CONTROL VALVE POSITION DEMAND
N	LINEAR REACTOR POWER
SKI	INHERENT REACTIVITY
SKD	CONTROL DRUM REACTIVITY
GH ₂	GASEOUS HYDROGEN
He	GASEOUS HELIUM
LN ₂	LIQUID NITROGEN
LH ₂	LIQUID HYDROGEN
M _T	TURBINE TORQUE

SIMULATOR BLOCK DIAGRAM
FOR TRAINING USE ONLY

FIGURE XXVI-1

TEST SIMULATION SYSTEM RACKS
FOR TRAINING USE ONLY

FIGURE XXVI-2

FIGURE XXVI 4

ENGINE CONTROLS AND
ENGINE SIMULATION FOR TSS
FOR TRAINING USE ONLY

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION XIV
RAILROAD TRANSPORT SYSTEM

A. RAILROAD TRANSPORT SYSTEM DESCRIPTION

The Railroad Transport System (RTS) is used to support the NERVA Rocket Engine Program at NRDS and is composed of the Manned Control Car (MCC), Engine Installation Vehicle (EIV), and L-3 Prime Mover. This system transports the NERVA Rocket Engine between E-MAD and ETS-1; the NRX reactor development series between E-MAD, Test Cell "C", and R-MAD; and any radioactive material to the Radioactive Material Storage Facility (RMSF). Figure XIV-1 shows the L-3, MCC, and EIV loaded with the XE Weighted Envelope Mockup (WEMU).

B. MANNED CONTROL CAR

The MCC is a specially designed railway vehicle equipped to provide electrical power, emergency tractive power, and compressed air for installation and removal of the NERVA engine from the ETS-1 Facility. A shielded cab includes radioactive shielding and life support equipment for the two MCC operators during operation. The MCC also provides the necessary controls, monitors, and viewing aids for controlling the entire RTS.

The MCC, shown in Figure XIV-2, basically consists of an undercarriage, engine compartment, and shielded control cab. The general characteristics are:

Length	31' 6"
Width	12' 6"
Height	18' 0"

Gross Weight	214,500 lbs.
Maximum Allowable Speed	6 mph
Tractive Effort	20,000 lbs.
Emergency Performance	Capable of moving the 80 ton L-3 (less EIV) up a 5% grade and a 14° curve for a distance of 1 mile.

The MCC Control System controls the MCC, EIV, and L-3. Utilizing the L-3 controls, the MCC is capable of starting, accelerating, stopping, and shutting down the L-3. In addition, the MCC control system controls all the functions of the EIV. These functions are discussed below in section C.

The Life Support Systems contained on the MCC are: Air Conditioning System, Radiation Monitoring System, Fire Control System, Emergency Escape Hatch through the MCC door, and Emergency Air Breathing Systems. The Emergency Air Breathing System contains a large storage tank and two portable units. The large storage tank is capable of supporting two men for four hours.

The MCC carries two transceivers, Net 21 and 24, for communication with E-MAD control and ETS-1 control. All communication with the MCC is accomplished on these transceivers.

C. ENGINE INSTALLATION VEHICLE

The EIV is a special purpose railroad vehicle used in conjunction with the MCC to install and remove the NERVA engine from the test stand and to support and protect the NERVA engine during periods of transport between the E-MAD and ETS-1 locations. A side view of the EIV is shown in Figure XIV-3. The general characteristics are:

Length	60'
Width across main jacks	19'
Height-Rail to top of superstructure	25'
Height-Rail to top of dust cover actuator	29' 9"
Weight, unloaded	140,000 lbs.

Load carrying capacity	40,000 lbs.
Maximum allowable speed	6 mph
Maximum radius of curvature	250'

The EIV is designed to provide the following functions: (1) inch the entire car back and forth in the test stand, (2) tilt the engine fore and aft and from side to side on outrigger jacks for leveling purposes, and (3) position the engine into the test stand using the vertical carriage, lateral carriage, longitudinal carriage, and azimuth carriage. The azimuth carriage rotates about the test article centerline and is equipped with a HOV-AIR bearing which facilitates test article installation in ETS-1.

The carriage systems provide vernier movement for precise positioning of the test article and for insertion of the test article into the test stand. Speed and travel limits of the carriage system are listed in Figure XIV-4.

The inching system will inch the EIV loaded with test article away from the MCC/L-3 at twelve inches-per-minute for precise positioning of the EIV with respect to ETS-1 Test Stand. During the inching mode, the EIV is connected to the MCC control through an expanding umbilical system shown in Figure XIV-5. The umbilical is capable of expanding a maximum of 15 feet.

The test article interface is brought to level condition utilizing the main jack system on the EIV. These jacks lift the entire EIV off the EIV springs and are independently adjustable so as to bring the test article level within twenty-two minutes of horizontal. The truck jacks provide a backup capability and accomplish all functions of the main jacks; however, the truck jacks bear against the EIV trucks, whereas the main jack system bears against the ETS-1 floor.

In addition to the leveling, inching, and carriage systems, the EIV is equipped with a Programmed and Remote Systems Corporation (PaR) manipulator system, TV system, load readout system, radiation monitoring system, dust cover system, and nozzle closure actuator system.

The PaR manipulator system consists of a vertical boom, boom extend, and a Class A manipulator capable of picking up 90 pounds gross weight in the fully extended position. Its limit of travel is approximately $4\frac{1}{2}$ feet

from top of rail to approximately 24 feet from top of rail. Mounted on the PaR system are two TV cameras, one on each side, which are capable of viewing the manipulator hand at any position around the test article.

The dust cover is normally stored in a storage rack mounted on the EIV and can be remotely operated and placed over the upper thrust structure interface for protection of the test article during transport.

The load readout system is capable of measuring loads in excess of 20,000 pounds and not exceeding 60,000 pounds with an accuracy of plus or minus 100 pounds.

The radiation monitoring system consists of two neutron detectors located on the EIV carriage system and are used for the detection of any abnormal nuclear activity on the test article during transport.

The nozzle closure actuator system is normally stored on the EIV. During the transport of the test article, the nozzle closure actuator system installs or removes the nozzle closure on the test article.

D. L-3 PRIME MOVER DESCRIPTION

The L-3, shown in Figure XIV-6, is a standard 80 ton, 56½ inch gage, 500 HP diesel electric locomotive which has been modified for NERVA use. The general characteristics are:

Length	41' 8"
Width	9' 6"
Height	13' 5½"
Gross Weight	80 tons
Maximum Allowable Speed	10 mph
Tractive Effort	80,000 lbs.

The L-3 is the prime mover for the RTS. It provides the tractive force to move the MCC and EIV between the NRDS Facilities. As stated previously, the MCC does have emergency tractive power should the L-3 fail. The L-3 has a separate motor generator which starts automatically and is used as backup electrical power in the event the MCC motor generator fails. The L-3 is normally controlled from the MCC.

FIGURE XIV-1

FIGURE XIV-3

ENGINE INSTALLATION VEHICLE
FOR TRAINING USE ONLY

FIGURE XIV-3

Carriage	Speed	Travel From Center Position
Vertical	12 IN/MIN	12 INCHES
	6 IN/MIN	
Longitudinal	7 IN/MIN	5 INCHES
Lateral	5 1/8 IN/MIN	5 INCHES
	1/8 IN/MIN	
Azimuth	5 3/8 IN/MIN	5° Rotation about the test article.

FIGURE XIV-4

FIGURE XIV-5

FIGURE XIV-5

MANNED CONTROL CAR
EXPANDING UMBILICLE SYSTEM
FOR TRAINING USE ONLY

FIGURE XIV-6

NERVA
TRAINING

L-3 PRIME MOVER
FOR TRAINING USE ONLY

FIGURE XIV-6

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION XV
TEST STAND ADAPTER

A. PURPOSE

The purpose of the Test Stand Adapter, TSA, is to provide the capability of remotely installing and removing the Test Article at the ETS-1 Facility.

B. DESCRIPTION

The TSA forms the physical link between the test stand and the test article. The TSA is mounted in the test stand and then the Upper Thrust Structure, UTS, of the test article is connected to the Test Stand Adapter. Figure XV-1 shows the TSA being transported on the Engine Installation Vehicle. The functions of the TSA are support of the Test Article and housing of the TSA/UTS Remote Interface Systems. These Remote Interface Systems include: (1) structural bolt actuation, (2) fluid systems coupling, (3) electrical connectors.

C. ALIGNMENT SYSTEM

Primary alignment of the remote TSA/UTS interface is provided by three alignment brackets mounted on the TSA at Station 42.89. The brackets incorporate lead-in chamfers that will compensate for 0.50 inch of azimuthal misalignment.

When the UTS/TSA interfaces are 3.40 inches from final mating position, the UTS lugs will fully engage the TSA alignment brackets and align the remote interface laterally. Both the alignment bracket and UTS lugs are shown in Figure XV-2.

Once interface alignment is established, the Test Article is raised vertically with the Engine Installation Vehicle (EIV) until coupling of the interface is complete. A mating load readout feature of the MCC/EIV provides verification of adequate mating load attainment.

D. STRUCTURAL BOLT ACTUATION

As the UTS is raised into contact with the TSA, captive nuts mounted on the UTS engage the twelve structural bolts, positioned around the TSA at the remote interface. These bolts secure the UTS to the TSA. Each bolt is connected to a pneumatic drive motor through a collar which mates the motor shaft to the splined head of the bolt. Figure XV-3A includes the structural bolts and captive nuts; Figure XV-3B is an internal view of the TSA showing the bolt actuators.

Each structural bolt is driven and torqued by an individual pneumatic system consisting of a filter, an oiler, pressure regulator, solenoid valve, and a motor. The motor is a standard industrial, rotary valve-position displacement pneumatic power tool. Three gear stages reduce its output speed from 14,000 to 40 RPM at 90 psig inlet pressure. The stalled torque capability in the forward direction, is 250 ft-lbs. In the reverse direction there is a 1.5 torque multiplication.

E. FLUID SYSTEM COUPLING

The fluid lines entering the Test Stand Adapter are shown in Figure XV-4. They are:

1. Engine Compartment and Thrust Structure Purge Line 201-GN-6"-AS
2. GH_2 Pneumatic Supply Line 240-GH-1"
3. Engine & TPA Purge Line 204-HE-1"-AS
4. Propellant Vent Line 203-GH-3"-AS
5. Main Propellant Feed Line 201-LH-8"-AS
6. Shield Fill Line H_2O -1"
7. Shield Vent Line H_2O -1 $\frac{1}{2}$ "
8. Pneumatic Vent Line 204-GH-2"-AS
9. Pneumatic Supply Line 201-GH-2"-ES
10. Actuator Supply Line 204-GN-1"-BS
11. Cooldown Supply Line 4-LH-6"-HV
12. Turbopump Assembly Discharge Vent Line 241-GH-5"-BS
13. Helium Pneumatic Supply Line 217-HE-1"-BS

Marmon conoseal joints are used in the TSA/UTS interfaces for the 5-inch cooldown line, the 8-inch main propellant line, and the 5-inch vent line. Each joint consists of a male and female flange, a conical metallic gasket, and a two-segment, remotely operated V-type coupling, shown in Figure XV-5A. The female flange, which is on the TSA, is designed with a lead-in guide to provide final alignment with the Test Article male flange during remote mate-up.

The coupling is suspended from the upper flange and positioned so that its horizontal centerline lies in the same plane as the mating face of the upper flange. Mounted in this manner, the coupling maintains its position relative to the upper flange during remote connect/disconnect operations.

The halves of the coupling are positioned by a pair of Acme-threaded drive screws coupled together through a chain-drive assembly. The coupling screws are driven and torqued by a pneumatic system similar to that of the structural bolts. Since the air motor is controlled from a remote location, a limit switch stops coupling travel when it reaches the "fully-open" position.

The coupling actuation air motor and chain drive assemblies are mounted on hinged platforms outside the TSA and connected to the Marmon couplings by universal drive shafts, see Figure XV-5B. With this arrangement, it is possible to remotely open the couplings in the event of a malfunction in the coupling-actuation system; i.e., the EIV manipulators would pull the hinged platform away from the TSA until the chain-drive assembly is free of the coupling screw drives. A remotely operated backup removal tool would then be engaged with the coupling drive screw, using the EIV mounted manipulators.

Seven additional "on mark" fluid line couplings provide quick connect/disconnect capability at the TSA/UTS interface. The female half of the connector is located in the TSA interface and has a self-alignment feature consisting of a flexible stainless steel bellows in line between the connector and the support bracket located in the TSA interior. The male half of the connector is rigidly fixed in the UTS interface. Both halves of the connector are shown in Figure XV-6. Axial location of the connector halves is referenced to the alignment guides joining the TSA and UTS at Station 42.89.

F. ELECTRICAL CONNECTORS

The TSA/UTS interface contains seven electrical connector modules, comprised of six connectors each. These electrical connectors provide the conductor continuity across the remote interface from the Test Article instrumentation to the readout system in the Control Point Building Control Room. Each connector is divided into two parts - male and female. The female connector is contained in the TSA interface and the male in the UTS interface, see Figure XV-7. Each connector half has a lateral and axial floating capability to permit a self-alignment feature during remote mating operations.

Each module assembly is further aligned by a guide pin on the TSA and a mating guide pin hole on the UTS. Each instrumentation conductor is checked for continuity and function prior to initiation of the Engine Test.

TEST STAND ADAPTER
EIV AND MCC

FOR TRAINING USE ONLY

FIGURE XV - 1

FIGURE XV-2

A. STRUCTURAL BOLTS AND CAPTIVE NUTS

B. TEST STAND ADAPTER - INTERNAL VIEW

STRUCTURAL BOLT ACTUATORS
FOR TRAINING USE ONLY

FIGURE XV-3

A. CONOSEAL JOINT

B. AIR MOTOR & CHAIN DRIVE

REMOTE FLUID SYSTEM COUPLING
FOR TRAINING USE ONLY

FIGURE XV-5

FIGURE XV-6

ON MARK FLUID LINE COUPLING
FOR TRAINING USE ONLY

FIGURE XV-6

TEST STAND ADAPTER INTERFACE

UPPER THRUST STRUCTURE INTERFACE