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No. NAS8-28887

E-SYSTEMS INC.

Montek Division

2268 SOUTH 3270 WEST SALT LAKE CITY, UTAH 84119

Technical Report

for the

Omni-Axis Secondary Injection

Thrust Vector Control System

July 18, 1973

E-Systems, Inc., Montek Division, Engineering Department
2268 South 3270 West, Salt Lake City, Utah 84119

OMNI-AXIS SECONDARY INJECTION THRUST VECTOR CONTROL SYSTEM

June 29, 1972 through June 29, 1973

By D. J. Kirkley

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Prepared for The George C. Marshall Space Flight Center
Huntsville, Alabama 35812

This Technical Report covers the concept, development, design study and preliminary analysis and layout of the required digital logic scheme to be used for injection valve control. It includes application and optimization study of an Omni-Axis Secondary Injection Control System applicable to the proposed Space Shuttle Pressure Fed Engine. Technical definition and analysis control procedures and test routines, as well as a supporting set of drawing sketches and reference manual, are enclosed.

SECTION I

INTRODUCTION

The goal of this program was to develop a digital Omni-axis control system for cold-gas tests to be conducted by the George C. Marshall Space Flight Center, Huntsville, Alabama. A digital control sequence was defined and implemented to control a subscale 30 valve compressed air system. The valving assembly consisted of 30 solenoid valves mounted around a nozzle exit cone that will be mated with the cold-gas test fixture at MSFC.

Interface and drive circuitry and control routines were supplied. The program yielded the data necessary to establish the feasibility of such a control system and vectoring technique. It is a major step toward future development of hot-gas control valves and systems.

The results of this program indicate that Precision Positioning Systems or Control Systems may be developed using these concepts of non-precisions hardware and low cost digital control techniques.

Figure 1-1 illustrates the cold-gas test system that was delivered to MSFC in the spring of 1973.

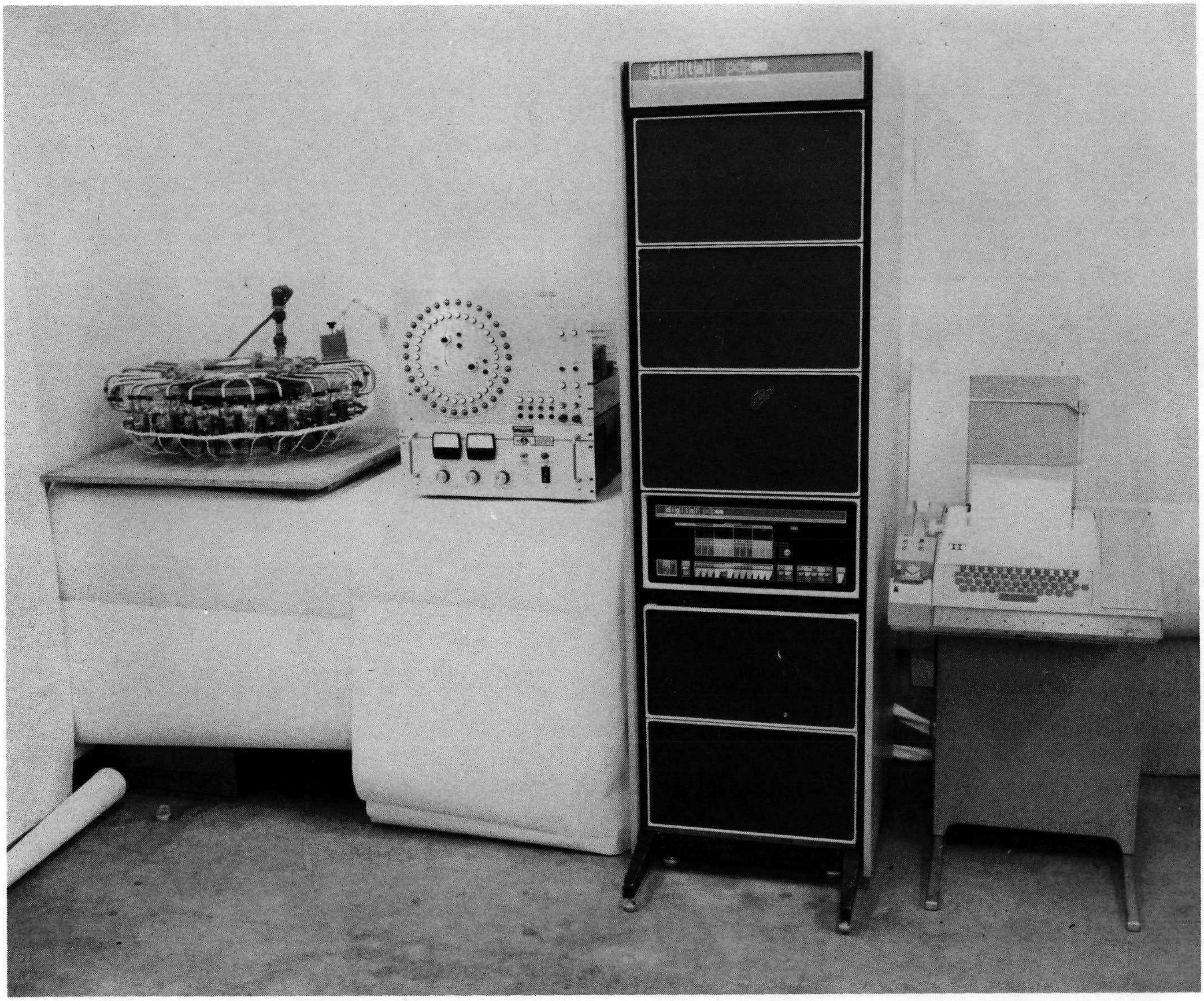


FIGURE 1-1
OMNIAXIS CONTROL ASSEMBLY

SECTION II

II. TECHNICAL DEFINITION

This Section describes the original program concept as depicted in Figure 2-1.

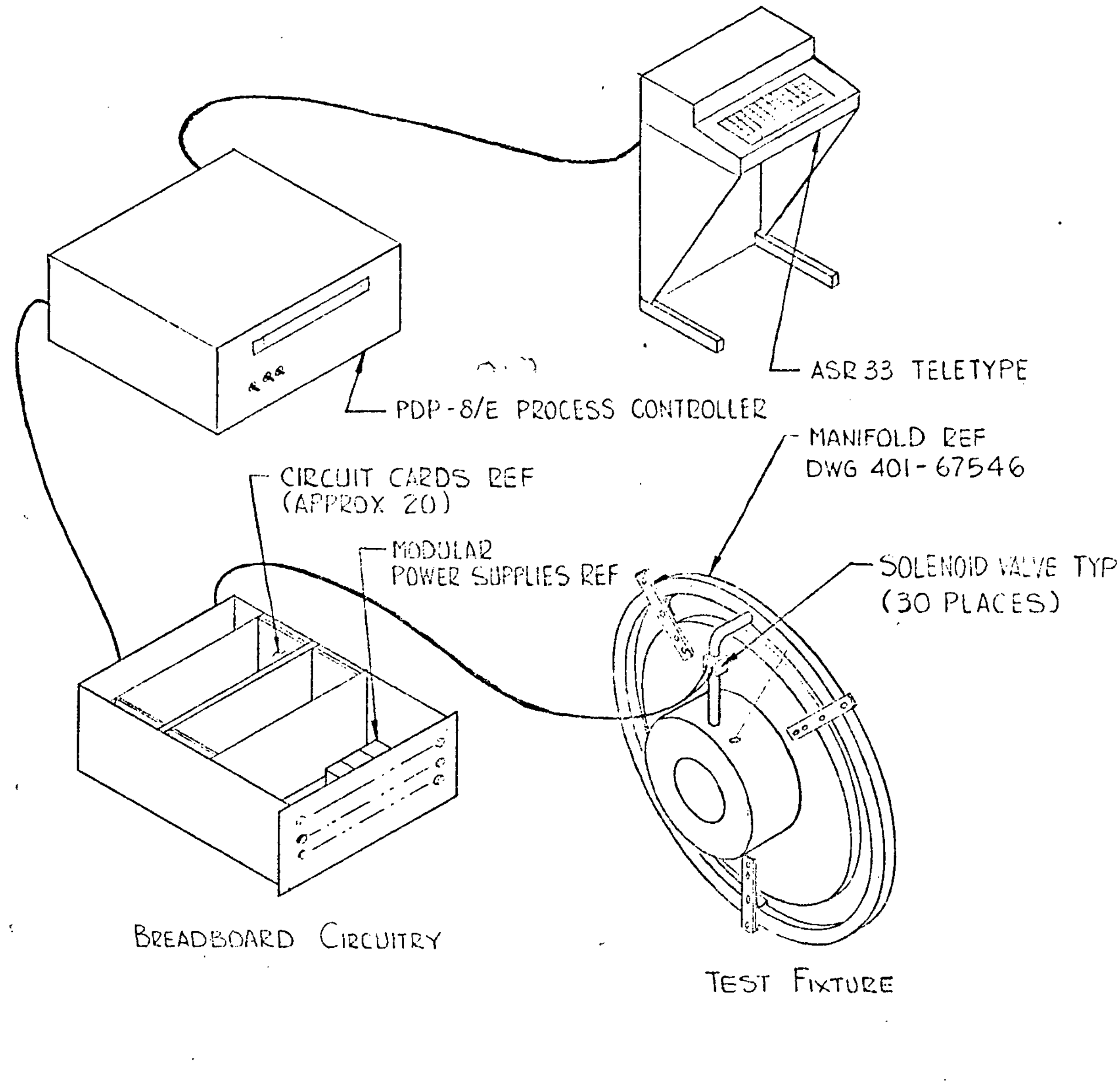
A. Omni-Axis Concept

(1) System Description

The cold-gas SITVC system consisted of 30 on - off injection valves controlled by a digital omni-axis electronic control system. The pitch - yaw (x-y) error signal from a simulated guidance system was resolved into polar coordinate signals by the valve controller and the appropriate number of valves opened around the thrust vector required for correction. The initial system was sized for 15 valves to be opened for maximum side thrust. The valves are opened sequentially, starting with the one or two valves in line with the desired vector, then additional valves are opened at a prescribed ripple rate to prevent rapid side thrust transients. This combination of sequencing and rate limiting provided a smooth transition to the desired side thrust. This is deemed necessary for a system that employs on - off valving.

(a) On - Off Valves

The use of on - off valving was chosen to be consistent with an all hot-gas system. To reduce valve actuation power requirements, it would be desirable to use the hot gases as



ORIGINAL OMNI-AXIS SITVC - COLD GAS TEST SET-UP

FIGURE 2-1

a power source. But, compressible hot gases cannot be used in a proportional system because of insufficient position stiffness. An on - off valve is required only to actuate between the seat and full open stop with no intermediate position stiffness required.

The on - off valve requires no position feedback and requires only a simple three-way pilot valve. This simplified the hot gas valve itself and reduces potential development problems. At low flow rates in a proportional valve the pintle and seat tend to burn and erode unevenly, causing leakage and unpredictable flow rates. The on - off valve does not dwell at small openings and the metering point on the pintle and seat can be made at a different point than the seating point.

(b) 30 Valve System

After deciding that the hot gas valves should be on - off, then the problem of on - off transients on the missile system must be considered. If only four valves are used, then there is only one thrust level and the valves must be fast acting to take care of small impulse requirements. If a number of valves are used, then there can be a number of incremental thrust levels by opening the number of valves required for a given impulse requirement. In addition, the valves can be opened sequentially to reduce the level of on - off transients on the missile.

The optimum number of valves will require more study; but, a 30 valve system gives 5 levels of side thrust (10 valve pattern) and keeps the manifold simple.

A 30 valve system would have 15 valves in 180^{o} and with a 10 valve segment this would allow 2 to 3 spare valves for failure redundance without severe degradation in maximum side thrust. Failure of a few valves will not cause failure of the system as with a four valve system.

Test results on multiple port injection patterns versus single port injection has shown the multiple ports more efficient when the pattern is not spread to the extent that cosine losses negate the increase. The specific impulse of small angle side thrust is higher than at large angles. Thus, the addition of a number of small angle side thrust injection points will be more efficient than one large angle side thrust injection point, so long as the cosine losses due to the spread-out pattern do not negate the gains.

B. Digital Omni-Axis Concept

(1) Background

In 1965, LTVE demonstrated omni-axis control systems on the Lockheed Propulsion Company 156-5 and 156-6 Solid Rocket Motor firings. The system demonstrated a 30% savings in required injectant fluid over a pitch - yaw vector system. This was possible because the most optimum injectors could be opened for any thrust vector orientation. A pitch - yaw system requires an injectant flow of 2 when the required thrust vector occurs midway between the pitch - yaw axis. This was negated somewhat by the cosine losses for the valve distribution of 90^o, but the overall gain was 30%.

The omni-axis system used on the 156 inch motors had a self compensating feedback circuit that spread the 90^o valve pattern out if one of the valves failed to open. This failure philosophy made man-rated reliability very easy to achieve.

The omni-axis system is proposed for the hot gas valves. However, the control system is a digital control system, instead of the analog system used on the 156 inch motor. The digital system utilizes a sequencing system to reduce the transients caused by on-off valving.

(2) On - Off Transients

In a SITVC system, the position (X) of the injector determines the mass flow rate of injectant, i.e.

$$\dot{M} = K_1 X.$$

The mass flow rate then determines the side thrust (T) which determines the angular pitch or yaw rates ($\ddot{\theta}$), i.e.

$$T = K_2 0 = K_3 \dot{M},$$

thus $K_2 0 = K_1 K_3 X$ or $0 = K_4 X$.

The slew rate of the valve ($\dot{X}$) then gives $\dddot{\theta} = K_4 \dot{X}$.

The jerk ($\dddot{\theta}$) on the missile is then a function of the valve slew rate.

Figure 2-2 shows the low jerk level associated with a proportional control valve with a slow slew rate. This is then compared to the high jerk level of a simultaneous on - off control with a fast slew rate. The time duration and level of jerk can be reduced by dequencing a number of on - off control levels. Then by adding reduced slew rate to the sequential on - off control, the system may be made to closely resemble the proportional system with a low jerk level.

The importance of low jerk levels is related to exciting missile vibration modes. Also, it is disconcerting to personnel in manned missions. By sequencing and limiting the slew rate of an on - off system, the side thrust jerk with injection valve opening can be reduced to that of a slow proportional position system.

(3) Digital Control Techniques

The digital electronic control system for this program provides a high degree of flexibility in the variation of sequencing parameters. This system consists of a small programmed process controller and interface breadboard circuitry connected to the 30 valves as described later in this report. The processor provides the limited arithmetic capability required for this system as well as all system timing and sequencing parameters as determined by its program. The breadboard interface circuitry converts signals from the controller into valve drive voltages and currents for selected valves and also converts the system response signals to a form acceptable by the controller. The breadboard unit will accept either analog or digital input thrust vector command signals for either dynamic or static testing of the injector system. The unit also displays the status of all valves in the test setup on front panel indicator lamps.

SMOOTHED, SEQUENCED ON-OFF CONTROL
MINIMIZES JERK

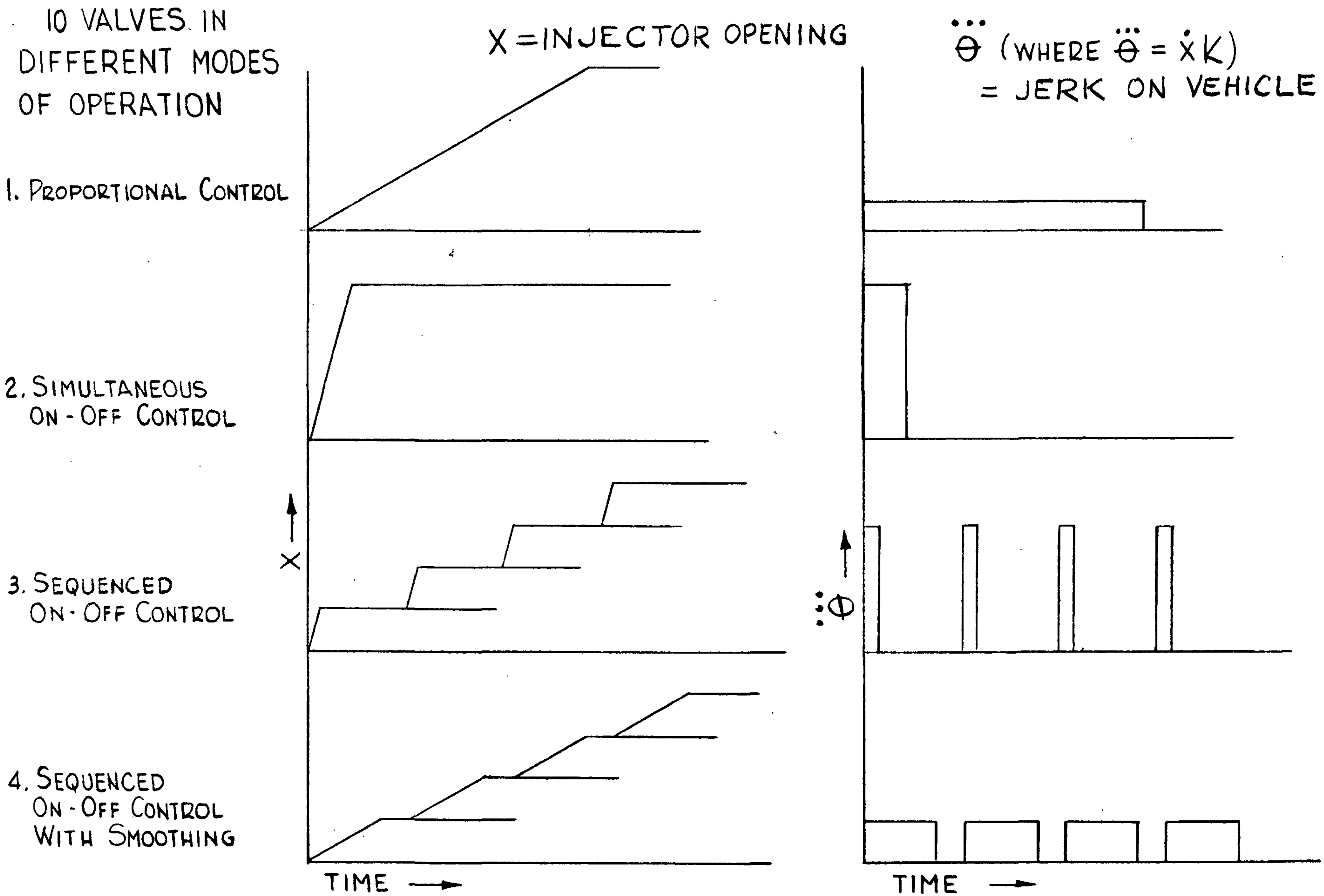


FIGURE 2-2

JERK EFFECTS

SECTION THREE

III. OMNI-AXIS DESIGN CONSIDERATIONS

This section presents the trade studies and design details developed during this program.

A. Nozzle Considerations & Design Aspects

A trade-off study of gas secondary injection for thrust vector control of a rocket nozzle shows that a multi-port on-off injectors with vector selector logic has many advantages. Proportional liquid TVC with omni-axis control (Reference 1) has demonstrated improved efficiency vector-selector valving. To simplify hot gas injection TVC, this concept can be carried further to include on-off control with digital computer logic.

The cold gas test system has 30 sonic ports at right angle to the nozzle axis on a plane 60% down the contour nozzle from throat to exit. The port diameter of 0.039 will give 6 degree vectoring with a 9 port pattern.

Omni-Axis SITVC

Generally rocket motor TVC is in terms of pitch and yaw from the guidance system. This fixed quadrant system utilizes a thrust vector summation of pitch and yaw to obtain the desired vector. This type of summation is wasteful of TVC mass flow since a desired vector may occur half-way between pitch and yaw, requiring $\sqrt{2} = 1.4$ times that required when the vector is in line with pitch or yaw (Reference 2). In an omni-axis system the pitch and yaw signals are summed electrically and only TVC valves closest in line with the desired vector are used.

The omni-axis concept can be refined further by using a segment of injectors to produce the desired vector. The number of injectors in a segment about the desired vector depends on the magnitude of the desired vector. For small vectors one or two injectors about the desired vector are used. For larger vectors the segment of injectors can be spread out to a segment approaching 180^{o} centered about the desired vector. In addition, the segment can be spread out in a sequental manner about the desired vector. Sequencing will make the system smooth by making total response time increase as the vector magnitude increases.

Duty Cycle

A typical launch duty cycle is shown in Figure 3-1. The duty cycle shows a maximum side force requirement during launch but very quickly falls off to some steady state valve represented by thrust misalignment and aerodynamic forces on the launch vehicle. The injection system should be sized for one injection point to provide most of the steady state thrust and then spread of the pattern can be quite large with resulting high cosine losses and still be acceptable since the integrated total impulse (S thrust X time) at the large angle is insignificant compared to the total impulse required for the steady state TVC.

The number of injection points should be such that one port can take care of the average duty cycle. The maximum thrust of 6^{o} can be provided with a number of valves spread out over a 90 degree to 180 degree sector centered around the desir ed vector. The efficiency

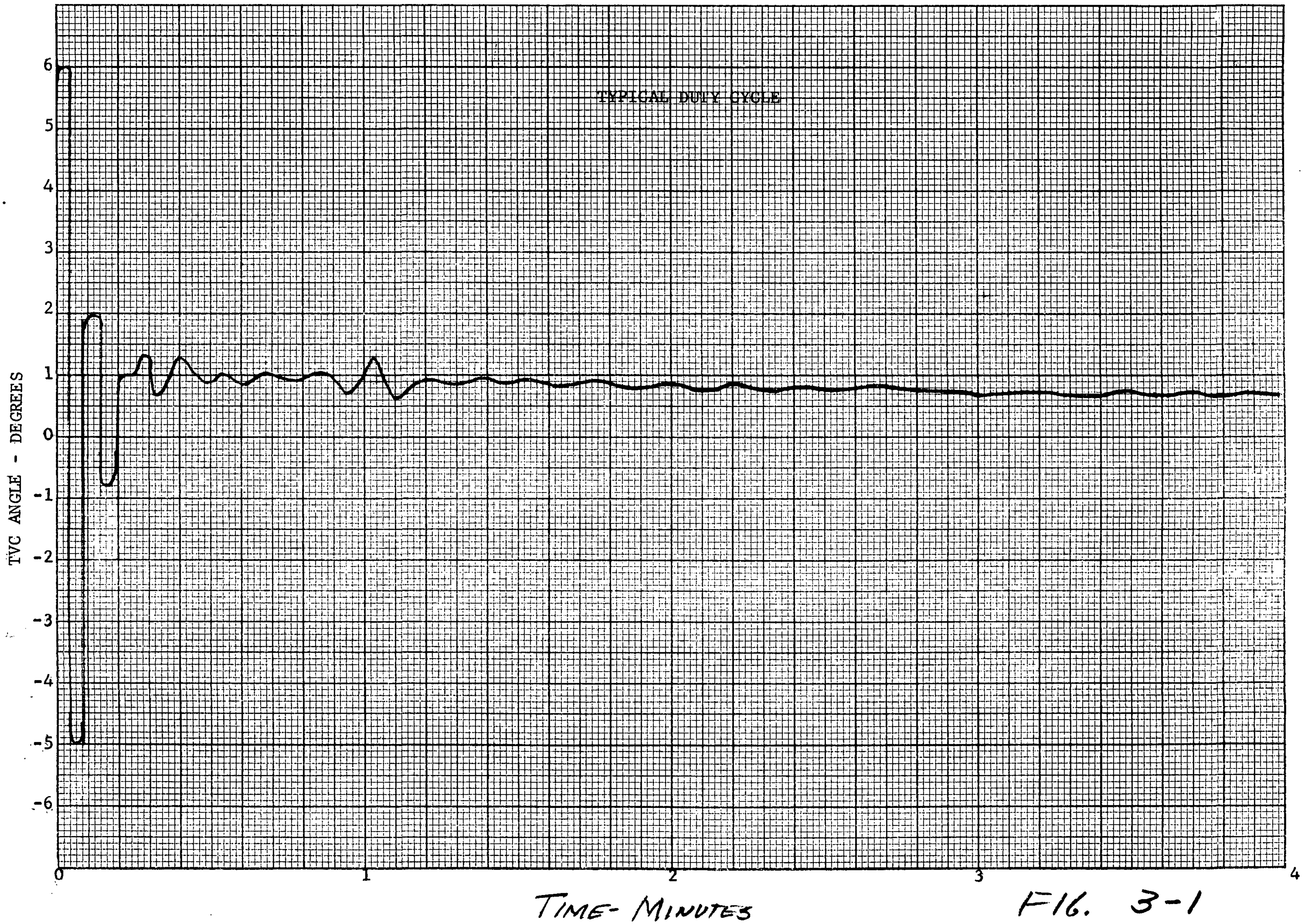
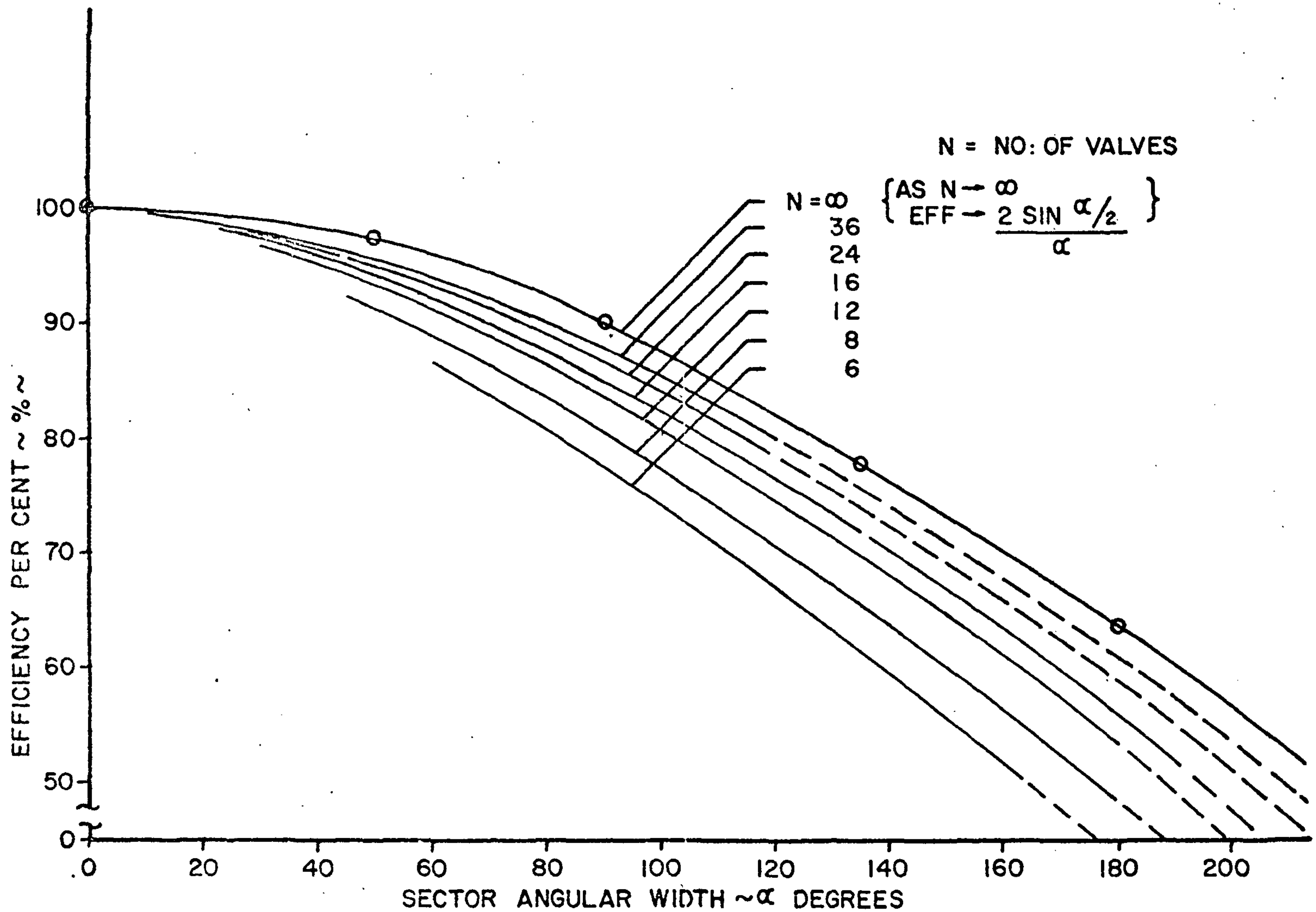

TYPICAL DUTY CYCLE
TVC ANGLE - DEGREES
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1
2
3
4
TIME- MINUTES

FIG. 3-1

is degraded by cosine losses with a large sector as shown in Figure 2 (Reference 2), but the duty cycle is low for 6^o. The efficiency for a large number of vavles spread over a segment of 120^o would be about 83%. This 100^o segment must contain at least 5 thrust levels since it is desired that the lowest level produce about 1^o side thrust for the steady state condition. Depending on whether the desired vector occurs in line or between a port, then 9 or 10 ports are required in a segment. Thus at least a 30 port system is required as shown in Figure 6.

Intermittant Bleed System

There are two methods of chamber bleed SITVC, a constant bleed system and an intermittant bleed system (Reference 4). In the constant-bleed system some number of valves are open during non-vectoring to provide a constant bleed flow rate equivalent to that required when vectoring. This system eliminates variations in chamber pressure and thrust level whether vectoring or not. In an intermittant bleed system valves are only open during vectoring. For a 6^o vectoring system the propulsion efficiency would be degraded about 6% for constant bleed. The constant bleed system would also have vectoring efficiency degraded by about 10%. Since steady state demands would probably be less than 1^o vectoring, then the intermittant bleed system would be more efficient without excessive variations in chamber pressure.



COSINE LOSS

FIGURE B-2

Supersonic or Sonic Injection

Sonic velocity injection is accomplished with a straight hole injection point. To obtain supersonic injection, the injection orifice must have an expansion nozzle. Obviously, the sonic injection is easier to implement with straight bored holes. Test data (Reference 3) on 17.5^{o} conical test nozzles with area ratios of 8:1 shows no advantage to supersonic nozzles for secondary injection to nozzle flow ratios Ws/Wp .08. However, the test data examined was for fixed injection nozzle diameters with injection pressure varied to change weight flow rates. This means that at lower flow rates the injection nozzles were overexpanded for the brake pressure in the main nozzle causing jet separation. It is probably that supersonic injection is better, but fabrication problems in the subscale test nozzle will prohibit its use.

Contour Nozzle versus Conical Nozzle

No data was available on SITVC with a contour nozzle. Almost all data has been taken on 15^{o} or 17.5^{o} half angle conical nozzle (Reference 3 and 4). The conical nozzle is generally used because of ease of fabrication and because at low expansion ratios there is little difference in performance compared to the contoured nozzle.

Generally jet separation occurs sooner in an overexpanded contour nozzle than in an overexpanded conical nozzle (Reference 5). Also, SITVC is more efficient in an overexpanded nozzle than in an optimum or underexpanded nozzle (Reference 3). Thus, the contour nozzle should have a slight advantage over the conical nozzle for SITVC. A booster vehicle at launch generally is operating overexpanded and requires the highest angle duty cycle. thus making the contour nozzle more attractive.

(ϵ = 5.06) (Ps = 250 - 350 psi) (γ = 1.4) (Sub-Scale = 1:125) (Max 2 = 6° deflection)

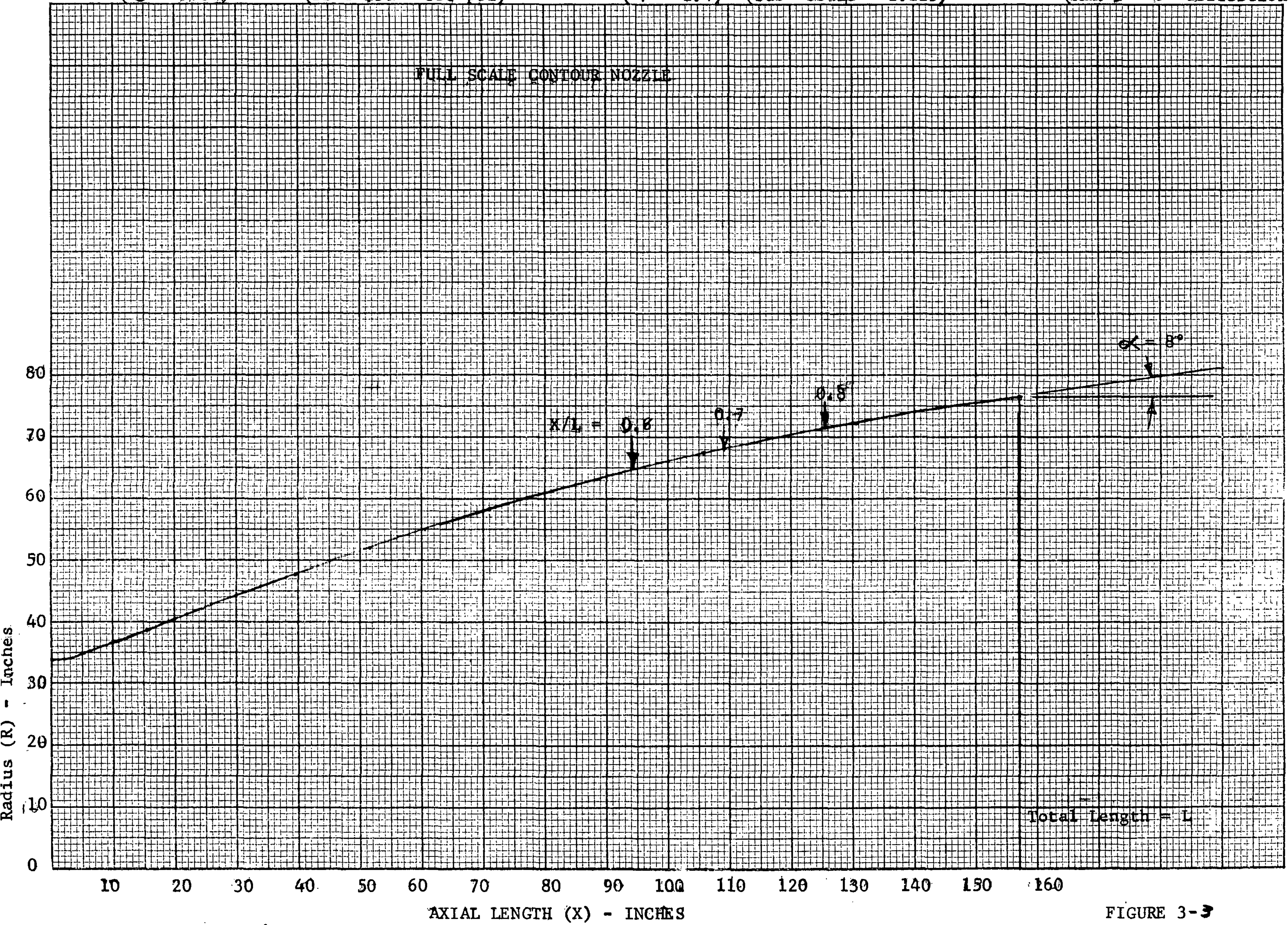


FIGURE 3-3

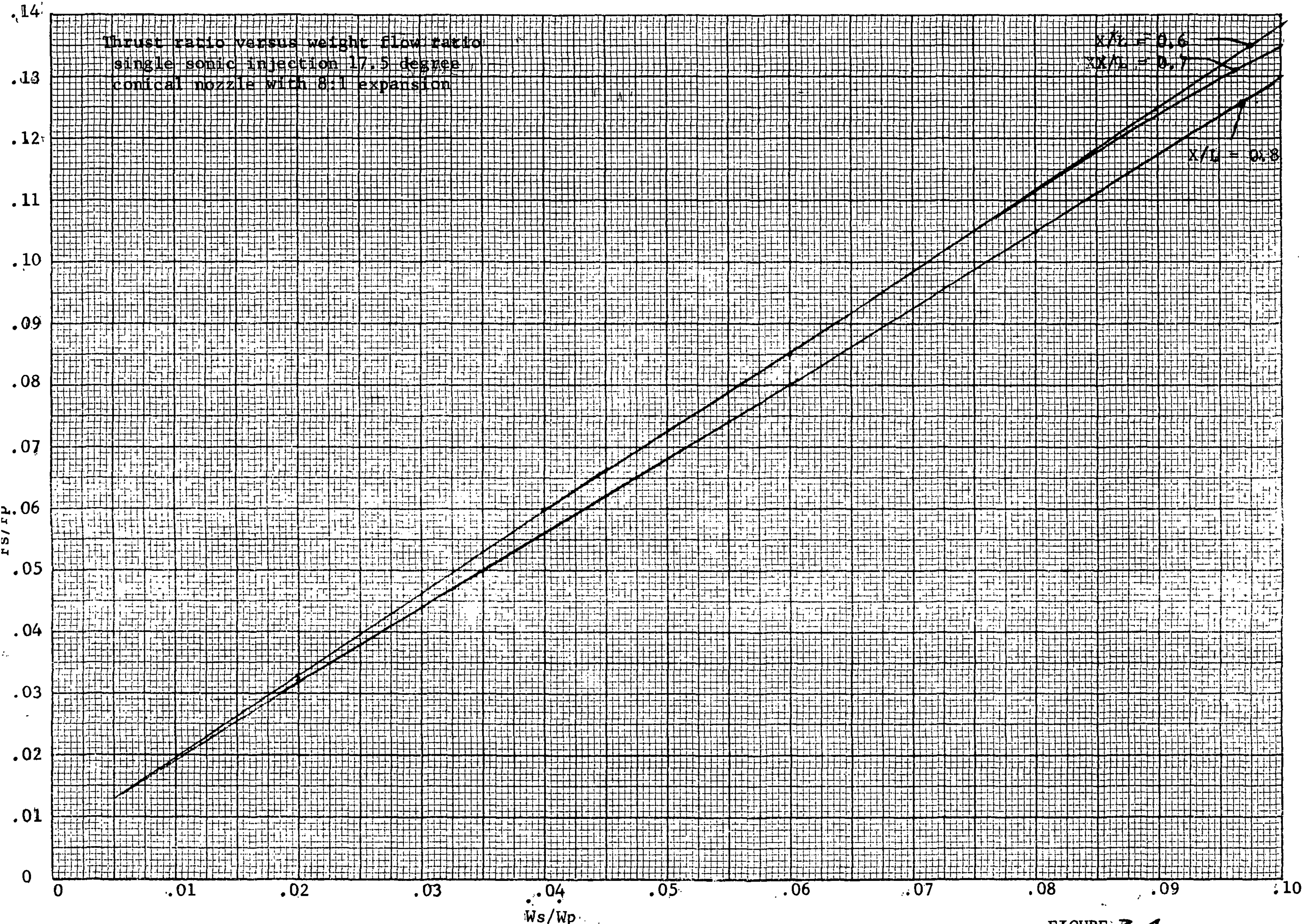
The contour nozzle is shown in Figure 3. Injection locations for X/L = 0.6, 0.7 and 0.8 are shown. L. H. Erickson of Thiokol was shown this contour nozzle and he suggested that the injection point of such a low expansion ratio (E=5) contour nozzle should be at an X/L = 0.6 or lower.

SITV Test Data

FluiDyne test data (Reference 3) will be used to size injectant ports in the 30 valve omni-axis SITVC system. The information from these extensive tests has been reduced to Figures 4 and 5. All the data is for a 17.5^{o} half angle conical nozzle with a 8:1 expansion ratio. The data was taken for over, under and optimum expanded nozzles at injection points of 0.6, 0.7, and 0.8 of the way down the nozzle from throat to exit plane.

The effect of injection port locations for X/L = 0.6, 0.7, and 0.8 are shown in Figure 4. Only the optimum expansion curves are shown. The side thrust ratio (Fs/Fp) is only slightly more for overexpansion and less for underexpansion for the same weight flow ratio (Ws/Wp). The curves show that X/L = 0.6 and 0.7 are equivalent and better than X/L - 0.8.

The effects of injectant port inclination (Ø) is shown in Figure 5. The inclination is the angle between the injectant port axis and the nozzle axis. These curves clearly show that aiming the injection upstream gives more side thrust for the same weight flow ratio. However, a



Thrust ratio versus weight flow ratio
single sonic injection 17.5 degree
conical nozzle with 8:1 expansion
X/L = 0.6
X/L = 0.7
X/L = 0.8
Fs/Fp
Ws/Wp
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14

FIGURE 3-4

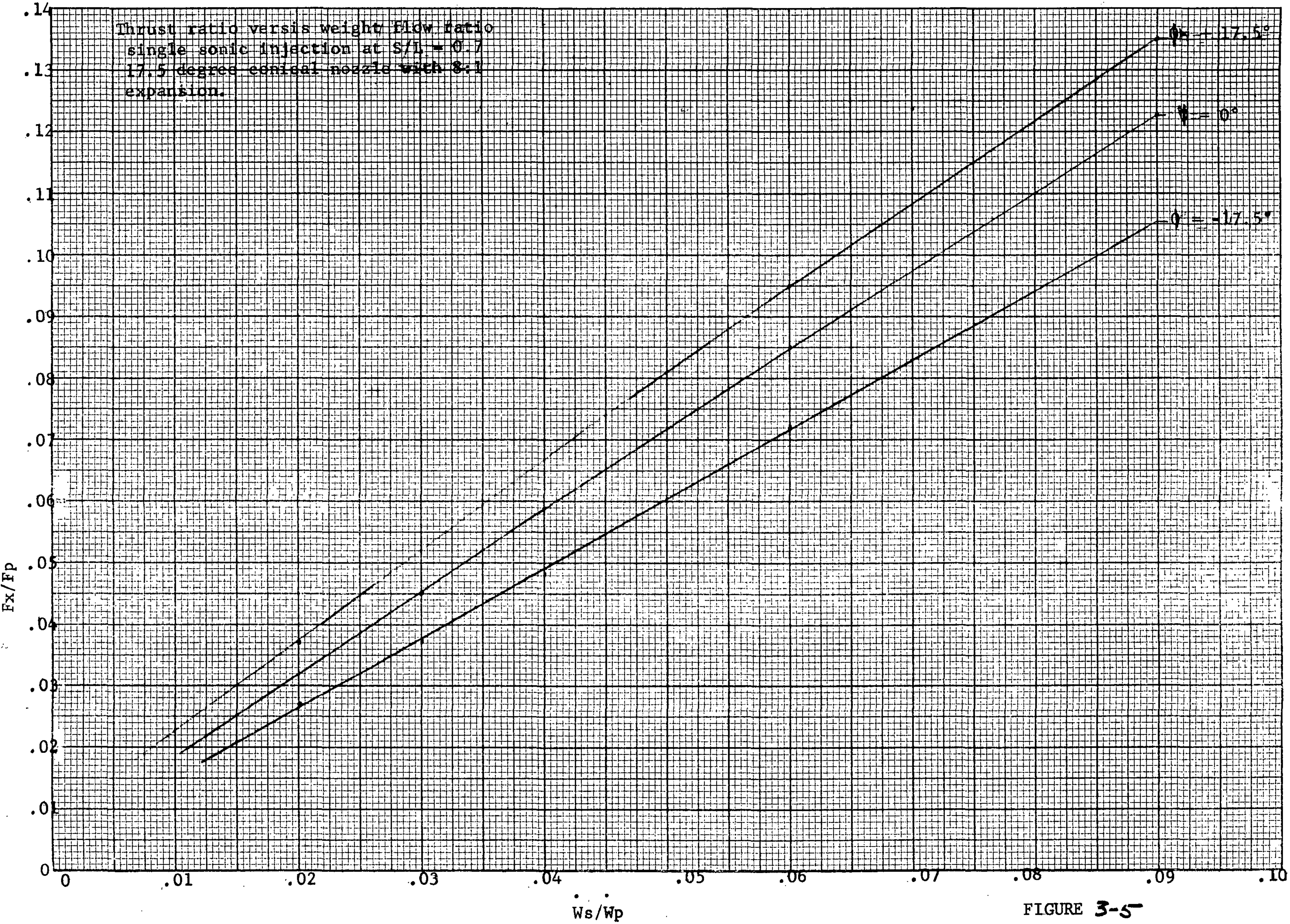

Thrust ratio versis weight flow ratio
single sonic injection at S/L = 0.7
17.5 degree conical nozzle with 8:1
expansion.
Φ = +17.5°
Ψ = 0°
Φ = -17.5°
Fx/Fp
Ws/Wp
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10

FIGURE 3-5

survey of all actual full scale rocket motor firings shows that none used any injection angle except $\emptyset = 0^o$. The reason for this is a practical one, the straight in port is easier to manufacture. Hot tests have also shown that the upstream inclined ports errode badly on the downstream lip of the port.

Nozzle Calculations

The sub-scale nozzle will have the following parameters:

$$A_t = 0.232 \text{ in}^2$$

$$A_e = 1.177 \text{ in}^2$$

$$E = 5.06$$

$$V = 1.4$$

For an optimum expanded nozzle the following holds (Reference 6).

$$\frac{Pe}{Ps} = .020, \; M = 3.2$$

If Pe = 14.5 psia, then Ps = 725 psia.

Thus the nozzle will be overexpanded for supply pressures Ps = 250 to 350 psia.

The thrust from an optimum expanded nozzle is (Reference 7):

$$F_{opt} = C_F A_t P_s = 110.66 \text{ lbs.}$$

where $C_f = 1.59$

P_s = 300 psia and Pe = 6 psi

At Pa = 14.5 psia the thrust is

$$F = F_{opt} \; T \; (Pe - Pa) \; A_t E = 109.66 \text{ lbs.}$$

Acutally this is reduced by the divergance angle (α) of the nozzle exist by

$$\alpha = 8^o$$

$$\lambda = \tfrac{1}{2}(1 + \cos \alpha) = \tfrac{1}{2}(1 + 0.99) = 0.995$$

$$F = F \quad = 109.1 \text{ lbs.}$$

Injectant Port Sizing

The 30 port system should be sized to give 6° vectoring with a 9 or 10 port segment. This system is shown in Figure 6. The cosine efficiency is between 86% for 9 ports and 83% for 10 ports. Neglecting port interaction, the control angle per port is 0.77° for 9 ports to yield a resultant 6° vector. At this size a 10 port segment will give a 6.4° vector.

Figure 4 shows that 0.77° (Fs/Fp = .0134) will require Ws/Wp = .005. The weight flow through a choked orifice is

$$\dot{W} = \frac{C_D C_M A P_U}{\sqrt{T}}$$

where: A = Orifice Area (in^2)

C_D = Orifice Coefficient = 1.0

C_M = Weight Flow Parameter

P_U = Upstream Pressure (lbs/in^2)

$\dot{W}$ = Weight Flow (lbs/sec)

T = Absolute Temperature ($^{\circ}R$)

Assuming C_D, C_M and P_U are the same for the injectant port and the rocket nozzle, Then

$$\frac{\dot{W}s}{Wp} = \frac{As}{At} = .005$$

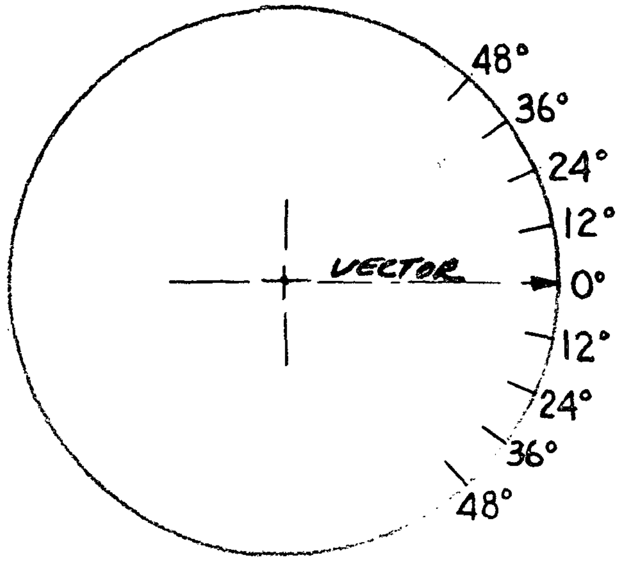
The rocket nozzle diameter is 68 inches then the injectant port area (As) is

$$As = \frac{\pi (68)^2}{4} \times .005 = 18.158 \ in^2$$

and port diameter Ds = 4.81 inches. The 125:1 scale reduction make the subscale ports Ds = .0385 inches.

OMNI-AXIS CONTROL

9 Port Segment

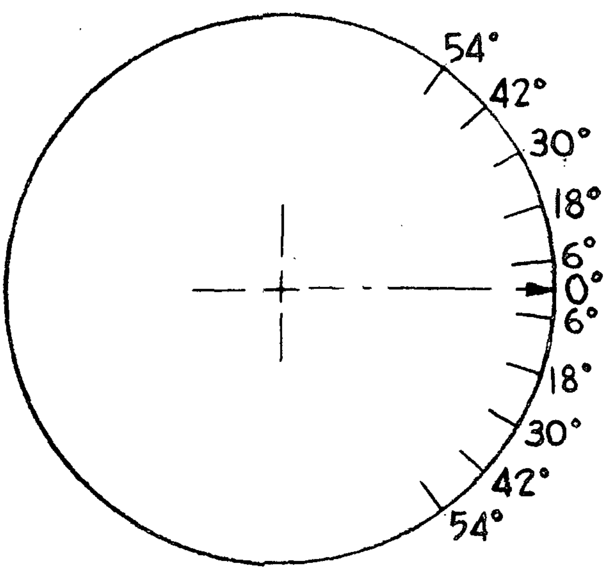


β	COS	N× COS
0°	1.000	1.000
12°	.978	1.956
24°	.914	1.828
36°	.809	1.618
48°	.669	1.338
	TOTAL	7.740

$$\text{EFFICIENCY} = \frac{7.740}{9} = .86$$

$$\text{ANGLE PER VALVE} = \frac{6°}{.86 \times 9} = .77°$$

10 Port Segment



β	COS	N× COS
6°	.995	1.990
18°	.951	1.902
30°	.866	1.732
42°	.743	1.486
54°	.588	1.176
	TOTAL	8.286

$$\text{EFFICIENCY} = \frac{8.286}{10} = .83$$

$$\text{ANGLE PER VALVE} = \frac{6°}{(.83)(10)} = .72°$$

FIGURE 3-6

General Comments

1. Better vectoring performance is obtained when rocket nozzle is in an overexpanded condition.

2. Injecting upstream into the nozzle is more efficient than injecting at right angles to the nozzle axis. Insufficient data was available to determine optimum angle. There are, of course, fabrication problems in injecting upstream. Also the lip of holes pointed upstream errode away rapidly and probably reduces the increased efficiency.

3. The best location for ports is probably between X/L = 0.5 and 0.6 for a nozzle expansion ratio of 5:1.

4. Supersonic injection is best for large vector angles (4^{o} to 6^{o}) per port, but vector angles less than 1^{o} per port performance is equivalent to sonic injection. The straight bore port for sonic injection is easier to fabricate than nozzles for supersonic injection.

5. Interaction between adjacent injection ports should increase efficiency. However, no data is available on ports separated by 12^{o}.

6. Tests on a four-port constant bleed system (Reference 4) showed a decrease in propulsion efficiency of about 1% for each degree of thrust deflection and lowered vectoring efficiency of 10%. Tests with an eight-port intermittant-bleed system were found most efficient.

General Comments Cont.

7. The injection valves should be located close to the nozzle and form part of the injection port to conserve stream momentum. Only a plug type fits the required geometry. Also, small plug valves can be mounted closer to the nozzle than large valves. The rotary type valves that divert flow cannot form part of the injection port and in some designs actually diverts high velocity gases causing high energy losses.

NOMENCLATURE

α	Nozzle exit divergence half-angle
A	Local cross-sectional area
Ae	Cross-sectional area at nozzle exit
At	Cross-sectional area of nozzle throat
As	Cross-sectional area of injectant orifice, in^2
Cd	Orifice coefficient
Cf	Thrust coefficient
Cm	Weight flow parameter
Ds	Diameter of injectant orifice, In
F	Thrust of Nozzle
Li	Length of nozzle from throat to exit plane, Inches
M	Mach Number
	Specific heat ratio (Cp/Cv)
P	Pressure, psia
Pa	Ambient or back pressure, psia
Ps	Nozzle supply pressure, psia
λ	Nozzle divergence angle correction factor
ϵ	Nozzle expansion area ratio (Ac/At)
X	Distance along nozzle axis from throat, Inches

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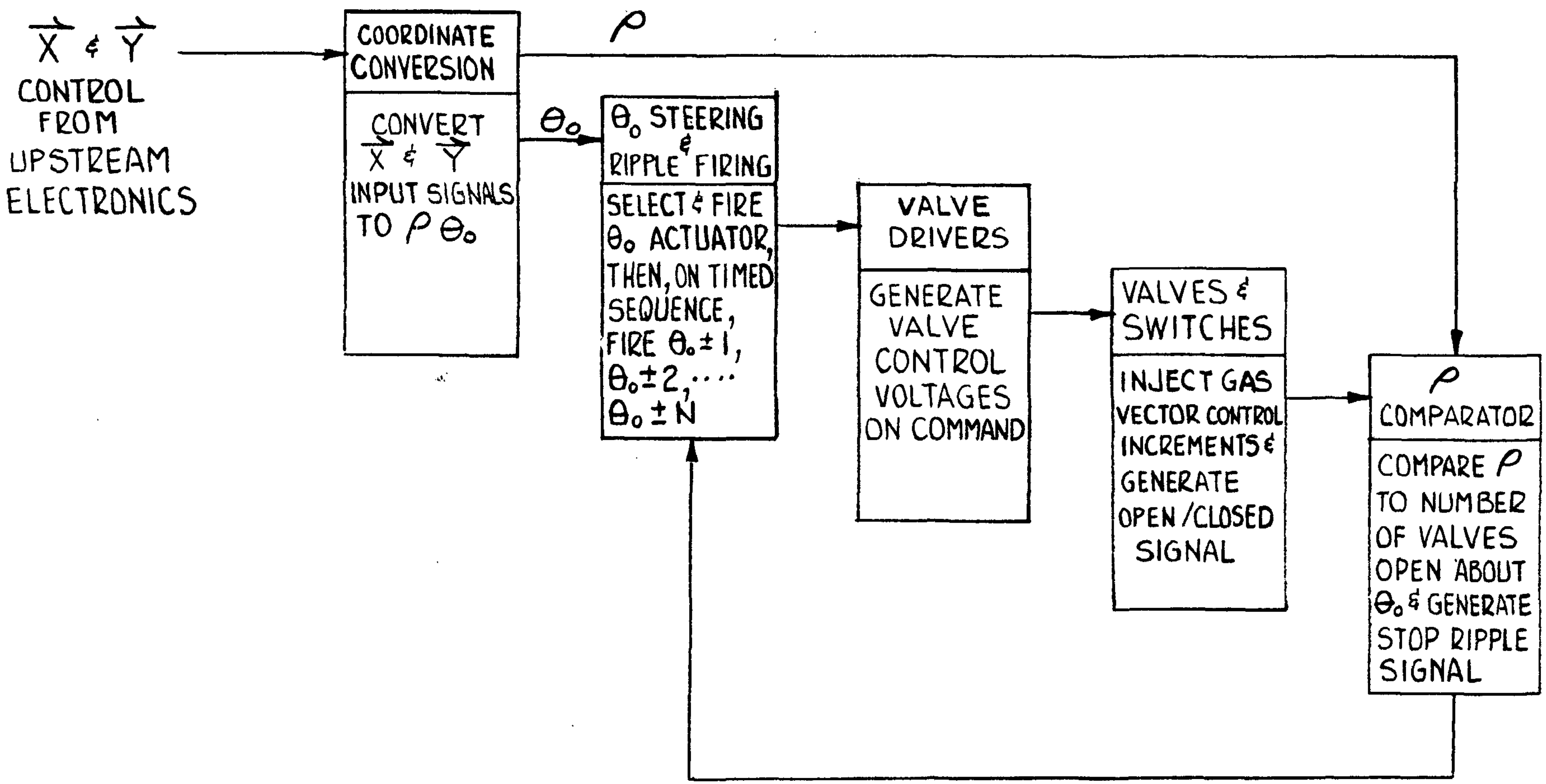
B. Digital Controller & Interface Panel Considerations

The digital control system consists of a PDP 8/E processor and an interface breadboard unit. The flow diagram Figure 3-7 indicates the process control flow for the hardware of this program. For purposes of this proposal only, $\vec{X}$ and $\vec{Y}$ analog thrust vector commands are considered, although any form of these commands i.e., polar coordinates, binary, BCD could ultimately be used.

The mechanized scheme first converts the $\vec{X}$ and $\vec{Y}$ commands to polar coordinates consisting of a vector of ρ amplitude located along a θ_o direction. From this information the θ_o injector valve is opened and then, under program control, successive pairs (or singles if desired) of valves on either side of θ_o are opened. The sequence and timing of this ripple effect is determined by the program. Gated valve drivers generate the necessary signals to operate the solenoid valves which generate a logic level when fully open. The comparator compares the number of valves actually open to a number computed from the amplitude of ρ. This technique has the advantage of automatically compensating directly for valves that are either stuck open or refuse to open on command. At this point, the thrust vector is held until the $\vec{X}$ and $\vec{Y}$ inputs are changed by outer loop control systems such as guidance.



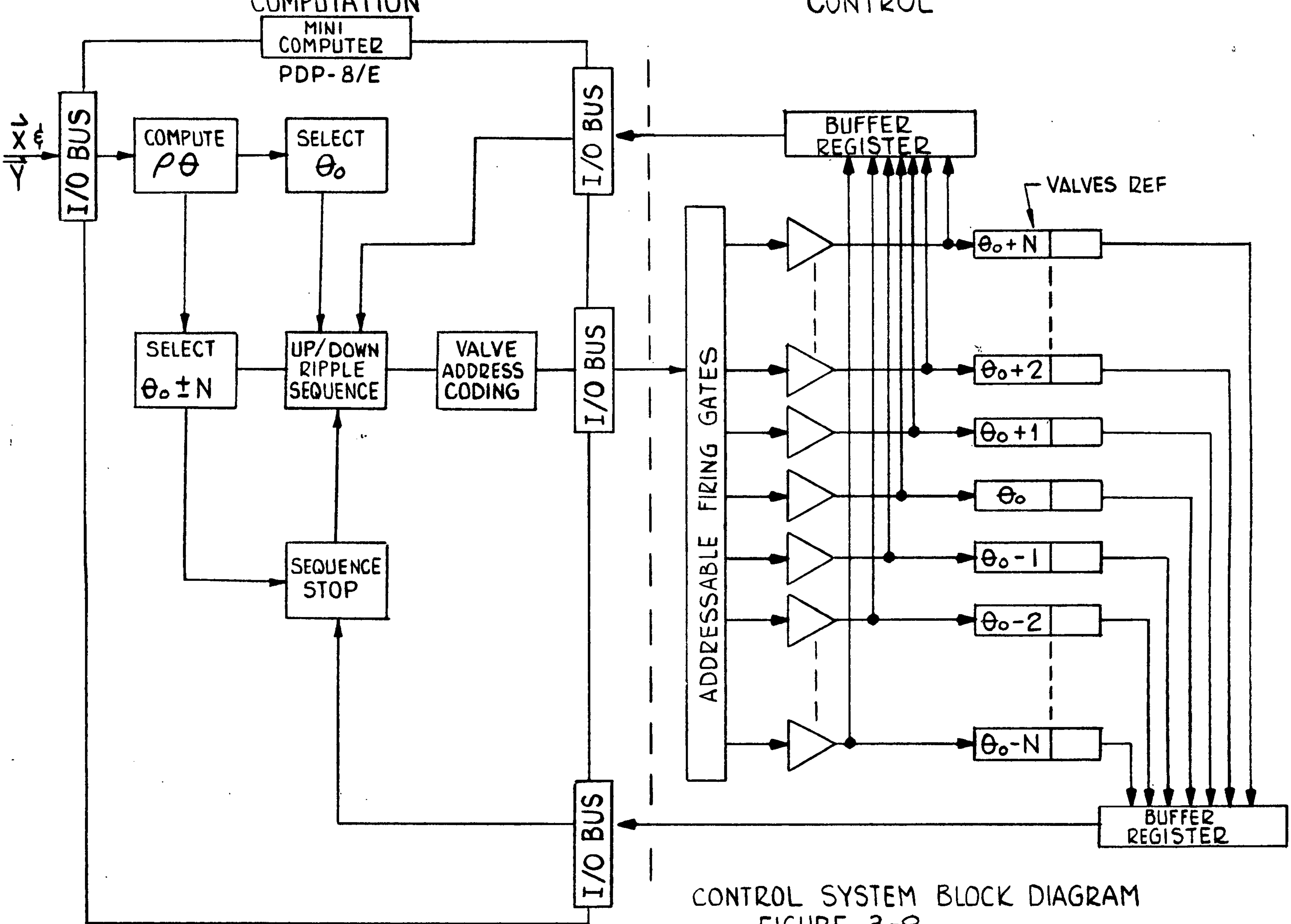
GENERAL FLOW DIAGRAM OF CONTROL SYSTEM

FIGURE 3-7

System Mechanization

This system is mechanized as shown in the block diagram, Figure 3-8. As indicated, the system is broken into two major parts -- computation and control. The computation section consists of a PDP-8/E controller while the control section is composed of the breadboard interface unit and the nozzle fixture containing 30 solenoid valves. Externally generated X and Y vector commands are routed through the breadboard unit for conditioning and conversion prior to entry in the processor. Under program control, the PDP-8/E computes $\rho\ \theta$, select θ_0 from a table contained in memory, calculates the number (θ_0 + N) of valves necessary to be opened for a given ρ, initiates and controls the up/down ripple sequencing, provides the binary address codes necessary to fire selected valves and stops the sequencing when the proper number of valves have been opened.

The addressable firing gates respond only to discrete addresses and commands issued by the processor. The amplifiers shown convert the logic levels used up to this point into voltage and current levels adequate to drive the solenoid valves. One buffer register contains the data as to which valves have been commanded open while the other buffer register contains the data as to which valves are actually open. All input and output signal levels are TTL compatible as required by the processor.



CONTROL SYSTEM BLOCK DIAGRAM
FIGURE 3-8

Process Flow

As shown in the control system block diagram, Figure 3-7, several operations are contained within the controller. As an example of control flow, the first block - compute $\rho\,\theta_0$ - may be accomplished as follows:

a. Solve for $\left|\frac{X}{Y}\right| = \tan\theta_0$

b. Look up θ_0 in 30 point memory table using X and Y signs to determine quadrant.

c. Look up $\cos\theta_0$ in memory table.

d. Solve for $\rho = \dfrac{X}{\cos\theta_0}$

e. Store ρ and θ_0 in memory.

The next computation block -- select $\theta_0 + N$ consists of another table look-up for $N = K\rho$. The up/down ripple sequence is initiated under the program control selected for a given test. For static $\vec{X}$ and $\vec{Y}$ inputs and a simple arithmetic progression such as θ_0, $\theta_0 \pm 1$, $\theta_0 \pm 2$, ..., $\theta_0 \pm N$ a simplified control flow example is:

a. Fire Command to

b. Interrogate θ_0 Amplifier for Response

c. If OK, Idle for Programmed Period T

d. Fire Command to $\theta_0 + 1$ and $\theta_0 - 1$

e. Interrogate $\theta_0 + 1$ and $\theta_0 - 1$ Amplifiers

.... etc.

The Valve Address Coding block converts θ_0, $\theta_0 \pm 1$, ... into discrete address codes recognizable only by specific valves. The control system now holds this static condition until changes in the $\vec{X}$ and $\vec{Y}$ inputs were detected at which time new $\rho\theta_o$ parameters are computed. Again under program control, the valves would be closed and opened in a ripple sequence to satisfy the new input requirements.

The basic clock, computation, and transfer speeds of the PDP-8/E are many orders of magnitude faster than required for this system -- 1.2 to 1.6 microseconds for a single simple operation. This allows a high degree of flexibility in programming ripple rates, response times, etc. for this laboratory system.

I/O Interface

The I/O (Input/Output) bus interface shown in the block diagram, Figure 3-8, are the signal entry and exit routes for data to and from the processor. In brief explanation, a large number of separate devices may be connected to this bus, each having its own discrete binary address code. For this program, all I/O transfer is initiated under program control rather than the more exotic flag or interrupt techniques used in higher level data processors. That is, no transfer of data, either to or from the PDP-8/E, is done except at program command. The I/O itself consists of 12 parallel lines using TTL logic levels (+2.5 to +5.5V for a logical "I" and +1.0 to -0.5V for a logical "0"). Part of the 12 bits may be used for address codes, part for command, and part for data. This is entirely under program control and quite often, when longer blocks of data are required, several words in series are required to accomplish one I/O transfer.

Programming

Montek has supplied all programs needed for operation of this system on a PDP-8/E control processor. The entire library was developed at Montek and supplied to MSFC. All operating routines are performed using programmed subroutines.

Control Technique

The system implemented by MONTEK, incorporates a circularly placed set of thirty (30) injection ports with two important characteristics:

Analog control can be approximated within practical limitations.

Valve failure is less serious than with existing quadruple port control systems.

It is the intent of the program to investigate the above claims, both on a theoretical potential basis and via a currently operating test facility.

(1) The Bias Vector

For the sake of simplification, consider the thirty ports distributed evenly (every 12 degrees) around a circle as shown in Figure 3-9.

Let each valve open state represent a unit vector from the center of the circle along a radial away from said valve. Define a "bias vector" as the vector sum of all valve open unit vectors for a given sequence of valve conditions (open/closed). For example the bias vector for open valves (numbered in octal from 1 to 36) 1,2,3,4,5 would be a radial vector pointing away from valve 3 with magnitude 4.7834 (the sum of cosines about the symmetry valve #3).

(2) Valve States

The power of analog thrust control lies in the multiplicity of bias vectors. For each bias vector we associate a valve state which represents a given sequence of open and closed valves for the selected set of thirty ports.

The number of possible valve states is given by the total number of binary combinations of thirty valves, namely 2↑30 - hence, an analog approximation!

Not all combinations of open/closed valves are desirable, however, due to the varying efficiency values for the different states. The efficiency of a given valve state is defined as the magnitude of its bias vector divided by the number of valves "on" that create the given vector. For example, the efficiency of the sequence of all thirty valves "on" is zero whereas the efficiency of a single valve "on" is one. This is important from the viewpoint of gas consumption vs. end result.

(3) The State Transition

Thrust control occurs via a set of state transition commands. The question arises as to the "smoothest" and most efficient transition from one valve state to another and avoidance of overshoot. In other words, which path - created by the envelope over bias vectors - will produce the least step control impulse on the rocket involved and - at the same time - minimize valve switching while maximizing valve state efficiency?

Consider the example of Figure 3-10. We desire to produce a transition from state A to state B. The smoothest transition will obviously lie along a straight line from A to B. The most effective transitional increments along this path are a matter of experimental testing.

(4) Symmetry Classes and State Transitions

There exists structure to various symmetry classes of valve states. For example, all states created with only two valves open form a definite pattern within the valve state circle. These symmetry classes have not yet been investigated. It is felt that such a study would generate a greater understanding of smooth state transitions and analog thrust control. Specific experiments could be carried out using as allowable bias vectors those belonging to selected valve state symmetry classes. Such tests might uncover means of minimizing valve switching during state transitions.

(5) Practical Limitations During State Transition Execution

It is evidently impractical to use a complete table of valve states in the selection process that occurs in state transitions.

The ideal valve state selection process would consist of finding the desired bias vector valve sequence from a generating function given an X and Y input. Whether or not this is feasible is yet to be investigated. If so, it will likely involve valve state symmetry classes.

(a) The Current State Transition Model

Let the valve state circle have radius 9.12 and restrict all valve sequences such that for each allowable sequence there exists a continuous segment of closed valves with length not less than 18 valves. Thus, the continuous valve segment containing the open valves will not be greater than 12 valves long.

Divide the valve state circle into 5400 sections bounded by concentric arcs of 2 degrees each and radial sides of 0.304 units long.

Select from each section a bias vector with the highest efficiency and assign it to that section via a look-up table in core memory.

Note that the look-up table need contain only 120 sequence values because of the angular symmetry around the valve state circle (i.e. for each six degrees).

For every possible X,Y pair a valve state sequence is thus defined. Transitions are made by specifying an initial and final X,Y pair and the transitional step distance. This produces intermediate transitions for the smoothing effect until the final X,Y state is reached. (See Figure 2.)

(6) Possible Future Investigations

Several items are suggested for future study. As previously mentioned, a study of valve state symmetry classes would aid in understanding smooth state transitions, analog thrust control, and minimization of valve switching during state transitions.

Creation of a bias vector generating function would eliminate the need for a look-up table in core memory and augment efficient state transition understanding.

Much insight could be gained by replacing the X-Y "pot" inputs with a "light pen" or "writing tablet" as used in computer graphics. Such a technique would provide the experimenter with visual correlation between X,Y inputs and valve state sequences.

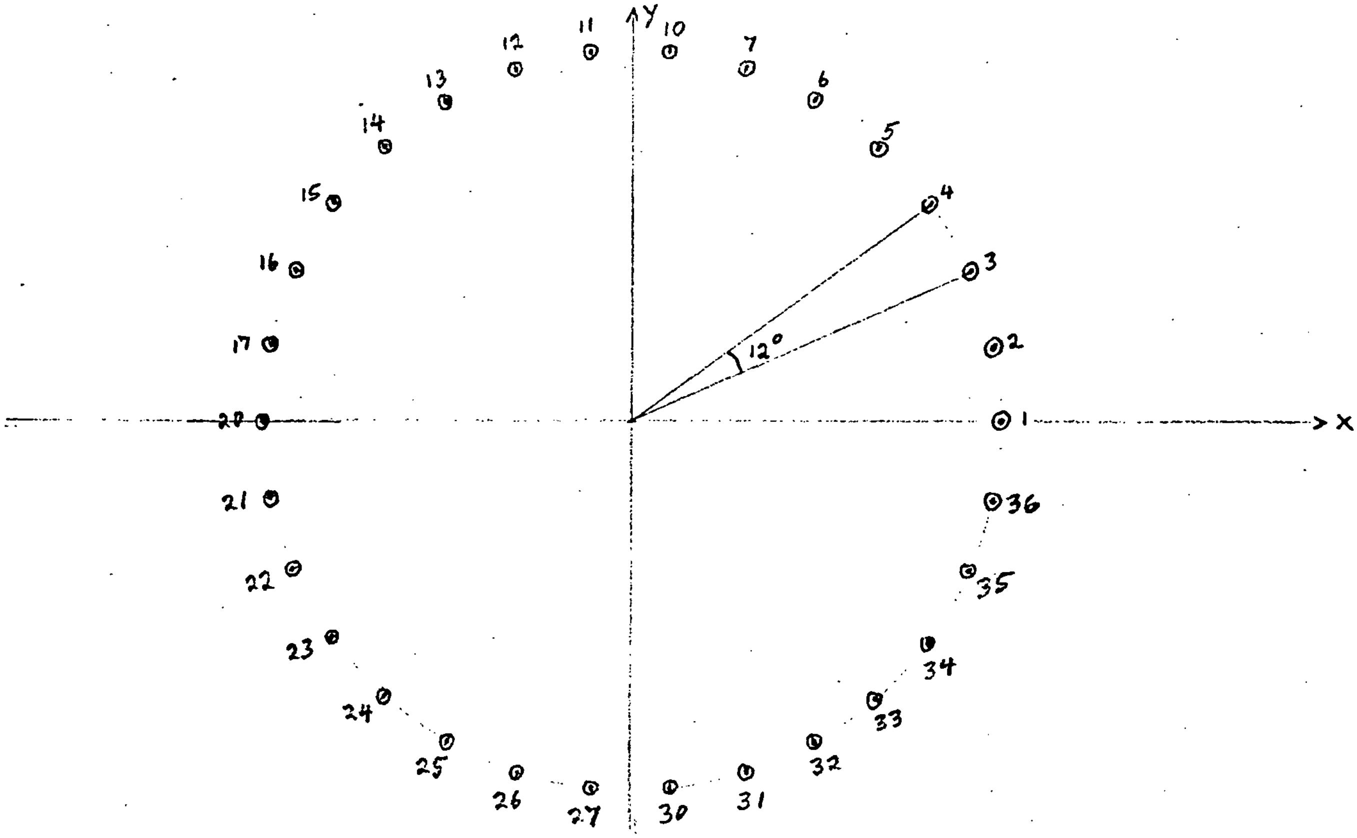


FIGURE 3-9:Valve ports numbered in octal and placed at 12 degree intervals.

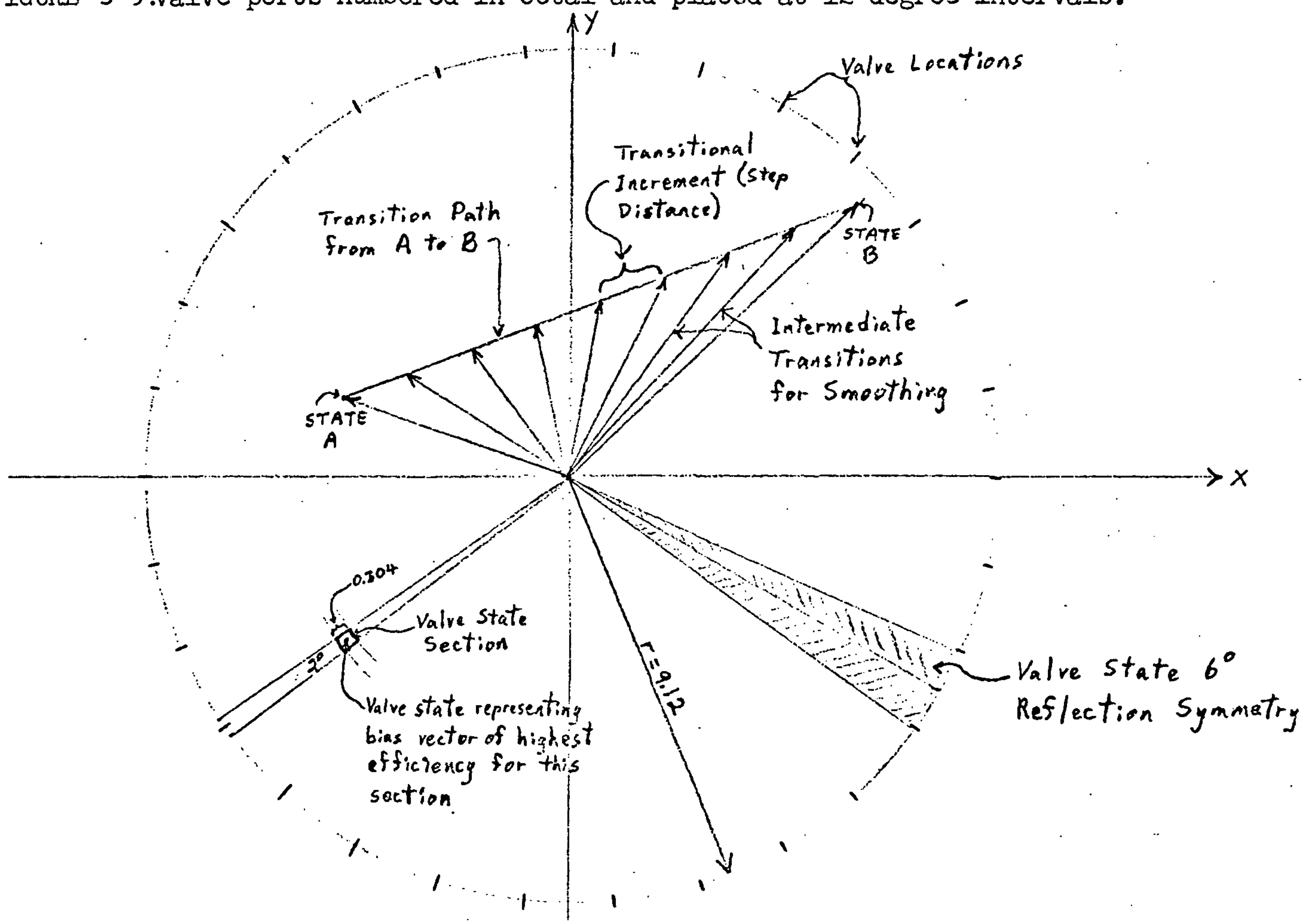


FIGURE3-10:Valve state circle with radius of 9.12 units.

SECTION FOUR

IV. CONTROL PROGRAMS

Two (2) separate control routines were developed for the omni-axis SITVC. One(1) is an Operational Routine incorporating a variable state-variable time computation sequence. This program provides for operator selection of control mode step interval length and step interval timing while in a programmed sequence mode of operation. It further provides for operator selected constants when the system is being controlled from external signal sources. The other routine is called the Test Routine and provides a simplified system of controlling any number and specific address of valves.

A. Operational Routine

This routine implements the control sequence described in the previous section. Operator inputs and data outputs are through the teletype ASR associated with the process controller. There are two (2) basic modes of operation, remote (R) and Sequence (S). While in the sequence mode all commands and control reside within the program. In the remote mode commands (X and Y Vector inputs) are generated from a remote source and are coded and controlled through the program. Command modes of the program are "MS" for Mode Select, "PS" for Program Select, "PE" for Program Execute and "PL" for Program List. The mode select command controls the mode under which the Test Program select command permits the operator to enter a variable state transition step length (from 10 to 2,000). It further permits an operator entry as to the variable state transition rate. This rate may be either constant or variable while in the sequence mode, with the operator providing the rate control for each step while in variable operation. Constant rate input is used in either remote or sequence modes and remains constant for any step within a test run. The valve of this rate may be set at any value from 50 to 10,000, and the number represents the approximate time in milli-seconds for that step. Rate values to as low as 20 may be used significantly where computation times are short, ie for small step increments.

While entering control constants in the PS command mode, other such constants may be included in the sequence mode. A cycle duration constant may be entered to repeat any number of cycles of the command sequence or may be left to run for a indefinite number of cycles. While in the sequence mode, each value of the X and Y Vectors must be entered by the operator. In the remote mode, the program sequence command mode provides an additional control feature in which a termination point is selected by the operator. In this mode when the inputs from external sources remain unchanged for an operator selected number of step cycles, the program is terminated and corrective commands are given the system. In this particular sequence, stuck valves are compensated by the program. That is, valves stuck shut will have adjacent closed valves opened and valves stuck open will be compensated by opening a valve 180^{o} away.

The program execute command is used to initiate operation of the entire system after program sequence constants and commands have been entered on the keyboard. The program list command is used following termination of a test run and provides a printed history of valving operation, both open and closed, with a clock count associated with each operation being displayed. It further provides an indication of compensation operations which may be necessary for failed valves. The following pages present the program listing for the omni-axis operational routine as mechanized for a PDP-8/E process controller with a 4-K memory and a ASR 33 teletype.

```
        0000  FIELD 0
        0000  *0
00000   0000  INTRPT, 0
00001   5777'         JMP SKPCHN
        0010  *10
00010   0000  LISTPT, 0          /LIST POINTER
00011   0000  XSTKPT, 0          /X STACK POINTER
00012   0000  YSTKPT, 0          /Y STACK POINTER
00013   0000  RSTKPT, 0          /R STACK POINTER
00014   0000  AUTO01, 0
00015   0000  AUTO02, 0
        0020  *20
00020   0000  STOR01, 0
00021   0000  STOR02, 0
00022   0000  STOR03, 0
00023   0000  STOR04, 0
00024   0000  STOR05, 0
00025   0000  STOR06, 0
00026   0000  STOR07, 0
00027   0000  STOR08, 0
00030   0000  INTCS1, 0
00031   0000  INTCS2, 0
00032   0000  INTCS3, 0
00033   0000  INTCS4, 0
00034   0000  INTCS7, 0
00035   0000  INTCS8, 0
00036   6202  RETURN, 6202       /CIF
00037   0000  XBEGIN, 0          /BEGIN VALUE OF X
00040   0000  YBEGIN, 0          /BEGIN VALUE OF Y
00041   0000  XEND,   0          /END VALUE OF X
00042   0000  YEND,   0          /END VALUE OF Y
00043   0000  DSTNCE, 0          /TOTAL TRANSITION DISTANCE
00044   0000  STEPDT, 0          /TRANSITION STEP DISTANCE
00045   0000  STPCNT, 0          /TRANSITION STEP COUNT
00046   0000  DELTAX, 0          /X TRANSITION STEP DISTANCE
00047   0000  DELTAY, 0          /Y TRANSITION STEP DISTANCE
00050   0000  ABTIME, 0          /ABSOLUTE TIME
00051   0000          0          /(DOUBLE PRECISION)
00052   0000  CDCONT, 0          /CYCLE DURATION COUNT
00053   0000  TRCONT, 0          /TRANSITION RATE COUNT
00054   0000  CYDURA, 0          /CYCLE DURATION
00055   0000  TRANSR, 0          /TRANSITION RATE
00056   0000  PGMODE, 0          /PROGRAM MODE
00057   6177  LISTST, 6177       /LIST START-1.
```

```
00060  6600  LISTLN, -1200   /(NEGATIVE) LIST LENGTH
00061  4777  RSTKBG, 4777    /BEGINNING ADDRESS -1 OF R STACK.
00062  5177  XSTKBG, 5177    /BEGINNING ADDRESS -1 OF X STACK.
00063  5377  YSTKBG, 5377    /BEGINNING ADDRESS -1 OF Y STACK.
00064  0000  AC,     0       /SAVE ACCUMULATOR HERE ON INTERRUPT.
00065  0000  L,      0       /SAVE LINK HERE ON INTERRUPT.
00066  0000  XACEPT, 0       /PUT A-D & SEQ. SAMPLE HERE FOR CONVERSION
00067  0000  YACEPT, 0       /PUT A-D & SEQ. SAMPLE HERE FOR CONVERSION
00070  0000  SEQNCE, 0       /12 BIT COMMAND SEQUENCE
00071  0000  ROTATN, 0       /# COUNTER CLOCKWISE SEQUENCE ROTATIONS
00072  0000  RHOIND, 0       /RHO INDEX FOR LOOKUP TABLE
00073  0000  SINTST, 0       /ABSOLUTE VALUE OF (SIN[THETA]-SIN[N])
00074  0000  THETA,  0       /EVEN THETA APPROXIMATION
00075  0000  SMLLST, 0       /PARAMETER FOR "SMALLEST" DIFFERENCE TEST.
00076  0000  RHO,    0       /SQRT[X↑2+Y↑2]
00077  0000  SINTHE, 0       /1000*SIN(THETA)
00100  5577  SINTBL, 5577    /POINTER (-1) TO SINE TABLE
00101  0000  VLVENM, 0       /"VALVE NUMBER" FOR EXECUTION COMMANDS.
00102  0000  COMMND, 0       /USED TO FORM EXECUTION COMMAND.
00103  5677  THETBL, 5677    /POINTER (-1) TO VALVE STATE TABLE.
00104  6000  SEQTBL, 6000    /POINTER TO SEQUENCE TABLE.
00105  0000  THEIND, 0       /THETA INDEX FOR LOOKUP TABLE.
00106  0000  PARITY, 0       /USED TO FIND SEQUENCE.
00107  0000  THETAL, 0       /USED TO FIND SEQUENCE.
00110  0000  THETAS, 0       /USED TO FIND SEQUENCE.
00111  0000  XSQARH, 0       /STORAGE FOR X↑2.
00112  0000  XSQARM, 0       /STORAGE FOR X↑2.
00113  0000  XSQARL, 0       /STORAGE FOR X↑2.
00114  0000  TERMNL, 0       /TERMINAL SPACING.
00115  0000  TRMCNT, 0       /TERMINAL COUNT.
00116  3400  TCC000, TCS000
00117  3414  TDC000, TDS000
00120  3422  TBC000, TBS000
00121  3455  TEC000, TES000
00122  3503  TGC000, TGS000
00123  3517  TPC000, TPS000
00124  3533  TQC000, TQS000
00125  3600  MLC000, MLS000
00126  4600  MBC000, MBS000
00127  4634  MAC000, MAS000
00130  1600  AHC000, AHS000
00131  4400  MIC000, MIS000
00132  4671  MCC000, MCS000
00133  4304  MJC000, MJS000
00134  3314  MDC000, MDS000
00135  3227  MMC000, MMS000

       0200  *200
00200  7300          CLA CLL
00201  6046          TLS              /SET PRINTER FLAG.
00202  7300  START,  CLA CLL
00203  4516          JMS I TCC000     /CARRIAGE RETURN-LINE FEED.
00204  1377          TAD ("@
00205  4517          JMS I TDC000     /TYPE "." ON TTY.
00206  4520          JMS I TBC000     /ACCEPT CHARACTER FROM TTY.
```

```
00207   1020                TAD STOR01
00210   1376                TAD (-"M
00211   7450                SNA                 /IS IT AN "M"?
00212   5235                JMP MODSLT          /YES, GO TO "MODE SELECT".
00213   1375                TAD (-3             /NO, TEST FOR "P".
00214   7440                SZA
00215   5231                JMP ERROR           /ILLEGAL CHARACTER
00216   4520                JMS I TBC000        /ACCEPT CHARACTER FROM TTY.
00217   1020                TAD STOR01
00220   1374                TAD (-"E
00221   7450                SNA                 /IS IT AN "E"?
00222   5773'               JMP PGEXCT          /YES, GO TO "PROGRAM EXECUTE".
00223   1372                TAD (-7             /NO, TEST FOR "L".
00224   7450                SNA                 /IS IT AN "L"?
00225   5265                JMP PGLIST          /YES, GO TO "PROGRAM LIST".
00226   1372                TAD (-7             /NO, TEST FOR "S".
00227   7450                SNA                 /IS IT AN "S"?
00230   5771'               JMP PGSLCT          /YES, GO TO "PROGRAM SELECT".
00231   7300        ERROR,  CLA CLL
00232   1370                TAD ("?
00233   4517                JMS I TDC000        /TYPE "?" ON TTY.
00234   5202                JMP START           /RETURN TO "START".
                    /THE FOLLOWING CODE REPRESENTS THE
                    /MODE SELECT (M) INSTRUCTION:
00235   1367        MODSLT, TAD (CMT000
00236   3021                DCA STOR02
00237   4516                JMS I TCC000        /CARRIAGE RETURN-LINE FEED
00240   4521                JMS I TEC000        /PRINT "MODE(0,1): ".
00241   4520                JMS I TBC000        /ACCEPT CHARACTER FROM TTY.
00242   1020                TAD STOR01
00243   1366                TAD (-"R            /IS IT AN "R"?
00244   7450                SNA
00245   5254                JMP .+7             /YES: SET FLAG(1).
00246   1365                TAD (-1             /NO: TEST FOR "S".
00247   7650                SNA CLA             /IS IT AN "S"?
00250   5255                JMP .+5             /YES: CLEAR FLAG(0).
00251   1370                TAD ("?             /NO: ILLEGAL CHARACTER.
00252   4517                JMS I TDC000        /TYPE "?" ON TTY.
00253   5235                JMP MODSLT
00254   7201                CLA IAC
00255   3056                DCA PGMODE          /STORE NUMBER (0 OR 1) IN "PGMODE".
00256   5202                JMP START           /RETURN TO START.
00257   1517        CMT000, TEXT /MODE(R,S): /
00260   0405
00261   5022
00262   5423
00263   5172
00264   4000
                    /THE FOLLOWING CODE REPRESENTS THE
                    /PROGRAM LIST (PL) INSTRUCTION:
00265   4267        PGLIST, JMS PRINT
00266   5202                JMP START
00267   0000        PRINT,  0
00270   7346                CLA CLL CMA RTL /PRINT HEADING:
00271   4522                JMS I TGC000        /3 LINE FEED.
```

```
00272   4516        JMS I TCC000    /CARRIAGE RETURN-LINE FEED
00273   1364        TAD (CMT001
00274   3021        DCA STOR02
00275   4521        JMS I TEC000    /PRINT "...VALVE...VALVE...ABSOLUTE
00276   4516        JMS I TCC000    /CARRIAGE RETURN-LINE FEED.
00277   1363        TAD (CMT002
00300   3021        DCA STOR02
```

```
00301  4521            JMS I TEC000      /PRINT "VALVE...COMMAND...STATE..."
00302  4516            JMS I TCC000      /CARRIAGE RETURN-LINE FEED
00303  4516            JMS I TCC000      /CARRIAGE RETURN-LINE FEED
                                         /END HEADING PRINT.
00304  1057            TAD LISTST
00305  3010            DCA LISTPT        /INITIALIZE LIST POINTER.
00306  7300   LOOP00,  CLA CLL           /LIST PRINT-OUT LOOP:
00307  1410            TAD I LISTPT
00310  7500            SMA               /IS PRINT-OUT COMPLETE?
00311  5762'           JMP FINISH        /YES, GO TO FINISH.
00312  3022            DCA STOR03        /NO, CONTINUE.
00313  7344            CLA CLL CMA RAL   /"TAD (-2"
00314  4523            JMS I TPC000      /2 SPACES
00315  1022            TAD STOR03
00316  7002            7002              /BSW
00317  0361            AND (37
00320  1176            TAD [-1
00321  4524            JMS I TQC000      /2 DIGIT OCTAL PRINT
00322  1372            TAD (-7
00323  4523            JMS I TPC000      /7 SPACES
00324  1022            TAD STOR03        /TEST VALVE COMMAND:
00325  7110            CLL RAR
00326  7430            SZL
00327  5341            JMP .+12
00330  7010            RAR
00331  7430            SZL
00332  5344            JMP .+12
00333  7010            RAR
00334  7430            SZL
00335  5347            JMP .+12
00336  7300            CLA CLL
00337  1360            TAD ("
00340  5351            JMP .+11
00341  7300            CLA CLL
00342  1357            TAD ("0
00343  5351            JMP .+6
00344  7300            CLA CLL
00345  1356            TAD ("C
00346  5351            JMP .+3
00347  7300            CLA CLL
00350  1355            TAD ("I
00351  4517            JMS I TDC000      /TYPE VALVE COMMAND ON TTY.
00352  5754'           JMP PAGE02
00354  0400
00355  0311
00356  0303
00357  0317
00360  0240
00361  0037
00362  0471
00363  0533
00364  0511
00365  7777
00366  7456
00367  0257
```

```
ØØ37Ø  Ø277
ØØ371  Ø6ØØ
ØØ372  7771
ØØ373  1Ø72
ØØ374  7473
ØØ375  7775
ØØ376  7463
ØØ377  Ø3ØØ
       Ø4ØØ  PAGE
ØØ4ØØ  1377  PAGEØ2, TAD (-7
ØØ4Ø1  4523          JMS I TPCØØØ    /7 SPACES
ØØ4Ø2  1Ø22          TAD STORØ3      /TEST VALVE STATE:
ØØ4Ø3  Ø376          AND (7Ø
ØØ4Ø4  745Ø          SNA             /IS IT A NULL STATE?
ØØ4Ø5  5234          JMP NULSTE      /YES, GO TO "NULL STATE".
ØØ4Ø6  Ø375          AND (6Ø         /NO.
ØØ4Ø7  745Ø          SNA             /IS IT AN INOPERATIVE STATE?
ØØ41Ø  5243          JMP INOPST      /YES, GO TO "INOP. STATE".
ØØ411  7346          CLA CLL CMA RTL /NO, CONTINUE TEST.("TAD(-3")
ØØ412  3Ø23          DCA STORØ4      /SET UP COUNTER
ØØ413  1Ø22          TAD STORØ3
ØØ414  Ø376          AND (7Ø
ØØ415  7ØØ2          7ØØ2            /BSW
ØØ416  3Ø22          DCA STORØ3
ØØ417  5224          JMP .+5
ØØ42Ø  73ØØ  LOOPØ1, CLA CLL
ØØ421  2Ø23          ISZ STORØ4      /INCREMENT AND TEST COUNTER.
ØØ422  741Ø          SKP
ØØ423  5252          JMP TIMEPR
ØØ424  1Ø22          TAD STORØ3
ØØ425  71Ø4          CLL RAL
ØØ426  3Ø22          DCA STORØ3
ØØ427  753Ø          SZL CLL
ØØ43Ø  1374          TAD (14
ØØ431  1373          TAD (3Ø3
ØØ432  4517          JMS I TDCØØØ    /TYPE "C" OR "O" ON TTY.
ØØ433  522Ø          JMP LOOPØ1
ØØ434  73ØØ  NULSTE, CLA CLL
ØØ435  1372          TAD (CMTØØ3
ØØ436  3Ø21          DCA STORØ2
ØØ437  4521          JMS I TECØØØ    /PRINT "...".
ØØ44Ø  5252          JMP TIMEPR
ØØ441  4Ø4Ø  CMTØØ3, TEXT /   /
ØØ442  4ØØØ
ØØ443  73ØØ  INOPST, CLA CLL
ØØ444  1371          TAD (CMTØØ4
ØØ445  3Ø21          DCA STORØ2
ØØ446  4521          JMS I TECØØØ    /PRINT "INP".
ØØ447  5252          JMP TIMEPR
ØØ45Ø  1116  CMTØØ4, TEXT /INP/
ØØ451  2ØØØ
ØØ452  73ØØ  TIMEPR, CLA CLL
ØØ453  137Ø          TAD (-4
ØØ454  4523          JMS I TPCØØØ    /4 SPACES
ØØ455  73Ø1          CLA CLL IAC
```

```
00456   3767'          DCA MLS030
00457   7346           CLA CLL CMA RTL /"TAD (-3"
00460   3766'          DCA MLS031
00461   3765'          DCA MAS002
00462   1410           TAD I LISTPT
00463   3764'          DCA MAS003
00464   1410           TAD I LISTPT
00465   3763'          DCA MAS004
00466   4525           JMS I MLC000    /PRINT OUT TIME.
00467   4516           JMS I TCC000    /CARRIAGE RETURN-LINE FEED
00470   5762'          JMP LOOP00      /RE-ENTER PRINT-OUT LOOP.
00471   7346   FINISH, CLA CLL CMA RTL /"TAD (-3
00472   4522           JMS I TGC000    /3 LINE FEED
00473   7300           CLA CLL
00474   1057           TAD LISTST
00475   3010           DCA LISTPT
00476   1060           TAD LISTLN
00477   3020           DCA STOR01
00500   3410           DCA I LISTPT    /ZERO LIST BUFFER
00501   2020           ISZ STOR01
00502   5300           JMP .-2
00503   1057           TAD LISTST
```

```
ØØ5Ø4  3Ø1Ø            DCA LISTPT        /RE-INITIALIZE LISTPT.
ØØ5Ø5  1761'           TAD PRINT
ØØ5Ø6  331Ø            DCA .+2
ØØ5Ø7  571Ø            JMP I .+1         /LEAVE SUBROUTINE "PRINT".
ØØ51Ø  ØØØØ            Ø
ØØ511  4Ø4Ø  CMTØØ1,   TEXT /            VALVE     VALVE    ABSOLUTE/
ØØ512  4Ø4Ø
ØØ513  4Ø4Ø
ØØ514  4Ø4Ø
ØØ515  4Ø26
ØØ516  Ø114
ØØ517  26Ø5
ØØ52Ø  4Ø4Ø
ØØ521  4Ø4Ø
ØØ522  26Ø1
ØØ523  1426
ØØ524  Ø54Ø
ØØ525  4Ø4Ø
ØØ526  Ø1Ø2
ØØ527  2317
ØØ53Ø  1425
ØØ531  24Ø5
ØØ532  ØØØØ
ØØ533  26Ø1  CMTØØ2,   TEXT /VALVE    COMMAND   STATE      TIME/
ØØ534  1426
ØØ535  Ø54Ø
ØØ536  4Ø4Ø
ØØ537  Ø317
ØØ54Ø  1515
ØØ541  Ø116
ØØ542  Ø44Ø
ØØ543  4Ø4Ø
ØØ544  2324
ØØ545  Ø124
ØØ546  Ø54Ø
ØØ547  4Ø4Ø
ØØ55Ø  4Ø4Ø
ØØ551  2411
ØØ552  15Ø5
ØØ553  ØØØØ
ØØ561  Ø267
ØØ562  Ø3Ø6
ØØ563  4662
ØØ564  4661
ØØ565  466Ø
ØØ566  43Ø2
ØØ567  43Ø1
ØØ57Ø  7774
ØØ571  Ø45Ø
ØØ572  Ø441
ØØ573  Ø3Ø3
ØØ574  ØØ14
ØØ575  ØØ6Ø
ØØ576  ØØ7Ø
ØØ577  7771
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        0600   PAGE
               /THE FOLLOWING CODE REPRESENTS THE
               /PROGRAM SELECT (PS) INSTRUCTION:
00600   7300   PGSLCT, CLA CLL
00601   4777'          JMS STPSLT      /STEP SELECT.
00602   1061           TAD RSTKBG
00603   3013           DCA RSTKPT      /INITIALIZE R STACK POINTER.
00604   1062           TAD XSTKBG
00605   3011           DCA XSTKPT      /INITIALIZE X STACK POINTER.
00606   1063           TAD YSTKBG
00607   3012           DCA YSTKPT      /INITIALIZE Y STACK POINTER.
00610   1056           TAD PGMODE      /WHICH MODE?
00611   7640           SZA CLA
00612   5246           JMP PGSL01      /REMOTE MODE.
00613   4516           JMS I TCC000    /CARRIAGE RETURN-LINE FEED
00614   1376           TAD (CMT005
00615   3021           DCA STOR02
00616   4521           JMS I TEC000    /PRINT "CD(I,F): ".
00617   4520           JMS I TBC000    /ACCEPT CHARACTER FROM TTY.
00620   1020           TAD STOR01
00621   1375           TAD (-"F
00622   7440           SZA             /IS IT AN "F"?
00623   5230           JMP .+5         /NO, TEST FOR "I".
00624   1374           TAD (CYDURA-1   /YES.
00625   3015           DCA AUTO02
00626   4533           JMS I MJC000    /ACCEPT CYCLE DURATION FROM TTY.
00627   5246           JMP PGSL01      /CONTINUE PROGRAM SELECT.
00630   1373           TAD (-3
00631   7640           SZA CLA         /IS IT AN "I"?
00632   5236           JMP .+4         /NO, GO TO "?".
00633   7313           CLA CLL IAC RTR /YES, SET BIT 0 OF CYDURA TO 1.
00634   3054           DCA CYDURA
00635   5246           JMP PGSL01      /CONTINUE PROGRAM SELECT.
00636   1372           TAD ("?         /ERROR CASE.
00637   4517           JMS I TDC000    /PRINT "?" ON TTY.
00640   5202           JMP PGSLCT+2    /ASK AGAIN CYCLE DURATION.
00641   0304   CMT005, TEXT /CD(I,F): /
00642   5011
00643   5406
00644   5172
00645   4000
00646   7300   PGSL01, CLA CLL
00647   4516           JMS I TCC000    /CARRIAGE RETURN-LINE FEED.
00650   1371           TAD (CMT006
00651   3021           DCA STOR02
00652   4521           JMS I TEC000    /PRINT "R(C,V): ".
00653   1056           TAD PGMODE
00654   7650           SNA CLA         /WHICH MODE?
00655   5261           JMP .+4         /SEQUENCE MODE.
00656   1370           TAD ("C         /REMOTE MODE.
00657   4517           JMS I TDC000    /TYPE "C" ON TTY.
00660   5266           JMP .+6
00661   4520           JMS I TBC000    /ACCEPT CHARACTER FROM TTY.
00662   1020           TAD STOR01
00663   1367           TAD (-"C
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00664   7440            SZA                  /IS IT A "C"?
00665   5272            JMP .+5              /NO, TEST FOR "V".
00666   1366            TAD (TRANSR-1        /YES.
00667   3015            DCA AUTO02
00670   4533            JMS I MJC000         /ACCEPT TRANSITION RATE FROM TTY.
00671   5765'           JMP PGSL03           /CONTINUE PROGRAM SELECT.
00672   1364            TAD (-23
00673   7640            SZA CLA              /IS IT A "V"?
00674   5300            JMP .+4              /NO, ERROR CASE.
00675   7313            CLA CLL IAC RTR      /YES, SET BIT 0 OF TRANSR TO 1.
00676   3055            DCA TRANSR
00677   5765'           JMP PGSL03           /CONTINUE PROGRAM SELECT.
00700   1372            TAD ("?              /ERROR CASE.
00701   4517            JMS I TDC000         /PRINT "?" ON TTY.
00702   5246            JMP PGSL01           /RETURN TO PGSL01.
00703   2250    CMT006, TEXT /R(C,V): /
00704   0354
00705   2651
00706   7240
00707   0000
00764   7755
00765   1000
00766   0054
00767   7475
00770   0303
00771   0703
00772   0277
00773   7775
00774   0053
00775   7472
00776   0641
00777   3055
        1000    PAGE
01000   7300    PGSL03, CLA CLL
01001   1056            TAD PGMODE
01002   7640            SZA CLA              /WHICH MODE?
01003   5252            JMP RECTRM           /REMOTE MODE, SELECT TERMINAL DEF.
01004   1377            TAD (-600            /SEQUENCE MODE. CONTINUE.
01005   3020            DCA STOR01
01006   1061            TAD RSTKBG
01007   3014            DCA AUTO01
```

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Ø1Ø1Ø  3414            DCA I AUTOØ1    /ZERO R,X,AND Y STACKS.
Ø1Ø11  2Ø2Ø            ISZ STORØ1
Ø1Ø12  521Ø            JMP .-2
Ø1Ø13  1376            TAD (-177
Ø1Ø14  3Ø27            DCA STORØ8
Ø1Ø15  5222            JMP .+5
Ø1Ø16  73ØØ  LOOPØ2,   CLA CLL         /SEQUENCE ACCEPT LOOP
Ø1Ø17  2Ø27            ISZ STORØ8
Ø1Ø2Ø  741Ø            SKP
Ø1Ø21  5775'           JMP START       /RETURN TO COMMAND MODE.
Ø1Ø22  4516            JMS I TCCØØØ    /CARRIAGE RETURN-LINE FEED.
Ø1Ø23  1374            TAD (CMTØ11
Ø1Ø24  4241            JMS SEQACT
Ø1Ø25  3411            DCA I XSTKPT    /INSERT X VALUE IN X STACK.
Ø1Ø26  1373            TAD (CMTØ12
Ø1Ø27  4241            JMS SEQACT
Ø1Ø3Ø  3412            DCA I YSTKPT    /INSERT Y VALUE IN Y STACK.
Ø1Ø31  1Ø55            TAD TRANSR
Ø1Ø32  75ØØ            SMA
Ø1Ø33  5237            JMP .+4
Ø1Ø34  73ØØ            CLA CLL
Ø1Ø35  1372            TAD (CMTØØ9
Ø1Ø36  4241            JMS SEQACT
Ø1Ø37  3413            DCA I RSTKPT    /INSERT R VALUE IN R STACK.
Ø1Ø4Ø  5216            JMP LOOPØ2      /RE-ENTER SEQUENCE ACCEPT LOOP.
Ø1Ø41  ØØØØ  SEQACT,   Ø
Ø1Ø42  3Ø21            DCA STORØ2
Ø1Ø43  1371            TAD (STORØ3-1
Ø1Ø44  3Ø15            DCA AUTOØ2
Ø1Ø45  4516            JMS I TCCØØØ    /CARRIAGE RETURN-LINE FEED
Ø1Ø46  4521            JMS I TECØØØ    /PRINT "X= ","Y= ", OR "R= ".
Ø1Ø47  4533            JMS I MJCØØØ    /ACCEPT SINGLE PRECISION VALUE
Ø1Ø5Ø  1Ø22            TAD STORØ3      /FROM TTY.
Ø1Ø51  5641            JMP I SEQACT
Ø1Ø52  137Ø  RECTRM,   TAD (CMTØ1Ø
Ø1Ø53  3Ø21            DCA STORØ2
Ø1Ø54  4516            JMS I TCCØØØ    /CARRIAGE RETURN-LINE FEED
Ø1Ø55  4521            JMS I TECØØØ    /PRINT "T= ".
Ø1Ø56  1367            TAD (TERMNL-1
Ø1Ø57  3Ø15            DCA AUTOØ2
Ø1Ø6Ø  4533            JMS I MJCØØØ    /ACCEPT TERMINAL DEFINITION
Ø1Ø61  5775'           JMP START       /LENGTH FROM TTY.

Ø1Ø62  2275  CMTØØ9,   TEXT /R= /
Ø1Ø63  4ØØØ
Ø1Ø64  2475  CMTØ1Ø,   TEXT /T= /
Ø1Ø65  4ØØØ
Ø1Ø66  3Ø75  CMTØ11,   TEXT /X= /
Ø1Ø67  4ØØØ
Ø1Ø7Ø  3175  CMTØ12,   TEXT /Y= /
Ø1Ø71  4ØØØ
             /THE FOLLOWING CODE REPRESENTS THE
             /PROGRAM EXECUTE (PE) INSTRUCTION:
Ø1Ø72  73ØØ  PGEXCT,   CLA CLL
Ø1Ø73  6Ø41            TSF
```

```
01074  5273           JMP .-1
01075  1366           TAD (-36
01076  3020           DCA STOR01
01077  1103           TAD THETBL
01100  3014           DCA AUTO01
01101  3414           DCA I AUTO01     /ZERO THETA STATE TABLE.
01102  2020           ISZ STOR01
01103  5301           JMP .-2
01104  1057           TAD LISTST
01105  3010           DCA LISTPT
01106  1060           TAD LISTLN
01107  3020           DCA STOR01
01110  3410           DCA I LISTPT     /ZERO EXECUTION RECORD LIST.
01111  2020           ISZ STOR01
01112  5310           JMP .-2
01113  1057           TAD LISTST       /INITIALIZE THE FOLLOWING:
01114  3010           DCA LISTPT       /     -LIST POINTER,
01115  3050           DCA ABTIME       /     -ABSOLUTE TIME,
01116  3051           DCA ABTIME+1
01117  1114           TAD TERMNL
01120  7041           CIA
01121  3115           DCA TRMCNT       /     -TERMINAL COUNT,
01122  3037           DCA XBEGIN       /     -INITIAL X,
01123  3040           DCA YBEGIN       /     -INITIAL Y,
01124  1061           TAD RSTKBG
01125  3013           DCA RSTKPT       /     -R STACK,
01126  1062           TAD XSTKBG
01127  3011           DCA XSTKPT       /     -X STACK,
01130  1063           TAD YSTKBG
01131  3012           DCA YSTKPT       /     -Y STACK, AND
01132  1054           TAD CYDURA
01133  7041           CIA
01134  3052           DCA CDCONT       /     -CYCLE DURATION COUNT.
01135  6007           6007             /CAF
01136  6501           6501             /ENABLE DBEI-0 INTERRUPT.
01137  6001           ION              /TURN ON INTERRUPT.
01140  5765'          JMP PGEXT1
01165  1200
01166  7742
01167  0113
01170  1064
01171  0021
01172  1062
01173  1070
01174  1066
01175  0202
01176  7601
01177  7200
       1200  PAGE
01200  7300  PGEXT1,  CLA CLL
01201  1056           TAD PGMODE
01202  7640           SZA CLA          /WHICH MODE?
01203  5206           JMP .+3          /REMOTE MODE(1).
01204  4777'          JMS TRESET       /SEQUENCE MODE(0).
01205  5211           JMP PGEXT2
```

```
01206   1055            TAD TRANSR
01207   7041            CIA
01210   3053            DCA TRCONT         /SET DELAY COUNTER.
01211   1056    PGEXT2, TAD PGMODE
01212   7640            SZA CLA            /WHICH MODE?
01213   5216            JMP .+3            /REMOTE MODE(1).
01214   4776'           JMS SEQRED         /SEQUENCE MODE(0).
01215   7410            SKP
01216   4775'           JMS RMTRED
01217   1041            TAD XEND
01220   7041            CIA
01221   1037            TAD XBEGIN
01222   7510            SPA                /FORM POSITIVE DIFFERENCE.
01223   7041            CIA
01224   0175            AND [7774          /NOISE ELIMINATION (+ OR -3).
01225   7640            SZA CLA            /INITIAL X=FINAL X?
01226   5261            JMP PGEXT3         /NO: GO TO EXECUTION.
01227   1042            TAD YEND           /YES: TEST Y'S.
01230   7041            CIA
01231   1040            TAD YBEGIN
01232   7510            SPA                /FORM POSITIVE DIFFERENCE.
01233   7041            CIA
01234   0175            AND [7774          /NOISE ELIMINATION (+ OR -3).
01235   7640            SZA CLA            /INITIAL Y=FINAL Y?
01236   5261            JMP PGEXT3         /NO: GO TO EXECUTION.
01237   1053            TAD TRCONT         /YES: TEST FOR TERMINATION:
01240   7640            SZA CLA            /DELAY=0?
01241   5237            JMP .-2            /NO: REMAIN IN DELAY LOOP.
01242   1056            TAD PGMODE         /YES: RESET DELAY COUNTER:
01243   7640            SZA CLA
01244   5247            JMP .+3
01245   4777'           JMS TRESET
01246   5252            JMP .+4
01247   1055            TAD TRANSR
01250   7041            CIA
01251   3053            DCA TRCONT
01252   2115            ISZ TRMCNT
01253   5211            JMP PGEXT2
01254   1114            TAD TERMNL
01255   7041            CIA
01256   3115            DCA TRMCNT         /RESET TERMINAL COUNT.
01257   4774'           JMS INTCOM
01260   5211            JMP PGEXT2
```

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Ø1261  1114   PGEXT3, TAD TERMNL      /EXECUTION:
Ø1262  7Ø41           CIA
Ø1263  3114           DCA TERMNL      /RESET TERMINAL COUNT.
Ø1264  1Ø37           TAD XBEGIN
Ø1265  7Ø41           CIA
Ø1266  1Ø41           TAD XEND
Ø1267  751Ø           SPA
Ø127Ø  7Ø41           CIA
Ø1271  3773'          DCA MASØØ4
Ø1272  3772'          DCA MASØØ3
Ø1273  3771'          DCA MASØØ2
Ø1274  1773'          TAD MASØØ4
Ø1275  377Ø'          DCA MCSØØ3
Ø1276  4532           JMS I MCCØØØ    /CALCULATE (X[I]-X[F])↑2.
Ø1277  1767'          TAD MASØØ8
Ø13ØØ  3111           DCA XSQARH
Ø13Ø1  1766'          TAD MASØØ9
Ø13Ø2  3112           DCA XSQARM
Ø13Ø3  1765'          TAD MASØ1Ø
Ø13Ø4  3113           DCA XSQARL
Ø13Ø5  1Ø4Ø           TAD YBEGIN
Ø13Ø6  7Ø41           CIA
Ø13Ø7  1Ø42           TAD YEND
Ø131Ø  751Ø           SPA
Ø1311  7Ø41           CIA
Ø1312  3773'          DCA MASØØ4
Ø1313  3772'          DCA MASØØ3
Ø1314  3771'          DCA MASØØ2
Ø1315  1773'          TAD MASØØ4
Ø1316  377Ø'          DCA MCSØØ3
Ø1317  4532           JMS I MCCØØØ    /CALCULATE (Y[I]-Y[F])↑2.
Ø132Ø  453Ø           JMS I AHCØØØ
Ø1321  1111           TAD XSQARH
Ø1322  3764'          DCA MASØØ5
Ø1323  1112           TAD XSQARM
Ø1324  3763'          DCA MASØØ6
Ø1325  1113           TAD XSQARL
Ø1326  3762'          DCA MASØØ7
Ø1327  4527           JMS I MACØØØ    /CALCULATE (DELX↑2+DELY↑2).
Ø133Ø  1767'          TAD MASØØ8
Ø1331  3761'          DCA MMSØØ5
Ø1332  1766'          TAD MASØØ9
Ø1333  376Ø'          DCA MMSØØ6
Ø1334  1765'          TAD MASØ1Ø
Ø1335  3757'          DCA MMSØØ7
Ø1336  1356           TAD (2734       /15ØØ - INITIAL UPPER BOUND
Ø1337  4535           JMS I MMCØØØ    /CALCULATE SQRT(DELX↑2+DELY↑2).
Ø134Ø  1755'          TAD MMSØØ4
Ø1341  3Ø43           DCA DSTNCE      /DSTNCE←SQRT(DELX↑2+DELY↑2).
Ø1342  1Ø43           TAD DSTNCE
Ø1343  3773'          DCA MASØØ4
Ø1344  3772'          DCA MASØØ3
Ø1345  1Ø44           TAD STEPDT
Ø1346  3762'          DCA MASØØ7
Ø1347  4534           JMS I MDCØØØ    /CALCULATE DSTNCE/STEPDT
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01350   5754'           JMP PAGE06
01354   1400
01355   3310
01356   2734
01357   3313
01360   3312
01361   3311
01362   4665
01363   4664
01364   4663
01365   4670
01366   4667
01367   4666
01370   4756
01371   4660
01372   4661
01373   4662
01374   2056
01375   3024
01376   3016
01377   1516
        1400    PAGE
01400   1777'   PAGE06, TAD MDS005
01401   7001            IAC
01402   3045            DCA STPCNT      /STPCNT←(DSTNCE/STEPDT)+1.
01403   1037            TAD XBEGIN
01404   7041            CIA
01405   1041            TAD XEND
01406   7510            SPA
01407   7041            CIA
01410   3776'           DCA MAS004
01411   3775'           DCA MAS003
01412   1045            TAD STPCNT
01413   3774'           DCA MAS007
01414   4534            JMS I MDC000    /CALCULATE ABS[(X[F]-X[I])/STPCNT].
01415   1037            TAD XBEGIN
01416   7041            CIA
01417   1041            TAD XEND
01420   7700            SMA CLA
01421   5225            JMP .+4
01422   1777'           TAD MDS005
01423   7041            CIA
01424   3777'           DCA MDS005
01425   1777'           TAD MDS005
01426   3046            DCA DELTAX      /DELTAX←(X[F]-X[I])/STPCNT
01427   1040            TAD YBEGIN
01430   7041            CIA
01431   1042            TAD YEND
01432   7510            SPA
01433   7041            CIA
01434   3776'           DCA MAS004
01435   3775'           DCA MAS003
01436   1045            TAD STPCNT
01437   3774'           DCA MAS007
01440   4534            JMS I MDC000    /CALCULATE ABS[(Y[F]-Y[I])/STPCNT].
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01441   1040            TAD YBEGIN
01442   7041            CIA
01443   1042            TAD YEND
01444   7700            SMA CLA
01445   5251            JMP .+4
01446   1777'           TAD MDS005
01447   7041            CIA
01450   3777'           DCA MDS005
01451   1777'           TAD MDS005
01452   3047            DCA DELTAY          /DELTAY←(Y[F]-Y[I])/STPCNT
01453   1045            TAD STPCNT
01454   7041            CIA
01455   3045            DCA STPCNT          /STPCNT←-SPTCNT
01456   2045   PGEXT4,  ISZ STPCNT
01457   7410            SKP
01460   5302            JMP EXCFNL
01461   1037            TAD XBEGIN
01462   1046            TAD DELTAX
01463   3037            DCA XBEGIN          /X[I]←X[I]+DELTAX
01464   1040            TAD YBEGIN
01465   1047            TAD DELTAY
01466   3040            DCA YBEGIN          /Y[I]←Y[I]+DELTAY
01467   1037            TAD XBEGIN
01470   3066            DCA XACEPT
01471   1040            TAD YBEGIN
01472   3067            DCA YACEPT
01473   4773'           JMS XYACPT          /CONVERT X,Y TO RHO, THETA.
01474   4772'           JMS RTISQ0          /LOOKUP SEQUENCE FOR RHO, THETA.
01475   4771'           JMS CMDOUT          /EXECUTE SEQUENCE COMMANDS
01476   1055            TAD TRANSR          /ON 0 DELAY.
01477   7041            CIA
01500   3053            DCA TRCONT          /RESET DELAY COUNTER
01501   5256            JMP PGEXT4
01502   1041   EXCFNL,  TAD XEND
01503   3066            DCA XACEPT
01504   1041            TAD XEND
01505   3037            DCA XBEGIN
01506   1042            TAD YEND
01507   3067            DCA YACEPT
01510   1042            TAD YEND
01511   3040            DCA YBEGIN
01512   4773'           JMS XYACPT          /CONVERT X,Y TO RHO, THETA.
01513   4772'           JMS RTISQ0          /LOOKUP SEQUENCE FOR RHO, THETA.
01514   4771'           JMS CMDOUT          /EXECUTE SEQUENCE COMMANDS.
01515   5770'           JMP PGEXT1          /ON 0 DELAY.

01516   0000   TRESET,  0
01517   1413            TAD I RSTKPT
01520   7440            SZA
01521   5341            JMP .+20
01522   1054            TAD CYDURA
01523   7710            SPA CLA
01524   5332            JMP .+6
01525   2052            ISZ CDCONT
01526   5332            JMP .+4
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01527  6002            IOF
01530  6046            TLS              /RESET PRINTER FLAG.
01531  5767'           JMP TTYSRV+5     /RETURN TO COMMAND MODE.
01532  1061            TAD RSTKBG       /RESET STACK POINTERS:
01533  3013            DCA RSTKPT
01534  1062            TAD XSTKBG
01535  3011            DCA XSTKPT
01536  1063            TAD YSTKBG
01537  3012            DCA YSTKPT
01540  1413            TAD I RSTKPT
01541  3055            DCA TRANSR
01542  1055            TAD TRANSR
01543  7041            CIA
01544  3053            DCA TRCONT       /RESET DELAY COUNT.
01545  5716            JMP I TRESET

01567  3112
01570  1200
01571  2474
01572  2400
01573  1611
01574  4665
01575  4661
01576  4662
01577  3362
       1600  PAGE
             /"AHS000" PUTS (CH,CM,CL) INTO (AH,AM,AL).

01600  0000  AHS000, 0
01601  7300            CLA CLL
01602  1777'           TAD MAS008
01603  3776'           DCA MAS002
01604  1775'           TAD MAS009
01605  3774'           DCA MAS003
01606  1773'           TAD MAS010
01607  3772'           DCA MAS004
01610  5600            JMP I AHS000

01611  0000  XYACPT, 0                  /CONVERT X,Y TO RHO, THETA:
01612  7300            CLA CLL
01613  1066            TAD XACEPT
01614  7510            SPA
01615  7041            CIA
01616  3772'           DCA MAS004
01617  3774'           DCA MAS003
01620  3776'           DCA MAS002
01621  1066            TAD XACEPT
01622  7510            SPA
01623  7041            CIA
01624  3771'           DCA MCS003
01625  4532            JMS I MCC000     /CALCULATE X↑2
01626  1777'           TAD MAS008       /STORE X↑2
01627  3111            DCA XSQARH
01630  1775'           TAD MAS009
01631  3112            DCA XSQARM
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01632   1773'        TAD MAS010
01633   3113         DCA XSQARL
01634   1067         TAD YACEPT
01635   7510         SPA
01636   7041         CIA
01637   3772'        DCA MAS004
01640   3774'        DCA MAS003
01641   3776'        DCA MAS002
01642   1067         TAD YACEPT
01643   7510         SPA
01644   7041         CIA
01645   3771'        DCA MCS003
01646   4532         JMS I MCC000    /CALCULATE Y↑2
01647   4530         JMS I AHC000
01650   1111         TAD XSQARH
01651   3770'        DCA MAS005
01652   1112         TAD XSQARM
01653   3767'        DCA MAS006
01654   1113         TAD XSQARL
01655   3766'        DCA MAS007
01656   4527         JMS I MAC000    /CALCULATE X↑2 + Y↑2
01657   1777'        TAD MAS008
01660   3765'        DCA MMS005
01661   1775'        TAD MAS009
01662   3764'        DCA MMS006
01663   1773'        TAD MAS010
01664   3763'        DCA MMS007
01665   1362         TAD (1356       /750 - INITIAL UPPER BOUND
01666   4535         JMS I MMC000    /CALCULATE SQRT(X↑2+Y↑2)
01667   1761'        TAD MMS004
01670   3076         DCA RHO         /RHO←SQRT[X↑2+Y↑2]
01671   1067         TAD YACEPT
01672   7510         SPA
01673   7041         CIA
01674   3772'        DCA MAS004
01675   3774'        DCA MAS003
01676   3776'        DCA MAS002
01677   1360         TAD (1750       /1000
01700   3771'        DCA MCS003
01701   4532         JMS I MCC000    /1000*Y
01702   4530         JMS I AHC000
01703   1076         TAD RHO
01704   7440         SZA
01705   5310         JMP .+3
01706   3074         DCA THETA
01707   5611         JMP I XYACPT
01710   3766'        DCA MAS007
01711   3770'        DCA MAS005
01712   3767'        DCA MAS006
01713   4534         JMS I MDC000    /CALCULATE ABS[(1000*Y)/RHO]
01714   1757'        TAD MDS005
01715   3077         DCA SINTHE      /SINTHETA←ABS[(1000*Y)/RHO]
01716   3021         DCA STOR02      /INITIALIZE COUNT.
01717   1100         TAD SINTBL      /PREPARE SINE
01720   3014         DCA AUTO01      /TABLE SEARCH.
```

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01721   1356            TAD (400
01722   3075            DCA SMLLST      /INITIALIZE SMLLST.
01723   7410            SKP
01724   2021   SINLOP,  ISZ STOR02      /SINE TABLE SEARCH LOOP:
01725   1021            TAD STOR02
01726   1355            TAD (-56        /-46
01727   7650            SNA CLA         /HAS COUNT REACHED 46?
01730   5754'           JMP THETAF      /YES: EXIT FROM LOOP
01731   5753'           JMP PAGE03
01753   2000
01754   2020
01755   7722
01756   0400
01757   3362
01760   1750
01761   3310
01762   1356
01763   3313
01764   3312
01765   3311
01766   4665
01767   4664
01770   4663
01771   4756
01772   4662
01773   4670
01774   4661
01775   4667
01776   4660
01777   4666
        2000   PAGE
02000   1414   PAGE03,  TAD I AUTO01    /NO: PROCEED WITH BODY
02001   7041            CIA             /OF LOOP:
02002   1077            TAD SINTHE
02003   7510            SPA
02004   7041            CIA
02005   3073            DCA SINTST      /SINTST=ABS[SINTHE-SIN(N)]
02006   1073            TAD SINTST
02007   7041            CIA
02010   1075            TAD SMLLST
02011   7750            SPA SNA CLA     /IS SMLLST LEQ SINTST?
02012   5777'           JMP SINLOP      /YES: REPEAT LOOP.
02013   1073            TAD SINTST      /NO: MAKE REPLACEMENTS:
02014   3075            DCA SMLLST
02015   1021            TAD STOR02
02016   3020            DCA STOR01
02017   5777'           JMP SINLOP      /REPEAT LOOP.
02020   7300   THETAF,  CLA CLL
02021   1020            TAD STOR01
02022   7004            RAL
02023   3074            DCA THETA
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02024  1066           TAD XACEPT      /THE FOLLOWING GIVES
02025  7710           SPA CLA         /A ROUNDED EVEN
02026  5237           JMP XNEG        /THETA APPROXIMATION:
02027  1067           TAD YACEPT
02030  7700           SMA CLA
02031  5252           JMP THEOUT
02032  1074           TAD THETA
02033  7041           CIA
02034  1376           TAD (550
02035  3074           DCA THETA
02036  5252           JMP THEOUT
02037  1067  XNEG,    TAD YACEPT
02040  7710           SPA CLA
02041  5247           JMP YNEG
02042  1074           TAD THETA
02043  7041           CIA
02044  1375           TAD (264
02045  3074           DCA THETA
02046  5252           JMP THEOUT
02047  1074  YNEG,    TAD THETA
02050  1375           TAD (264
02051  3074           DCA THETA
02052  1774' THEOUT,  TAD XYACPT
02053  3255           DCA .+2
02054  5655           JMP I .+1       /EXIT SUB. XYACPT
02055  0000           0

02056  0000  INTCOM,  0               /INTERROGATE AND COMPENSATE:
02057  7300           CLA CLL
02060  1103           TAD THETBL
02061  7001           IAC
02062  3031           DCA INTCS2
02063  1373           TAD (-36
02064  3030           DCA INTCS1
02065  7410           SKP
02066  2030  INTLP1,  ISZ INTCS1      /INTERROGATE LOOP:
02067  7410           SKP
02070  5327           JMP INTCNT
02071  7240           CLA CMA
02072  6505           6505            /DBCO-0
02073  6503           6503            /DBCI-0
02074  7200           CLA
02075  1030           TAD INTCS1
02076  1372           TAD (37
02077  7002           7002            /BSW
02100  6506           6506            /DBSO-0
02101  1371           TAD (4
02102  6506           6506            /DBSO-0
02103  6504           6504            /DBRI-0
02104  3034           DCA INTCS7
02105  7040           CMA
02106  6505           6505            /DBCO-0
02107  6503           6503            /DBCI-0
02110  7200           CLA
02111  1034           TAD INTCS7
```

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Ø2112  711Ø           CLL RAR
Ø2113  762Ø           SNL CLA         /IS IT AN "OPEN" RESPONSE?
Ø2114  5324           JMP .+1Ø        /NO: PUT Ø IN BIT 11
Ø2115  71ØØ           CLL             /YES: PUT 1 IN BIT 11
Ø2116  1431           TAD I INTCS2    /OF VALVE STATE TABLE.
Ø2117  Ø37Ø           AND (16
Ø212Ø  7ØØ1           IAC
Ø2121  3431           DCA I INTCS2
Ø2122  2Ø31           ISZ INTCS2
Ø2123  5266           JMP INTLP1
Ø2124  1431           TAD I INTCS2
Ø2125  Ø37Ø           AND (16
Ø2126  5321           JMP .-5
Ø2127  73ØØ   INTCNT, CLA CLL
Ø213Ø  11Ø3           TAD THETBL
Ø2131  7ØØ1           IAC
Ø2132  3Ø31           DCA INTCS2
Ø2133  1373           TAD (-36
Ø2134  3Ø3Ø           DCA INTCS1
Ø2135  741Ø           SKP
Ø2136  2Ø3Ø   INTLP2, ISZ INTCS1      /COMPENSATE LOOP:
Ø2137  5344           JMP .+5
Ø214Ø  1114           TAD TERMNL
Ø2141  7Ø41           CIA
Ø2142  3115           DCA TRMCNT      /RESET TERMINAL COUNT
Ø2143  5656           JMP I INTCOM
Ø2144  1431           TAD I INTCS2
Ø2145  Ø367           AND (11
Ø2146  3Ø32           DCA INTCS3
Ø2147  7Ø4Ø           CMA
Ø215Ø  1Ø32           TAD INTCS3
Ø2151  765Ø           SNA CLA         /IS IT 1?
Ø2152  5361           JMP STUCKO      /YES: STUCK OPEN.
Ø2153  1Ø32           TAD INTCS3      /NO: TEST FOR CLOSED.
Ø2154  1366           TAD (-1Ø
Ø2155  765Ø           SNA CLA         /IS IT 1Ø?
Ø2156  5765'          JMP STUCKC      /YES: STUCK CLOSED.
Ø2157  2Ø31           ISZ INTCS2      /NO: RETURN TO LOOP.
Ø216Ø  5336           JMP INTLP2
Ø2161  1Ø3Ø   STUCKO, TAD INTCS1
Ø2162  1372           TAD (37
Ø2163  5764'          JMP PAGEØ5
Ø2164  22ØØ
Ø2165  2251
Ø2166  777Ø
Ø2167  ØØ11
Ø217Ø  ØØ16
Ø2171  ØØØ4
Ø2172  ØØ37
Ø2173  7742
Ø2174  1611
Ø2175  Ø264
Ø2176  Ø55Ø
Ø2177  1724
       22ØØ   PAGE
```

```
Ø22ØØ   3Ø32   PAGEØ5, DCA INTCS3      /VALVE # STUCK OPEN.
Ø22Ø1   1Ø32           TAD INTCS3
Ø22Ø2   7ØØ2           7ØØ2            /BSW
Ø22Ø3   1377           TAD (4Ø54
Ø22Ø4   341Ø           DCA I LISTPT    /PUT "STUCK OPEN" IN LIST.
Ø22Ø5   1Ø5Ø           TAD ABTIME
Ø22Ø6   341Ø           DCA I LISTPT
Ø22Ø7   1Ø51           TAD ABTIME+1
Ø221Ø   341Ø           DCA I LISTPT
Ø2211   1Ø32           TAD INTCS3
Ø2212   1376           TAD (17
Ø2213   3Ø32           DCA INTCS3      /18Ø DEG. VALVE #.
Ø2214   1Ø32           TAD INTCS3
Ø2215   1375           TAD (-36
Ø2216   754Ø           SMA SZA         /TEST FOR > 36.
Ø2217   3Ø32           DCA INTCS3
Ø222Ø   73ØØ           CLA CLL
Ø2221   1Ø32           TAD INTCS3
Ø2222   11Ø3           TAD THETBL
Ø2223   3Ø33           DCA INTCS4
Ø2224   1433           TAD I INTCS4
Ø2225   Ø374           AND (6
Ø2226   1373           TAD (11
Ø2227   3433           DCA I INTCS4    /RECORD "OPEN" COMMAND
Ø223Ø   7Ø4Ø           CMA
Ø2231   65Ø5           65Ø5            /DBCO-Ø
Ø2232   72ØØ           CLA
Ø2233   1Ø32           TAD INTCS3
Ø2234   7ØØ2           7ØØ2            /BSW
Ø2235   65Ø6           65Ø6            /DBSO-Ø
Ø2236   7ØØ1           IAC
Ø2237   65Ø6           65Ø6            /DBSO-Ø
Ø224Ø   65Ø5           65Ø5            /DBCO-Ø
Ø2241   1372           TAD (4ØØØ
Ø2242   341Ø           DCA I LISTPT    /PUT COMMAND IN LIST
Ø2243   1Ø5Ø           TAD ABTIME
Ø2244   341Ø           DCA I LISTPT
Ø2245   1Ø51           TAD ABTIME+1
Ø2246   341Ø           DCA I LISTPT
Ø2247   2Ø31           ISZ INTCS2
Ø225Ø   5771'          JMP INTLP2      /RETURN TO LOOP
Ø2251   1Ø3Ø   STUCKC, TAD INTCS1
Ø2252   137Ø           TAD (37
Ø2253   3Ø32           DCA INTCS3      /VALVE # STUCK CLOSED
Ø2254   1Ø32           TAD INTCS3
Ø2255   7ØØ2           7ØØ2            /BSW
Ø2256   1367           TAD (4Ø24
Ø2257   341Ø           DCA I LISTPT    /PUT "STUCK CLOSED" IN LIST.
Ø226Ø   1Ø5Ø           TAD ABTIME
Ø2261   341Ø           DCA I LISTPT
Ø2262   1Ø51           TAD ABTIME+1
Ø2263   341Ø           DCA I LISTPT
Ø2264   3Ø33           DCA INTCS4      /N (COUNTER)
Ø2265   2Ø33   STCLOP, ISZ INTCS4      /"CLOSED" SEARCH LOOP:
Ø2266   1366           TAD (-1Ø
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Ø2267  1Ø33            TAD INTCS4
Ø227Ø  765Ø            SNA CLA
Ø2271  5247            JMP STUCKC-2
Ø2272  1Ø32            TAD INTCS3
Ø2273  1Ø33            TAD INTCS4
Ø2274  3Ø34            DCA INTCS7         /THETA+N.
Ø2275  1Ø34            TAD INTCS7
Ø2276  1375            TAD (-36
Ø2277  754Ø            SMA SZA            /TEST FOR > 36.
Ø23ØØ  3Ø34            DCA INTCS7
Ø23Ø1  73ØØ            CLA CLL
Ø23Ø2  1Ø34            TAD INTCS7
Ø23Ø3  11Ø3            TAD THETBL
Ø23Ø4  3Ø35            DCA INTCS8
Ø23Ø5  1435            TAD I INTCS8
Ø23Ø6  Ø373            AND (11
Ø23Ø7  764Ø            SZA CLA            /IS THETA + N CLOSED?
Ø231Ø  5335            JMP THNNEG         /NO: TEST THETA - N.
Ø2311  1435   OPNCMD,  TAD I INTCS8       /YES: ISSUE "OPEN" COMMAND
Ø2312  Ø374            AND (6
Ø2313  1373            TAD (11
Ø2314  3435            DCA I INTCS8       /RECORD "OPEN" COMMAND.
Ø2315  7Ø4Ø            CMA
Ø2316  65Ø5            65Ø5               /DBCO-Ø
Ø2317  72ØØ            CLA
Ø232Ø  1Ø34            TAD INTCS7
Ø2321  7ØØ2            7ØØ2               /BSW
Ø2322  65Ø6            65Ø6               /DBSO-Ø
Ø2323  7ØØ1            IAC
Ø2324  65Ø6            65Ø6               /DBSO-Ø
Ø2325  65Ø5            65Ø5               /DBCO-Ø
Ø2326  1372            TAD (4ØØØ
Ø2327  341Ø            DCA I LISTPT       /PUT COMMAND IN LIST
Ø233Ø  1Ø5Ø            TAD ABTIME
Ø2331  341Ø            DCA I LISTPT
Ø2332  1Ø51            TAD ABTIME+1
Ø2333  341Ø            DCA I LISTPT
Ø2334  5247            JMP STUCKC-2
Ø2335  1Ø33   THNNEG,  TAD INTCS4
Ø2336  7Ø41            CIA
Ø2337  1365            TAD (36
Ø234Ø  1Ø32            TAD INTCS3
Ø2341  3Ø34            DCA INTCS7         /THETA-N.
Ø2342  1Ø34            TAD INTCS7
Ø2343  1375            TAD (-36
Ø2344  754Ø            SMA SZA            /TEST FOR > 36.
Ø2345  3Ø34            DCA INTCS7
Ø2346  73ØØ            CLA CLL
Ø2347  1Ø34            TAD INTCS7
Ø235Ø  11Ø3            TAD THETBL
Ø2351  3Ø35            DCA INTCS8
Ø2352  1435            TAD I INTCS8
Ø2353  Ø373            AND (11
Ø2354  764Ø            SZA CLA            /IS THETA-N CLOSED?
Ø2355  5265            JMP STCLOP         /NO: RETURN TO LOOP.
```

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02356  5311        JMP OPNCMD      /YES: ISSUE "OPEN" COMMAND.
```

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Ø2365   ØØ36
Ø2366   777Ø
Ø2367   4Ø24
Ø237Ø   ØØ37
Ø2371   2136
Ø2372   4ØØØ
Ø2373   ØØ11
Ø2374   ØØØ6
Ø2375   7742
Ø2376   ØØ17
Ø2377   4Ø54
        24ØØ  PAGE
Ø24ØØ   ØØØØ  RTISQO,  Ø                    /LOOKUP SEQUENCE FOR RHO, THETA:
Ø24Ø1   73ØØ           CLA CLL
Ø24Ø2   1377           TAD (12              /1Ø
Ø24Ø3   3776'          DCA MCSØØ3
Ø24Ø4   1Ø76           TAD RHO
Ø24Ø5   3775'          DCA MASØØ4
Ø24Ø6   3774'          DCA MASØØ2
Ø24Ø7   3773'          DCA MASØØ3
Ø241Ø   4532           JMS I MCCØØØ         /CALCULATE 1Ø*RHO
Ø2411   453Ø           JMS I AHCØØØ
Ø2412   1372           TAD (371             /249
Ø2413   3771'          DCA MASØØ7
Ø2414   377Ø'          DCA MASØØ6
Ø2415   3767'          DCA MASØØ5
Ø2416   4534           JMS I MDCØØØ
Ø2417   1766'          TAD MDSØØ5
Ø242Ø   3Ø72           DCA RHOIND           /RHOIND←(1Ø*RHO/249)
Ø2421   3Ø71           DCA ROTATN           /INITIALIZE ROTATN
Ø2422   1Ø74           TAD THETA
Ø2423   311Ø           DCA THETAS           /AND THETAS
Ø2424   111Ø  SLECTH,  TAD THETAS
Ø2425   7Ø41           CIA
Ø2426   1365           TAD (-6
Ø2427   77ØØ           SMA CLA              /IS THETAS > -6?
Ø243Ø   5235           JMP .+5              /NO: PROCEED WITH LOOP BODY.
Ø2431   111Ø           TAD THETAS           /YES: CONTINUE TEST.
Ø2432   1365           TAD (-6
Ø2433   775Ø           SPA SNA CLA          /IS THETAS LEQ 6?
Ø2434   5242           JMP .+6              /YES: EXIT LOOP.
Ø2435   2Ø71           ISZ ROTATN           /NO: PROCEED WITH LOOP BODY
Ø2436   111Ø           TAD THETAS
Ø2437   1364           TAD (-14             /-12
Ø244Ø   311Ø           DCA THETAS
Ø2441   5224           JMP SLECTH
Ø2442   111Ø           TAD THETAS
Ø2443   771Ø           SPA CLA
Ø2444   7ØØ1           IAC
Ø2445   31Ø6           DCA PARITY           /SET PARITY
Ø2446   111Ø           TAD THETAS
Ø2447   751Ø           SPA
Ø245Ø   7Ø41           CIA
Ø2451   31Ø7           DCA THETAL           /THETAL←ABS(THETAS)
Ø2452   71ØØ           CLL
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02453  1107              TAD THETAL
02454  7010              RAR
02455  3105              DCA THEIND         /THEIND←(THETAL/2)
02456  1363              TAD (36
02457  3775'             DCA MAS004
02460  3773'             DCA MAS003
02461  3774'             DCA MAS002
02462  1105              TAD THEIND
02463  3776'             DCA MCS003
02464  4532              JMS I MCC000       /30*THEIND
02465  1762'             TAD MAS010
02466  1072              TAD RHOIND
02467  1104              TAD SEQTBL
02470  3020              DCA STOR01
02471  1420              TAD I STOR01       /LOOKUP SEQUENCE
02472  3070              DCA SEQNCE
02473  5600              JMP I RTISQO

02474  0000    CMDOUT,   0                  /EXECUTE SEQUENCE COMMANDS:
02475  7301              CLA CLL IAC
02476  1103              TAD THETBL
02477  3020              DCA STOR01
02500  1361              TAD (-36
02501  3021              DCA STOR02         /INITIALIZE COUNTER
02502  7410              SKP
02503  2021    CMLOP1,   ISZ STOR02
02504  7410              SKP
02505  5313              JMP .+6
02506  1420              TAD I STOR01
02507  0360              AND (7             /SET BIT 8 OF
02510  3420              DCA I STOR01       /VALVE STATES TO 0.
02511  2020              ISZ STOR01
02512  5303              JMP CMLOP1
02513  1357              TAD (32
02514  1071              TAD ROTATN
02515  3101              DCA VLVENM         /ESTABLISH VALVE # FOR BIT 0 OF SEQ
02516  1361              TAD (-36
02517  1101              TAD VLVENM
02520  7550              SPA SNA
02521  7410              SKP
02522  3101              DCA VLVENM         /CORRECT VALVE # FOR > 36.
02523  7300              CLA CLL
02524  1364              TAD (-14
02525  3021              DCA STOR02         /SET SEQUENCE BIT COUNT
02526  7410              SKP
02527  2021    CMLOP3,   ISZ STOR02
02530  7410              SKP
02531  5756'             JMP CMDOT1
02532  1361              TAD (-36
02533  1101              TAD VLVENM
02534  7550              SPA SNA
02535  7410              SKP
02536  3101              DCA VLVENM         /CORRECT VALVE # FOR > 36.
02537  7300              CLA CLL
02540  1070              TAD SEQNCE
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02541   7004            RAL                  /PUT COMMAND IN LINK.
02542   3070            DCA SEQNCE
02543   5755'           JMP PAGE04
02555   2600
02556   2612
02557   0032
02560   0007
02561   7742
02562   4670
02563   0036
02564   7764
02565   7772
02566   3362
02567   4663
02570   4664
02571   4665
02572   0371
02573   4661
02574   4660
02575   4662
02576   4756
02577   0012
        2600    PAGE
02600   1101    PAGE04, TAD VLVENM
02601   1103            TAD THETBL
02602   3020            DCA STOR01
02603   1377            TAD (10
02604   1420            TAD I STOR01
02605   7420            SNL
02606   0376            AND (7
02607   3420            DCA I STOR01         /PUT COMMAND IN BIT 8 OF VALVE STAE
02610   2101            ISZ VLVENM           /GO TO NEXT VALVE
02611   5775'           JMP CMLOP3           /RETURN TO LOOP.
02612   7301    CMDOT1, CLA CLL IAC
02613   1103            TAD THETBL
02614   3020            DCA STOR01           /ESTABLISH VALVE STATE POINTER.
02615   7001            IAC
02616   3022            DCA STOR03           /M
02617   1374            TAD (-36
02620   3023            DCA STOR04           /SET VALVE STATE COUNT.
02621   7410            SKP
02622   2023    CMLOP4, ISZ STOR04
02623   7410            SKP
02624   5316            JMP CMDOT3
02625   1420            TAD I STOR01
02626   0373            AND (11
02627   3021            DCA STOR02
02630   3102            DCA COMMND
02631   1021            TAD STOR02
02632   1372            TAD (-1
02633   7100            CLL
02634   7640            SZA CLA
02635   5243            JMP .+6
02636   1420            TAD I STOR01
02637   0371            AND (16
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02640  3420           DCA I STORØ1
02641  7005           IAC RAL
02642  5254           JMP .+12
02643  1021           TAD STORØ2
02644  1370           TAD (-1Ø
02645  7100           CLL
02646  7640           SZA CLA
02647  5312           JMP CMDOT2       /SKIP COMMAND EXECUTION.
02650  7001           IAC
02651  1420           TAD I STORØ1
02652  3420           DCA I STORØ1
02653  7001           IAC
02654  3027           DCA STORØ8
02655  1022           TAD STORØ3
02656  7002           7ØØ2             /BSW
02657  3102           DCA COMMND       /ESTABLISH VALVE COMMAND
02660  1053           TAD TRCONT
02661  7640           SZA CLA
02662  5260           JMP .-2
02663  1057           TAD LISTST
02664  7041           CIA
02665  1010           TAD LISTPT
02666  1060           TAD LISTLN
02667  7710           SPA CLA          /IS LIST FULL?
02670  7410           SKP              /NO: PUT COMMAND IN LIST.
02671  5302           JMP .+11         /YES: DON'T PUT COMMAND IN LIST.
02672  7130           STL RAR
02673  1102           TAD COMMND
02674  1027           TAD STORØ8
02675  3410           DCA I LISTPT
02676  1050           TAD ABTIME
02677  3410           DCA I LISTPT
02700  1051           TAD ABTIME+1
02701  3410           DCA I LISTPT
02702  7040           CMA
02703  6505           65Ø5             /DBCO-Ø
02704  7200           CLA
02705  1102           TAD COMMND
02706  6506           65Ø6             /DBSO-Ø EXECUTE COMMAND.
02707  1027           TAD STORØ8
02710  6506           65Ø6             /DBSO-Ø
02711  6505           65Ø5             /DBCO-Ø
02712  7300   CMDOT2, CLA CLL
02713  2020           ISZ STORØ1       /INCREMENT VALVE STATE POINTER.
02714  2022           ISZ STORØ3       /INCREMENT VALVE #.
02715  5222           JMP CMLOP4       /RETURN TO LOOP.
02716  7300   CMDOT3, CLA CLL
02717  1767'          TAD CMDOUT
02720  3322           DCA .+2
02721  5722           JMP I .+1        /EXIT SUBROUTINE "CMDOUT".
02722  0000           Ø

02723  3064   SKPCHN, DCA AC           /SAVE ACCUMULATOR
02724  7004           RAL
02725  3065           DCA L            /SAVE LINK
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02726  6046            TLS             /RESET PRINTER FLAG.
02727  6031            KSF             /TTY INT.?
02730  7410            SKP             /NO: CHECK KA8-E
02731  5766'           JMP TTYSRV      /YES: SERVICE TTY.
02732  6141            6141            /KA8-E INT.(TIME)?
02733  7410            SKP             /NO: CHECK DR8-0 INT.(VALVES).
02734  5765'           JMP TMESRV      /YES: SERVICE KA8-E(TIME).
02735  6502            6502            /DR8-0 INT.(VALVES)?
02736  5764'           JMP START       /NO: RETURN TO COMMAND MODE.
02737  5763'           JMP DR8SRV      /YES: SERVICE DR8-0(VALVES).

02763  3121
02764  0202
02765  3000
02766  3105
02767  2474
02770  7770
02771  0016
02772  7777
02773  0011
02774  7742
02775  2527
02776  0007
02777  0010
       3000   PAGE
03000  6142   TMESRV,  6142            /CLEAR TIME FLAG
03001  7300            CLA CLL
03002  1051            TAD ABTIME+1    /INCREMENT TIME:
03003  7001            IAC
03004  3051            DCA ABTIME+1
03005  7004            RAL
03006  1050            TAD ABTIME
03007  3050            DCA ABTIME      /END TIME INCREMENT.
03010  1053            TAD TRCONT
03011  7650            SNA CLA
03012  5273            JMP EXIT
03013  2053            ISZ TRCONT
03014  7000            NOP
03015  5273            JMP EXIT

03016  0000   SEQRED,  0
03017  1411            TAD I XSTKPT
03020  3041            DCA XEND
03021  1412            TAD I YSTKPT
03022  3042            DCA YEND
03023  5616            JMP I SEQRED

03024  0000   RMTRED,  0               /SAMPLE X,Y FROM DR8-1:
03025  7240            CLA CMA
03026  6515            6515            /DBC0-1
03027  7307            CLA CLL IAC RTL
03030  6516            6516            /DBS0-1
03031  6515            6515            /DBC0-1
03032  6002            IOF
03033  4241            JMS CYCLE
```

```
03034  3041           DCA XEND
03035  4241           JMS CYCLE
03036  3042           DCA YEND
03037  6001           ION
03040  5624           JMP I RMTRED

03041  0000  CYCLE,   0
03042  7305           CLA CLL IAC RAL
03043  6516           6516              /DBSO-1
03044  6515           6515              /DBCO-1
03045  7240           CLA CMA
03046  6513           6513              /DBCI-1
03047  6512           6512              /DBSK-1
03050  5247           JMP .-1
03051  6514           6514              /DBRI-1
03052  7500           SMA
03053  0377           AND (4777
03054  5641           JMP I CYCLE

03055  0000  STPSLT,  0                 /SELECT "STEPDT":
03056  7300           CLA CLL
03057  4516           JMS I TCC000      /CARRIAGE RETURN-LINE FEED.
03060  1376           TAD (CMT007
03061  3021           DCA STOR02
03062  1375           TAD (STEPDT-1
03063  3015           DCA AUTO02
03064  4521           JMS I TEC000      /PRINT "STEP: ".
03065  4533           JMS I MJC000      /ACCEPT STEPDT FROM TTY.
03066  5655           JMP I STPSLT
03067  2324  CMT007,  TEXT /STEP: /
03070  0520
03071  7240
03072  0000
```

```
03073  6007  EXIT,    6007              /CAF
03074  6501           6501              /DBEI-0
03075  1000           TAD INTRPT
03076  3304           DCA .+6
03077  1065           TAD L
03100  7110           CLL RAR
03101  1064           TAD AC
03102  6001           ION
03103  5704           JMP I .+1
03104  0000           0

03105  7300  TTYSRV,  CLA CLL
03106  6036           KRB
03107  1374           TAD (-225
03110  7640           SZA CLA
03111  5273           JMP EXIT
03112  7300           CLA CLL
03113  1373           TAD ("↑
03114  4517           JMS I TDC000
03115  1372           TAD ("U
03116  4517           JMS I TDC000
03117  4771'          JMS DR8SUB
03120  5770'          JMP START

03121  7300  DR8SRV,  CLA CLL
03122  6504           6504              /DBRI-0
03123  6503           6503              /DBCI-0
03124  7012           RTR
03125  7100           CLL
03126  7010           RAR
03127  7430           SZL               /IS IT A RETURN TO COMMAND MODE?
03130  5312           JMP TTYSRV+5      /YES.
03131  7010           RAR               /NO.
03132  7430           SZL               /IS IT A START RESET?
03133  5336           JMP .+3           /YES.
03134  7300           CLA CLL           /NO.
03135  5273           JMP EXIT          /RETURN TO BACKGROUND PROGRAM.
03136  4771'          JMS DR8SUB
03137  5767'          JMP PGEXCT
03167  1072
03170  0202
03171  3200
03172  0325
03173  0336
03174  7553
03175  0043
03176  3067
03177  4777
       3200  PAGE
03200  0000  DR8SUB,  0                 /SHUT ALL VALVES:
03201  7300           CLA CLL
03202  1377           TAD (-36
03203  3020           DCA STOR01
03204  7410           SKP
03205  2020  DR8LOP,  ISZ STOR01
```

```
03206  7410           SKP
03207  5600           JMP I DR8SUB
03210  7040           CMA
03211  6505           6505              /DBCO-0
03212  7200           CLA
03213  1020           TAD STOR01
03214  7041           CIA
03215  7002           7002              /BSW
03216  6506           6506              /DBSO-0
03217  1376           TAD (2
03220  6506           6506              /DBSO-0
03221  6505           6505              /DBCO-0
03222  7300           CLA CLL
03223  3021           DCA STOR02
03224  2021           ISZ STOR02        /18.432 MSEC. DELAY LOOP.
03225  5224           JMP .-1
03226  5205           JMP DR8LOP

              /"MMS000" - TRIPLE PRECISION SQUARE ROOT WITH
              /FORMAT:  SQRT(DH,DM,DL)=CT.

03227  0000   MMS000, 0
03230  3306           DCA MMS002        /UPPER BOUND
03231  3307           DCA MMS003        /LOWER BOUND
03232  7300   MMS001, CLA CLL
03233  1306           TAD MMS002
03234  1307           TAD MMS003
03235  7010           RAR
03236  3310           DCA MMS004        /CENTER MARK
03237  1307           TAD MMS003
03240  7041           CIA
03241  1310           TAD MMS004
03242  7650           SNA CLA
03243  5627           JMP I MMS000      /EXIT (CT=SQRT(A))
03244  7300           CLA CLL
03245  1310           TAD MMS004
03246  3775'          DCA MCS003
03247  1310           TAD MMS004
03250  3774'          DCA MAS004
03251  3773'          DCA MAS003
03252  3772'          DCA MAS002
03253  4532           JMS I MCC000      /SQCT←CT*CT
03254  4530           JMS I AHC000
03255  1311           TAD MMS005
03256  3771'          DCA MAS005
03257  1312           TAD MMS006
03260  3770'          DCA MAS006
03261  1313           TAD MMS007
03262  3767'          DCA MAS007
03263  4526           JMS I MBC000      /SQCT-NUMBER
03264  1766'          TAD MAS008
03265  7640           SZA CLA
03266  5275           JMP .+7
03267  1765'          TAD MAS009
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03270  7640            SZA CLA
03271  5275            JMP .+4
03272  1764'           TAD MAS010
03273  7650            SNA CLA
03274  5627            JMP I MMS000     /EXIT (CT=SQRT(A))
03275  1766'           TAD MAS008
03276  7710            SPA CLA
03277  5303            JMP .+4
03300  1310            TAD MMS004
03301  3306            DCA MMS002       /UB←CT
03302  5232            JMP MMS001       /RETURN TO LOOP
03303  1310            TAD MMS004
03304  3307            DCA MMS003       /LB←CT
03305  5232            JMP MMS001       /RETURN TO LOOP
03306  0000  MMS002,   0                /UPPER BOUND (UB)
03307  0000  MMS003,   0                /LOWER BOUND (LB)
03310  0000  MMS004,   0                /CENTER MARK (CT)
03311  0000  MMS005,   0                /NUMBER H (DH)
03312  0000  MMS006,   0                /NUMBER M (DM)
03313  0000  MMS007,   0                /NUMBER L (DL)
```

```
                /"MDSØØØ" - DOUBLE PRECISION DIVISION WITH FORMAT
                /(AM,AL)/BL=TL PLUS REMAINDER FOUND IN "SAMPLE".

Ø3314   ØØØØ   MDSØØØ, Ø
Ø3315   73ØØ           CLA CLL
Ø3316   3362           DCA MDSØØ5
Ø3317   1773'          TAD MASØØ3
Ø332Ø   336Ø           DCA MDSØØ2      /INITIALIZE SAMPLE:
Ø3321   1774'          TAD MASØØ4
Ø3322   7ØØ4           RAL
Ø3323   3774'          DCA MASØØ4
Ø3324   136Ø           TAD MDSØØ2
Ø3325   7ØØ4           RAL
Ø3326   336Ø           DCA MDSØØ2
Ø3327   1363           TAD (-13
Ø333Ø   3361           DCA MDSØØ3
Ø3331   741Ø           SKP
Ø3332   2361   MDSØØ1, ISZ MDSØØ3      /ALL BITS SAMPLED?
Ø3333   741Ø           SKP             /NO: CONTINUE DIVISION.
Ø3334   5714           JMP I MDSØØØ    /YES: EXIT FROM SUBROUTINE.
Ø3335   1774'          TAD MASØØ4      /ATTACH NEXT BIT TO RHS OF SAMPLE:
Ø3336   7ØØ4           RAL
Ø3337   3774'          DCA MASØØ4
Ø334Ø   136Ø           TAD MDSØØ2
Ø3341   7ØØ4           RAL
Ø3342   336Ø           DCA MDSØØ2
Ø3343   1767'          TAD MASØØ7
Ø3344   7Ø41           CIA
Ø3345   136Ø           TAD MDSØØ2
Ø3346   751Ø           SPA             /IS SAMPLE>DIVISOR?
Ø3347   5353           JMP .+4         /NO: PUT Ø ON RHS OF DIVIDEND.
Ø335Ø   336Ø           DCA MDSØØ2      /YES: ESTABLISH NEW SAMPLE
Ø3351   712Ø           STL             /AND PUT 1 ON RHS OF DIVIDEND.
Ø3352   741Ø           SKP
Ø3353   73ØØ           CLA CLL
Ø3354   1362           TAD MDSØØ5
Ø3355   7ØØ4           RAL
Ø3356   3362           DCA MDSØØ5
Ø3357   5332           JMP MDSØØ1
Ø336Ø   ØØØØ   MDSØØ2, Ø               /SAMPLE
Ø3361   ØØØØ   MDSØØ3, Ø               /COUNT
Ø3362   ØØØØ   MDSØØ5, Ø               /TL
```

```
Ø3363  7765
Ø3364  467Ø
Ø3365  4667
Ø3366  4666
Ø3367  4665
Ø337Ø  4664
Ø3371  4663
Ø3372  466Ø
Ø3373  4661
Ø3374  4662
Ø3375  4756
Ø3376  ØØØ2
Ø3377  7742
       34ØØ   PAGE
              /"TCSØØØ" - SUPPLIES A CARRIAGE RETURN -
              /LINE FEED TO THE TELETYPE.

              /(15 LOCATIONS)

Ø34ØØ  ØØØØ   TCSØØØ, Ø
Ø34Ø1  72ØØ           CLA
Ø34Ø2  6214           RDF
Ø34Ø3  62Ø1           CDF Ø
Ø34Ø4  1Ø36           TAD RETURN
Ø34Ø5  3212           DCA TCSØØ1
Ø34Ø6  1377           TAD (215
Ø34Ø7  4214           JMS TDSØØØ
Ø341Ø  1376           TAD (212
Ø3411  4214           JMS TDSØØØ
Ø3412  ØØØØ   TCSØØ1, Ø
Ø3413  56ØØ           JMP I TCSØØØ

              /"TDSØØØ" - TYPES THE CHARACTER STORED IN
              /THE ACCUMULATOR ON THE TELEPRINTER.

              /(14 LOCATIONS)

Ø3414  ØØØØ   TDSØØØ, Ø
Ø3415  6Ø41           TSF
Ø3416  5215           JMP .-1
Ø3417  6Ø46           TLS
Ø342Ø  73ØØ           CLA CLL
Ø3421  5614           JMP I TDSØØØ

              /"TBSØØØ" - ACCEPTS CHARACTER FROM TELETYPE,
              /ECHOS IT ON THE TELEPRINTER, AND STORES IT
              /IN "STORØ1" IN FIELD Ø.

              /(13 LOCATIONS)

Ø3422  ØØØØ   TBSØØØ, Ø
Ø3423  72ØØ           CLA
Ø3424  6Ø31           KSF
Ø3425  5224           JMP .-1
Ø3426  6Ø36           KRB
```

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03427  6041              TSF
03430  5227              JMP .-1
03431  6046              TLS
03432  3020              DCA STOR01
03433  1020              TAD STOR01
03434  1375              TAD (-203
03435  7440              SZA
03436  5245              JMP .+7
03437  1374              TAD ("↑
03440  4517              JMS I TDC000
03441  1373              TAD ("C
03442  4517              JMS I TDC000
03443  5644              JMP I .+1         /RETURN TO OS/8 KEYBOARD MONITOR.
03444  7600              7600
03445  1372              TAD (-22
03446  7640              SZA CLA
03447  5622              JMP I TBS000
03450  1374              TAD ("↑
03451  4517              JMS I TDC000
03452  1371              TAD ("U
03453  4517              JMS I TDC000
03454  5770'             JMP START         /RETURN TO COMMAND MODE.

              /"TES000" - UNPACKS AND TYPES ON THE
              /TELEPRINTER THE CHARACTER STRING IN THE
              /FIELD OF THE CALLING PROGRAM BEGINNING
              /AT THE ADDRESS IN "STOR02". IT
              /TERMINATES WITH RECEPTION OF AN UNPACKED
              /ZERO. ALSO USES "STOR01" AND SHOULD
              /BE LOADED INTO FIELD 0.

              /(37 LOCATIONS)

03455  0000   TES000, 0
03456  7340              CLA CLL CMA
03457  3020              DCA STOR01
03460  1421              TAD I STOR02
03461  2020              ISZ STOR01
03462  7410              SKP
03463  7002              7002           /BSW.
03464  0367              AND (77
03465  7450              SNA
03466  7410              SKP
03467  5271              JMP .+2
03470  5655              JMP I TES000
03471  1366              TAD (-40
03472  7510              SPA
03473  1365              TAD (100
03474  1364              TAD (240
03475  4214              JMS TDS000
03476  1020              TAD STOR01
03477  7450              SNA
03500  5260              JMP TES000+3
03501  2021              ISZ STOR02
03502  5256              JMP TES000+1
```

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                  /"TGSØØØ" - SUPPLIES A SPECIFIED NUMBER OF
                  /LINE FEED TO THE TELEPRINTER. IT USES
                  /"STORØ2" AND SUBROUTINE "TDSØØØ". SPECIFY
                  /THE NEGATIVE OF THE DESIRED NUMBER OF
                  /LINE FEED IN "STORØ2" BEFORE ENTERING THE
                  /SUBROUTINE.

                  /(13 LOCATIONS)

Ø35Ø3   ØØØØ    TGSØØØ, Ø
Ø35Ø4   3Ø21            DCA STORØ2
Ø35Ø5   6214            RDF
Ø35Ø6   62Ø1            CDF Ø
Ø35Ø7   1Ø36            TAD RETURN
Ø351Ø   3315            DCA TGSØØ1
Ø3511   1376            TAD (212
Ø3512   4214            JMS TDSØØØ
Ø3513   2Ø21            ISZ STORØ2
Ø3514   5311            JMP .-3
Ø3515   ØØØØ    TGSØØ1, Ø
Ø3516   57Ø3            JMP I TGSØØØ


Ø3517   ØØØØ    TPSØØØ, Ø
Ø352Ø   3Ø21            DCA STORØ2
Ø3521   6214            RDF
Ø3522   62Ø1            CDF Ø
Ø3523   1Ø36            TAD RETURN
Ø3524   3331            DCA TPSØØ1
Ø3525   1364            TAD (24Ø
Ø3526   4517            JMS I TDCØØØ
Ø3527   2Ø21            ISZ STORØ2
Ø353Ø   5325            JMP .-3
Ø3531   ØØØØ    TPSØØ1, Ø
Ø3532   5717            JMP I TPSØØØ


Ø3533   ØØØØ    TQSØØØ, Ø
Ø3534   3355            DCA TQSØØ2
Ø3535   6214            RDF
Ø3536   62Ø1            CDF Ø
Ø3537   1Ø36            TAD RETURN
Ø354Ø   3353            DCA TQSØØ1
Ø3541   1355            TAD TQSØØ2
Ø3542   7Ø12            RTR
Ø3543   7Ø1Ø            RAR
Ø3544   Ø363            AND (7
Ø3545   1362            TAD (26Ø
Ø3546   4517            JMS I TDCØØØ
Ø3547   1355            TAD TQSØØ2
Ø355Ø   Ø363            AND (7
Ø3551   1362            TAD (26Ø
Ø3552   4517            JMS I TDCØØØ
Ø3553   ØØØØ    TQSØØ1, Ø
```

```
Ø3554  5733            JMP I TQSØØØ
Ø3555  ØØØØ  TQSØØ2,  Ø
```

```
03562  0260
03563  0007
03564  0240
03565  0100
03566  7740
03567  0077
03570  0202
03571  0325
03572  7756
03573  0303
03574  0336
03575  7575
03576  0212
03577  0215
       3600  PAGE
             /"MLS000" - TRIPLE BINARY TO DECIMAL CONVERT -
             /CONVERTS A TRIPLE PRECISION BINARY NUMBER
             /STORED IN (AH,AM,AL) TO DECIMAL FORM AND
             /PRINTS IT ON THE TELEPRINTER WITH A DECIMAL
             /POINT PRIOR TO THE LAST TWO DIGITS (I.E.
             /DOLLARS AND CENTS).  SPECIFY (AH,AM,AL) BEFORE
             /ENTERING THE SUBROUTINE.  USES SUBROUTINES
             /"MBS000", "AHS000", AND "TDS000".  SET
             /MLS030 TO 0 TO SUPRESS LEADING ZEROS.  SET
             /MLS030 TO 1 TO ESTABLISH NUMBER LENGTH BY
             /REPLACING LEADING ZEROS WITH SPACES; IN THIS
             /CASE SET MLS031 TO D-11, WHERE "D" IS THE
             /DESIRED NUMBER OF DIGIT SPACES.

             /(332 LOCATIONS)

03600  0000  MLS000, 0
03601  7200          CLA
03602  6214          RDF
03603  6201          CDF 0
03604  1036          TAD RETURN
03605  3777'         DCA MLS014
03606  7300          CLA CLL
03607  1376          TAD (-13
03610  3775'         DCA MLS032
03611  1774'         TAD MLS018
03612  3014          DCA AUTO01
03613  3414          DCA I AUTO01  /SET ALL 11 CH'S TO ZERO.
03614  2775'         ISZ MLS032
03615  5213          JMP .-2
03616  7300          CLA CLL
03617  1773'         TAD MAS002
03620  7004          RAL
03621  7420          SNL           /"M" NEGATIVE?
03622  5245          JMP MLS001-1
03623  7300          CLA CLL
03624  1772'         TAD MAS004
03625  7041          CIA
03626  3772'         DCA MAS004
03627  7004          RAL
```

```
Ø363Ø  3Ø2Ø            DCA STORØ1
Ø3631  1771'           TAD MASØØ3
Ø3632  7Ø4Ø            CMA
Ø3633  1Ø2Ø            TAD STORØ1
Ø3634  3771'           DCA MASØØ3
Ø3635  7ØØ4            RAL
Ø3636  3Ø2Ø            DCA STORØ1
Ø3637  1773'           TAD MASØØ2
Ø364Ø  7Ø4Ø            CMA
Ø3641  1Ø2Ø            TAD STORØ1
Ø3642  3773'           DCA MASØØ2
Ø3643  137Ø            TAD ("-
Ø3644  4767'           JMS TDSØØØ
Ø3645  73ØØ            CLA CLL
Ø3646  1366  MLSØØ1,   TAD (1124
Ø3647  3765'           DCA MASØØ5
Ø365Ø  1364            TAD (276
Ø3651  3763'           DCA MASØØ6
Ø3652  1362            TAD (2ØØØ
Ø3653  3761'           DCA MASØØ7
Ø3654  476Ø'           JMS MBSØØØ
Ø3655  1757'           TAD MASØØ8
Ø3656  7ØØ4            RAL
Ø3657  743Ø            SZL
Ø366Ø  5264            JMP MLSØØ2
Ø3661  4756'           JMS AHSØØØ
Ø3662  2755'           ISZ MLSØ19
Ø3663  5246            JMP MLSØØ1
Ø3664  73ØØ  MLSØØ2,   CLA CLL
Ø3665  1354            TAD (73
Ø3666  3765'           DCA MASØØ5
Ø3667  1353            TAD (4654
Ø367Ø  3763'           DCA MASØØ6
Ø3671  1352            TAD (5ØØØ
Ø3672  3761'           DCA MASØØ7
Ø3673  476Ø'           JMS MBSØØØ
Ø3674  1757'           TAD MASØØ8
Ø3675  7ØØ4            RAL
Ø3676  743Ø            SZL
Ø3677  53Ø3            JMP MLSØØ3
Ø37ØØ  4756'           JMS AHSØØØ
Ø37Ø1  2751'           ISZ MLSØ2Ø
Ø37Ø2  5264            JMP MLSØØ2
Ø37Ø3  73ØØ  MLSØØ3,   CLA CLL
Ø37Ø4  135Ø            TAD (5
Ø37Ø5  3765'           DCA MASØØ5
Ø37Ø6  1347            TAD (7536
Ø37Ø7  3763'           DCA MASØØ6
Ø371Ø  1346            TAD (4ØØ
Ø3711  3761'           DCA MASØØ7
Ø3712  476Ø'           JMS MBSØØØ
Ø3713  1757'           TAD MASØØ8
Ø3714  7ØØ4            RAL
Ø3715  743Ø            SZL
Ø3716  5745'           JMP MLSØØ4
```

```
03717  4756'          JMS AHS000
03720  2744'          ISZ MLS021
03721  5303           JMP MLS003
03744  4270
03745  4000
03746  0400
03747  7536
03750  0005
03751  4267
03752  5000
03753  4654
03754  0073
03755  4266
03756  1600
03757  4666
03760  4600
03761  4665
03762  2000
03763  4664
03764  0276
03765  4663
03766  1124
03767  3414
03770  0255
03771  4661
03772  4662
03773  4660
03774  4265
03775  4303
03776  7765
03777  4227
       4000   PAGE
04000  7300   MLS004, CLA CLL
04001  3777'          DCA MAS005
04002  1376"          TAD (4611
04003  3775'          DCA MAS006
04004  1374"          TAD (3200
04005  3773'          DCA MAS007
04006  4772'          JMS MBS000
04007  1771'          TAD MAS008
04010  7004"          RAL
04011  7430           SZL
04012  5216           JMP MLS005
04013  4770'          JMS AHS000
04014  2767'          ISZ MLS022
04015  5200"          JMP MLS004
04016  7300   MLS005, CLA CLL
04017  3777'          DCA MAS005
04020  1366"          TAD (364
04021  3775'          DCA MAS006
04022  1365"          TAD (1100
04023  3773'          DCA MAS007
04024  4772'          JMS MBS000
04025  1771'          TAD MAS008
04026  7004"          RAL
```

```
04027  7430        SZL
04030  5234        JMP MLS006
04031  4770'       JMS AHS000
04032  2764'       ISZ MLS023
04033  5216        JMP MLS005
```

```
04034  7300  MLS006,  CLA CLL
04035  3777'          DCA MAS005
04036  1363           TAD (30
04037  3775'          DCA MAS006
04040  1362           TAD (3240
04041  3773'          DCA MAS007
04042  4772'          JMS MBS000
04043  1771'          TAD MAS008
04044  7004           RAL
04045  7430           SZL
04046  5252           JMP MLS007
04047  4770'          JMS AHS000
04050  2761'          ISZ MLS024
04051  5234           JMP MLS006
04052  7300  MLS007,  CLA CLL
04053  3777'          DCA MAS005
04054  7005           IAC RAL       /SAME AS "TAD (2"
04055  3775'          DCA MAS006
04056  1360           TAD (3420
04057  3773'          DCA MAS007
04060  4772'          JMS MBS000
04061  1771'          TAD MAS008
04062  7004           RAL
04063  7430           SZL
04064  5270           JMP MLS008
04065  4770'          JMS AHS000
04066  2757'          ISZ MLS025
04067  5252           JMP MLS007
04070  7300  MLS008,  CLA CLL
04071  3777'          DCA MAS005
04072  3775'          DCA MAS006
04073  1356           TAD (1750
04074  3773'          DCA MAS007
04075  4772'          JMS MBS000
04076  1771'          TAD MAS008
04077  7004           RAL
04100  7430           SZL
04101  5305           JMP MLS009
04102  4770'          JMS AHS000
04103  2755'          ISZ MLS026
04104  5270           JMP MLS008
04105  7300  MLS009,  CLA CLL
04106  3777'          DCA MAS005
04107  3775'          DCA MAS006
04110  1354           TAD (144
04111  3773'          DCA MAS007
04112  4772'          JMS MBS000
04113  1771'          TAD MAS008
04114  7004           RAL
04115  7430           SZL
04116  5322           JMP MLS010
04117  4770'          JMS AHS000
04120  2753'          ISZ MLS027
04121  5305           JMP MLS009
04122  7300  MLS010,  CLA CLL
```

```
04123  3777'         DCA MAS005
04124  3775'         DCA MAS006
04125  1352          TAD (12
04126  3773'         DCA MAS007
04127  4772'         JMS MBS000
04130  1771'         TAD MAS008
04131  7004          RAL
04132  7430          SZL
04133  5751'         JMP MLS011
04134  4770'         JMS AHS000
04135  2750'         ISZ MLS028
04136  5322          JMP MLS010
04150  4277
04151  4200
04152  0012
04153  4276
04154  0144
04155  4275
04156  1750
04157  4274
04160  3420
04161  4273
04162  3240
04163  0030
04164  4272
04165  1100
04166  0364
04167  4271
04170  1600
04171  4666
04172  4600
04173  4665
04174  3200
04175  4664
04176  4611
04177  4663
       4200   PAGE
04200  7300   MLS011, CLA CLL
04201  1777'         TAD MAS004
04202  3300          DCA MLS029
04203  1376          TAD (-11
04204  3303          DCA MLS032
04205  1265          TAD MLS018
04206  3014          DCA AUTO01
04207  7300   MLS012, CLA CLL
04210  2303          ISZ MLS032
04211  5232          JMP MLS015
04212  1414   MLS013, TAD I AUTO01
04213  1375          TAD (260
04214  7410          SKP
04215  1374          TAD (256
04216  4773'         JMS TDS000
04217  1414          TAD I AUTO01
04220  1375          TAD (260
04221  4773'         JMS TDS000
```

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04222  1414            TAD I AUTO01
04223  1375            TAD (260
04224  4773'           JMS TDS000
04225  1772'           TAD MLS000
04226  3231            DCA .+3
04227  0000  MLS014,   0
04230  5631            JMP I .+1
04231  0000            0
04232  1414  MLS015,   TAD I AUTO01
04233  7450            SNA
04234  7410            SKP
04235  5242            JMP .+5
04236  1301            TAD MLS030
04237  7440            SZA
04240  5253            JMP MLS017
04241  5207            JMP MLS012
04242  1375            TAD (260
04243  4773'           JMS TDS000
04244  2303  MLS016,   ISZ MLS032
04245  7410            SKP
04246  5212            JMP MLS013
04247  1414            TAD I AUTO01
04250  1375            TAD (260
04251  4773'           JMS TDS000
04252  5244            JMP MLS016
04253  7300  MLS017,   CLA CLL
04254  2302            ISZ MLS031
04255  7000            NOP
04256  1302            TAD MLS031
04257  7550            SPA SNA
04260  5207            JMP MLS012
04261  7300            CLA CLL
04262  1371            TAD (240
04263  4773'           JMS TDS000
04264  5207            JMP MLS012
04265  4265  MLS018,   .
04266  0000  MLS019,   0            /CH11
04267  0000  MLS020,   0            /CH10
04270  0000  MLS021,   0            /CH9
04271  0000  MLS022,   0            /CH8
04272  0000  MLS023,   0            /CH7
04273  0000  MLS024,   0            /CH6
04274  0000  MLS025,   0            /CH5
04275  0000  MLS026,   0            /CH4
04276  0000  MLS027,   0            /CH3
04277  0000  MLS028,   0            /CH2
04300  0000  MLS029,   0            /CH1
04301  0000  MLS030,   0
04302  0000  MLS031,   0
04303  0000  MLS032,   0


             /"MJS000" - ACCEPTS A SINGLE PRECISION DECIMAL
             /NUMBER FROM THE TELETYPE, CONVERTS IT TO BINARY
```

```
          /USING SUBROUTINE "MISØØØ" AND DEPOSITS IT IN THE
          /ADDRESS FOLLOWING THAT STORED IN "AUTOØ2". ALSO
          /USES "AUTOØ1".

          /(16 LOCATIONS)

Ø43Ø4  ØØØØ  MJSØØØ, Ø
Ø43Ø5  72ØØ          CLA
Ø43Ø6  6214          RDF
Ø43Ø7  62Ø1          CDF Ø
Ø431Ø  1Ø36          TAD RETURN
Ø4311  3321          DCA MJSØØ1
Ø4312  477Ø'         JMS MISØØØ
Ø4313  ØØØØ          Ø
Ø4314  1313          TAD .-1
Ø4315  7ØØ1          IAC
Ø4316  3Ø14          DCA AUTOØ1
Ø4317  1414          TAD I AUTOØ1
Ø432Ø  3415          DCA I AUTOØ2
Ø4321  ØØØØ  MJSØØ1, Ø
Ø4322  57Ø4          JMP I MJSØØØ
```

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04370  4400
04371  0240
04372  3600
04373  3414
04374  0256
04375  0260
04376  7767
04377  4662
       4400   PAGE
              /"MIS000" - ACCEPTS UP TO 11 DECIMAL NUMBERS FROM
              /THE TELETYPE AND CONVERTS THEM TO A TRIPLE
              /PRECISION NUMBER STORED IN "STOR03", "STOR04",
              /AND "STOR05".  THE FIRST INSTRUCTION FOLLOWING
              /THE CALL TO THIS SUBROUTINE WILL BE CHANGED TO
              /CONTAIN THE ADDRESS OF THE HIGH WORD (I.E.
              /"STOR03") IN THE TRIPLE PRECISION NUMBER.  THE
              /SUBROUTINE RETURNS TO THE SECOND INSTRUCTION
              /FOLLOWING THE CALL TO THE SUBROUTINE.

              /(122 LOCATIONS)

04400  0000   MIS000, 0
04401  7200           CLA
04402  1204           TAD .+2
04403  7410           SKP
04404  0022           STOR03
04405  3600           DCA I MIS000
04406  7200           CLA
04407  6214           RDF
04410  6201           CDF 0
04411  1036           TAD RETURN
04412  3346           DCA MIS005
04413  2200           ISZ MIS000
04414  3021           DCA STOR02
04415  3022           DCA STOR03
04416  3023           DCA STOR04
04417  3024           DCA STOR05
04420  1377           TAD (-13
04421  3025           DCA STOR06
04422  4776'  MIS001, JMS TBS000
04423  1020           TAD STOR01
04424  1375           TAD (-"0
04425  7510           SPA
04426  5305           JMP MIS003
04427  1374           TAD (-12
04430  7500           SMA
04431  5305           JMP MIS003
04432  7300           CLA CLL
04433  1022           TAD STOR03
04434  3773'          DCA MAS002
04435  1023           TAD STOR04
04436  3772'          DCA MAS003
04437  1024           TAD STOR05
04440  3771'          DCA MAS004
04441  1370           TAD (12
```

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04442   3767'            DCA MCS003
04443   4766'            JMS MCS000
04444   1020             TAD STOR01
04445   1375             TAD (-260
04446   7100             CLL
04447   1765'            TAD MAS010
04450   3024             DCA STOR05
04451   7004             RAL
04452   1764'            TAD MAS009
04453   3023             DCA STOR04
04454   7004             RAL
04455   1763'            TAD MAS008
04456   3022             DCA STOR03
04457   2025             ISZ STOR06
04460   5222             JMP MIS001
04461   1021   MIS002,   TAD STOR02
04462   7450             SNA
04463   5345             JMP MIS004
04464   7300             CLA CLL
04465   1024             TAD STOR05
04466   7041             CIA
04467   3024             DCA STOR05
04470   7004             RAL
04471   3020             DCA STOR01
04472   1023             TAD STOR04
04473   7040             CMA
04474   1020             TAD STOR01
04475   3023             DCA STOR04
04476   7004             RAL
04477   3020             DCA STOR01
04500   1022             TAD STOR03
04501   7040             CMA
04502   1020             TAD STOR01
04503   3022             DCA STOR03
04504   5345             JMP MIS004
04505   7300   MIS003,   CLA CLL
04506   1020             TAD STOR01
04507   1362             TAD (-",
04510   7440             SZA
04511   5313             JMP .+2
04512   5222             JMP MIS001
04513   7300             CLA CLL
04514   1020             TAD STOR01
04515   1361             TAD (-".
04516   7440             SZA
04517   5321             JMP .+2
04520   5222             JMP MIS001
04521   7300             CLA CLL
04522   1020             TAD STOR01
04523   1360             TAD (-"+
04524   7440             SZA
04525   5330             JMP .+3
04526   3021             DCA STOR02
04527   5222             JMP MIS001
04530   1357             TAD (-2
```

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04531   7440            SZA
04532   5336            JMP .+4
04533   7040            CMA
04534   3021            DCA STOR02
04535   5222            JMP MIS001
04536   7200            CLA
04537   1020            TAD STOR01
04540   1356            TAD (-"-
04541   7450            SNA
04542   5214            JMP MIS001-6
04543   7300            CLA CLL
04544   5261            JMP MIS002
04545   7300    MIS004, CLA CLL
04546   0000    MIS005, 0
04547   5600            JMP I MIS000

04556   7441
04557   7776
04560   7525
04561   7522
04562   7524
04563   4666
04564   4667
04565   4670
04566   4671
04567   4756
04570   0012
04571   4662
04572   4661
04573   4660
04574   7766
04575   7520
04576   3422
04577   7765
        4600    PAGE
                /"MBS000" - TRIPLE PRECISION SUBTRACTION WITH
                /FORMAT (AH,AM,AL) - (BH,BM,BL) = (CH,CM,CL).
                /SPECIFY (AH,AM,AL) AND (BH,BM,BL) BEFORE ENTERING
                /THE SUBROUTINE. DIFFERENCE IS (CH,CM,CL).

                /(37 LOCATIONS)

04600   0000    MBS000, 0
04601   7200            CLA
04602   6214            RDF
04603   6201            CDF 0
04604   1036            TAD RETURN
04605   3231            DCA MBS001
04606   7300            CLA CLL
04607   1265            TAD MAS007
04610   7041            CIA
04611   1262            TAD MAS004
04612   3270            DCA MAS010
04613   7004            RAL
04614   3233            DCA MBS002
```

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04615   1264              TAD MASØØ6
04616   7Ø4Ø              CMA
04617   1261              TAD MASØØ3
0462Ø   1233              TAD MBSØØ2
04621   3267              DCA MASØØ9
04622   7ØØ4              RAL
04623   3233              DCA MBSØØ2
04624   1263              TAD MASØØ5
04625   7Ø4Ø              CMA
04626   126Ø              TAD MASØØ2
04627   1233              TAD MBSØØ2
0463Ø   3266              DCA MASØØ8
04631   ØØØØ    MBSØØ1,   Ø
04632   56ØØ              JMP I MBSØØØ
04633   ØØØØ    MBSØØ2,   Ø

                /"MASØØØ" - TRIPLE PRECISION ADDITION WITH FORMAT
                /(AH,AM,AL) + (BH,BM,BL) = (CH,CM,CL).  SPECIFY
                /(AH,AM,AL) AND (BH,BM,BL) BEFORE ENTERING THE
                /SUBROUTINE.  SUM IS (CH,CM,CL).

                /(29 LOCATIONS)

04634   ØØØØ    MASØØØ,   Ø
04635   72ØØ              CLA
04636   6214              RDF
04637   62Ø1              CDF Ø
0464Ø   1Ø36              TAD RETURN
04641   3256              DCA MASØØ1
04642   73ØØ              CLA CLL
04643   1262              TAD MASØØ4
04644   1265              TAD MASØØ7
04645   327Ø              DCA MASØ1Ø
04646   7ØØ4              RAL
04647   1261              TAD MASØØ3
0465Ø   1264              TAD MASØØ6
04651   3267              DCA MASØØ9
04652   7ØØ4              RAL
04653   126Ø              TAD MASØØ2
04654   1263              TAD MASØØ5
04655   3266              DCA MASØØ8
04656   ØØØØ    MASØØ1,   Ø
04657   5634              JMP I MASØØØ
0466Ø   ØØØØ    MASØØ2,   Ø            /AH
04661   ØØØØ    MASØØ3,   Ø            /AM
04662   ØØØØ    MASØØ4,   Ø            /AL
04663   ØØØØ    MASØØ5,   Ø            /BH
04664   ØØØØ    MASØØ6,   Ø            /BM
04665   ØØØØ    MASØØ7,   Ø            /BL
04666   ØØØØ    MASØØ8,   Ø            /CH
04667   ØØØØ    MASØØ9,   Ø            /CM
0467Ø   ØØØØ    MASØ1Ø,   Ø            /CL

                /"MCSØØØ" - TRIPLE PRECISION MULTIPLICATION WITH
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                        /FORMAT BHL*(AH,AM,AL)=(CH,CM,CL).  SPECIFY
                        /BHL AND (AH,AM,AL) BEFORE ENTERING SUBROUTINE.

04671   0000    MCS000, 0
04672   7300            CLA CLL
04673   3266            DCA MAS008
04674   3267            DCA MAS009
04675   3270            DCA MAS010
04676   1377            TAD (-14           /-12
04677   3357            DCA MCS005         /WORD BIT COUNT
04700   7410            SKP
04701   2357    MCS001, ISZ MCS005         /WORD BIT LOOP:
04702   7410            SKP
04703   5671            JMP I MCS000
04704   7300            CLA CLL
04705   1356            TAD MCS003
04706   7004            RAL
04707   3356            DCA MCS003
04710   7420            SNL
04711   5301            JMP MCS001
04712   7100            CLL
04713   1357            TAD MCS005
04714   3360            DCA MCS006         /2MPY COUNT
04715   1260            TAD MAS002
04716   3263            DCA MAS005
04717   1261            TAD MAS003
04720   3264            DCA MAS006
04721   1262            TAD MAS004
04722   3265            DCA MAS007
04723   2360    MCS002, ISZ MCS006         /2MPY LOOP:
04724   7410            SKP
04725   5341            JMP MCS004
04726   7300            CLA CLL
04727   1265            TAD MAS007
04730   7004            RAL
04731   3265            DCA MAS007
04732   1264            TAD MAS006
04733   7004            RAL
04734   3264            DCA MAS006
04735   1263            TAD MAS005
04736   7004            RAL
04737   3263            DCA MAS005
04740   5323            JMP MCS002
04741   7300    MCS004, CLA CLL            /ADD PARTIAL PRODUCT TO PRODUCT:
04742   1265            TAD MAS007
04743   1270            TAD MAS010
04744   3270            DCA MAS010
04745   7004            RAL
04746   1264            TAD MAS006
04747   1267            TAD MAS009
04750   3267            DCA MAS009
04751   7004            RAL
04752   1263            TAD MAS005
04753   1266            TAD MAS008
04754   3266            DCA MAS008
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04755   5301             JMP MCS001
04756   0000   MCS003,   0                  /BHL
04757   0000   MCS005,   0
04760   0000   MCS006,   0

04777   7764
        5600   *5600
05600   0000             0
05601   0043             43
05602   0106             106
05603   0151             151
05604   0213             213
05605   0256             256
05606   0320             320
05607   0362             362
05610   0424             424
05611   0465             465
05612   0526             526
05613   0567             567
05614   0627             627
05615   0666             666
05616   0725             725
05617   0764             764
05620   1022             1022
05621   1057             1057
05622   1114             1114
05623   1150             1150
05624   1203             1203
05625   1235             1235
05626   1267             1267
05627   1317             1317
05630   1347             1347
05631   1376             1376
05632   1424             1424
05633   1451             1451
05634   1475             1475
05635   1520             1520
05636   1542             1542
05637   1560             1560
05640   1603             1603
05641   1622             1622
05642   1637             1637
05643   1654             1654
05644   1667             1667
05645   1701             1701
05646   1712             1712
05647   1722             1722
05650   1731             1731
05651   1736             1736
05652   1743             1743
05653   1746             1746
05654   1747             1747
05655   1750             1750
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```
        6000   *6000
06000   0000          0              /THETA=0:
06001   0000          0
06002   0100          0100
06003   0100          0100
06004   2004          2004
06005   1010          1010
06006   0240          0240
06007   2104          2104
06010   0610          0610
06011   0340          0340
06012   2244          2244
06013   1250          1250
06014   0660          0660
06015   2524          2524
06016   1530          1530
06017   0760          0760
06020   2664          2664
06021   1670          1670
06022   3552          3552
06023   3354          3354
06024   2764          2764
06025   1770          1770
06026   3674          3674
06027   5771          5771
06030   3772          3772
06031   3774          3774
06032   3774          3774
06033   7776          7776
06034   7776          7776
06035   7776          7776
06036   0000          0              /THETA=2:
06037   0000          0
06040   0100          0100
06041   0100          0100
06042   2004          2004
06043   4101          4101
06044   0240          0240
06045   1202          1202
06046   0604          0604
06047   2422          2422
06050   1424          1424
06051   0704          0704
06052   0650          0650
06053   2324          2324
06054   1330          1330
06055   0750          0750
06056   2564          2564
06057   1570          1570
06060   2761          2761
06061   2754          2754
06062   1764          1764
06063   5374          5374
06064   3574          3574
```

C2

```
Ø6Ø65   5766         5766
Ø6Ø66   3766         3766
Ø6Ø67   7376         7376
Ø6Ø7Ø   7376         7376
Ø6Ø71   7773         7773
Ø6Ø72   7773         7773
Ø6Ø73   7773         7773
Ø6Ø74   ØØØØ         Ø               /THETA=4:
Ø6Ø75   ØØØØ         Ø
Ø6Ø76   4ØØ1         4ØØ1
Ø6Ø77   2ØØ2         2ØØ2
Ø61ØØ   1ØØ4         1ØØ4
Ø61Ø1   Ø41Ø         Ø41Ø
Ø61Ø2   12Ø1         12Ø1
Ø61Ø3   4Ø3Ø         4Ø3Ø
Ø61Ø4   Ø51Ø         Ø51Ø
Ø61Ø5   Ø32Ø         Ø32Ø
Ø61Ø6   2144         2144
Ø61Ø7   115Ø         115Ø
Ø611Ø   Ø56Ø         Ø56Ø
Ø6111   1514         1514
Ø6112   Ø744         Ø744
Ø6113   Ø73Ø         Ø73Ø
Ø6114   1654         1654
Ø6115   1564         1564
Ø6116   137Ø         137Ø
Ø6117   1752         1752
Ø612Ø   1754         1754
Ø6121   3372         3372
Ø6122   2774         2774
Ø6123   3755         3755
Ø6124   3756         3756
Ø6125   6775         6775
Ø6126   6776         6776
Ø6127   6776         6776
Ø613Ø   6776         6776
Ø6131   6776         6776
Ø6132   ØØØØ         Ø               /THETA=6:
Ø6133   ØØØØ         Ø
Ø6134   4ØØ1         4ØØ1
Ø6135   2ØØ2         2ØØ2
Ø6136   1ØØ4         1ØØ4
Ø6137   Ø41Ø         Ø41Ø
Ø614Ø   Ø14Ø         Ø14Ø
Ø6141   Ø6Ø2         Ø6Ø2
Ø6142   4221         4221
Ø6143   2412         2412
Ø6144   1414         1414
Ø6145   Ø63Ø         Ø63Ø
Ø6146   Ø36Ø         Ø36Ø
Ø6147   1322         1322
Ø615Ø   Ø724         Ø724
Ø6151   1651         1651
Ø6152   1562         1562
Ø6153   1364         1364
```

Ø6154	Ø77Ø	Ø77Ø
Ø6155	2674	2674
Ø6156	1674	1674
Ø6157	2771	2771
Ø616Ø	2772	2772
Ø6161	1774	1774
Ø6162	7367	7367
Ø6163	6773	6773
Ø6164	3775	3775
Ø6165	3776	3776
Ø6166	3776	3776
Ø6167	7777	7777

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ØØ175	7774
ØØ176	7777
ØØ177	2723

ABTIME	ØØ5Ø
AC	ØØ64
AHCØØØ	Ø13Ø
AHSØ77	167Ø
AUTOØ1	ØØ14
AUTOØ2	ØØ15
CDCONT	ØØ52
CMDOT1	2612
CMDOT2	2712
CMDOT3	2716
CMDOUT	2474
CMLOP1	25Ø3
CMLOP3	2527
CMLOP4	2622
CMTØØØ	Ø257
CMTØØ1	Ø511
CMTØØ2	Ø533
CMTØØ3	Ø441
CMTØØ4	Ø45Ø
CMTØØ5	Ø641
CMTØØ6	Ø7Ø3
CMTØØ7	3Ø67
CMTØØ9	1Ø62
CMTØ1Ø	1Ø64
CMTØ11	1Ø66
CMTØ12	1Ø7Ø
COMMND	Ø1Ø2
CYCLE	3Ø41
CYDURA	ØØ54
DELTAX	ØØ46
DELTAY	ØØ47
DR8LOP	32Ø5
DR8SRV	3121
DR8SUB	32ØØ
DSTNCE	ØØ43
ERROR	Ø231
EXCFNL	15Ø2
EXIT	3Ø73
FINISH	Ø471
INOPST	Ø443
INTCNT	2127
INTCOM	2Ø56
INTCS1	ØØ3Ø
INTCS2	ØØ31
INTCS3	ØØ32
INTCS4	ØØ33
INTCS7	ØØ34
INTCS8	ØØ35
INTLP1	2Ø56
INTLP2	2136
INTRPT	ØØØØ
L	ØØ65
LISTLN	ØØ6Ø
LISTPT	ØØ1Ø
LISTST	ØØ57
LOOPØØ	Ø3Ø6
LOOPØ1	Ø42Ø
LOOPØ2	1Ø16
MACØØØ	Ø127
MASØØØ	4634
MASØØ1	4656
MASØØ2	466Ø
MASØØ3	4661
MASØØ4	4662
MASØØ5	4663
MASØØ6	4664
MASØØ7	4665
MASØØ8	4666
MASØØ9	4667
MASØ1Ø	467Ø
MBCØØØ	Ø126
MBSØØØ	46ØØ
MBSØØ1	4631
MBSØØ2	4633
MCCØØØ	Ø132
MCSØØØ	4671
MCSØØ1	47Ø1
MCSØØ2	4723
MCSØØ3	4756
MCSØØ4	4741
MCSØØ5	4757
MCSØØ6	476Ø
MDCØØØ	Ø134
MDSØØØ	3314
MDSØØ1	3332
MDSØØ2	336Ø
MDSØØ3	3361
MDSØØ5	3362
MICØØØ	Ø131
MISØØØ	44ØØ
MISØØ1	4422
MISØØ2	4461
MISØØ3	45Ø5
MISØØ4	4545
MISØØ5	4546
MJCØØØ	Ø133
MJSØØØ	43Ø4
MJSØØ1	4321
MLCØØØ	Ø125
MLSØØØ	36ØØ
MLSØØ1	3646
MLSØØ2	3664
MLSØØ3	37Ø3
MLSØØ4	4ØØØ
MLSØØ5	4Ø16
MLSØØ6	4Ø34
MLSØØ7	4Ø52
MLSØØ8	4Ø7Ø
MLSØØ9	41Ø5
MLSØ1Ø	4122
MLSØ11	42ØØ
MLSØ12	42Ø7
MLSØ13	4212
MLSØ14	4227
MLSØ15	4232
MLSØ16	4244
MLSØ17	4253
MLSØ18	4265
MLSØ19	4266
MLSØ2Ø	4267
MLSØ21	427Ø
MLSØ22	4271
MLSØ23	4272
MLSØ24	4273
MLSØ25	4274
MLSØ26	4275
MLSØ27	4276
MLSØ28	4277
MLSØ29	43ØØ
MLSØ3Ø	43Ø1
MLSØ31	43Ø2
MLSØ32	43Ø3
MMCØØØ	Ø135
MMSØØØ	3227
MMSØØ1	3232
MMSØØ2	33Ø6
MMSØØ3	33Ø7
MMSØØ4	331Ø
MMSØØ5	3311
MMSØØ6	3312
MMSØØ7	3313
MODSLT	Ø235
NULSTE	Ø434
OPNCMD	2311
PAGEØ2	Ø4ØØ
PAGEØ3	2ØØØ
PAGEØ4	26ØØ
PAGEØ5	22ØØ
PAGEØ6	14ØØ
PARITY	Ø1Ø6
PGEXCT	1Ø72
PGEXT1	12ØØ
PGEXT2	1211
PGEXT3	1261
PGEXT4	1456
PGLIST	Ø265
PGMODE	ØØ56
PGSLCT	Ø6ØØ
PGSLØ1	Ø646
PGSLØ3	1ØØØ
PRINT	Ø267
RECTRM	1Ø52
RETURN	ØØ36
RHO	ØØ76
RHOIND	ØØ72
RMTRED	3Ø24
ROTATN	ØØ71
RSTKBG	ØØ61
RSTKPT	ØØ13
RTISQO	24ØØ
SEQACT	1Ø41
SEQNCE	ØØ7Ø
SEQRED	3Ø16
SEQTBL	Ø1Ø4
SINLOP	1724
SINTBL	Ø1ØØ
SINTHE	ØØ77
SINTST	ØØ73
SKPCHN	2723
SLECTH	2424
SMLLST	ØØ75
START	Ø2Ø2
STCLOP	2265
STEPDT	ØØ44
STORØ1	ØØ2Ø
STORØ2	ØØ21
STORØ3	ØØ22
STORØ4	ØØ23
STORØ5	ØØ24
STORØ6	ØØ25
STORØ7	ØØ26
STORØ8	ØØ27
STPCNT	ØØ45
STPSLT	3Ø55
STUCKC	2251
STUCKO	2161
TBCØØØ	Ø12Ø
TBSØØØ	3422
TCCØØØ	Ø116
TCSØØØ	34ØØ
TCSØØ1	3412
TDCØØØ	Ø117
TDSØØØ	3414
TECØØØ	Ø121
TERMNL	Ø114
TESØØØ	3455
TGCØØØ	Ø122
TGSØØØ	35Ø3
TGSØØ1	3515
THEIND	Ø1Ø5
THEOUT	2Ø52
THETA	ØØ74
THETAF	2Ø2Ø
THETAL	Ø1Ø7
THETAS	Ø11Ø
THETBL	Ø1Ø3
THNNEG	2335
TIMEPR	Ø452
TMESRV	3ØØØ
TPCØØØ	Ø123

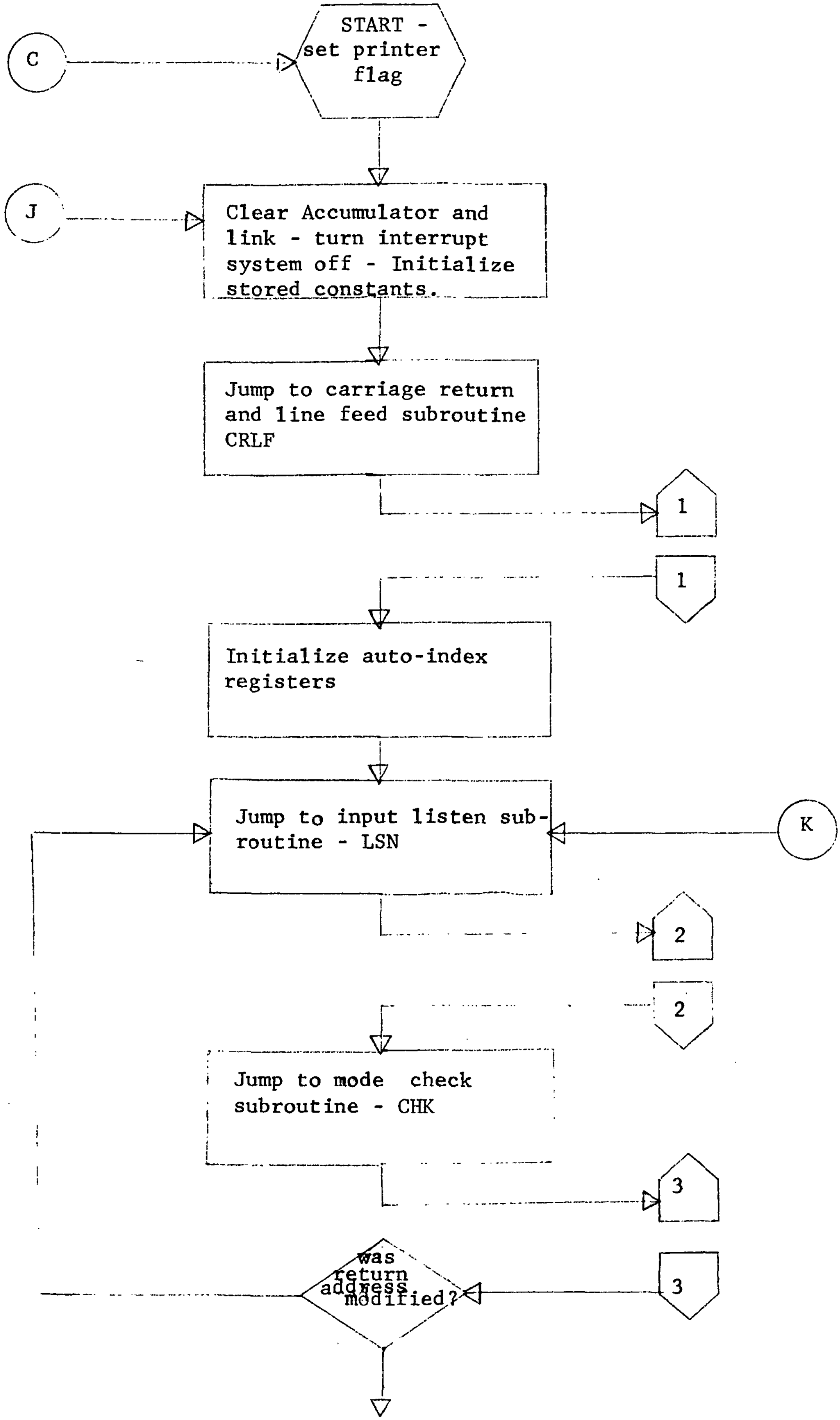
```
TPS000 3517
TPS001 3531
TQC000 0124
TQS000 3533
TQS001 3553
TQS002 3555
TRANSR 0055
TRCONT 0053
TRESET 1516
TRMCNT 0115
TTYSRV 3105
VLVENM 0101
XACEPT 0066
XBEGIN 0037
XEND   0041
XNEG   2037
XSQARH 0111
XSQARL 0113
XSQARM 0112
XSTKBG 0062
XSTKPT 0011
XYACPT 1611
YACEPT 0067
YBEGIN 0040
YEND   0042
YNEG   2047
YSTKBG 0063
YSTKPT 0012
```

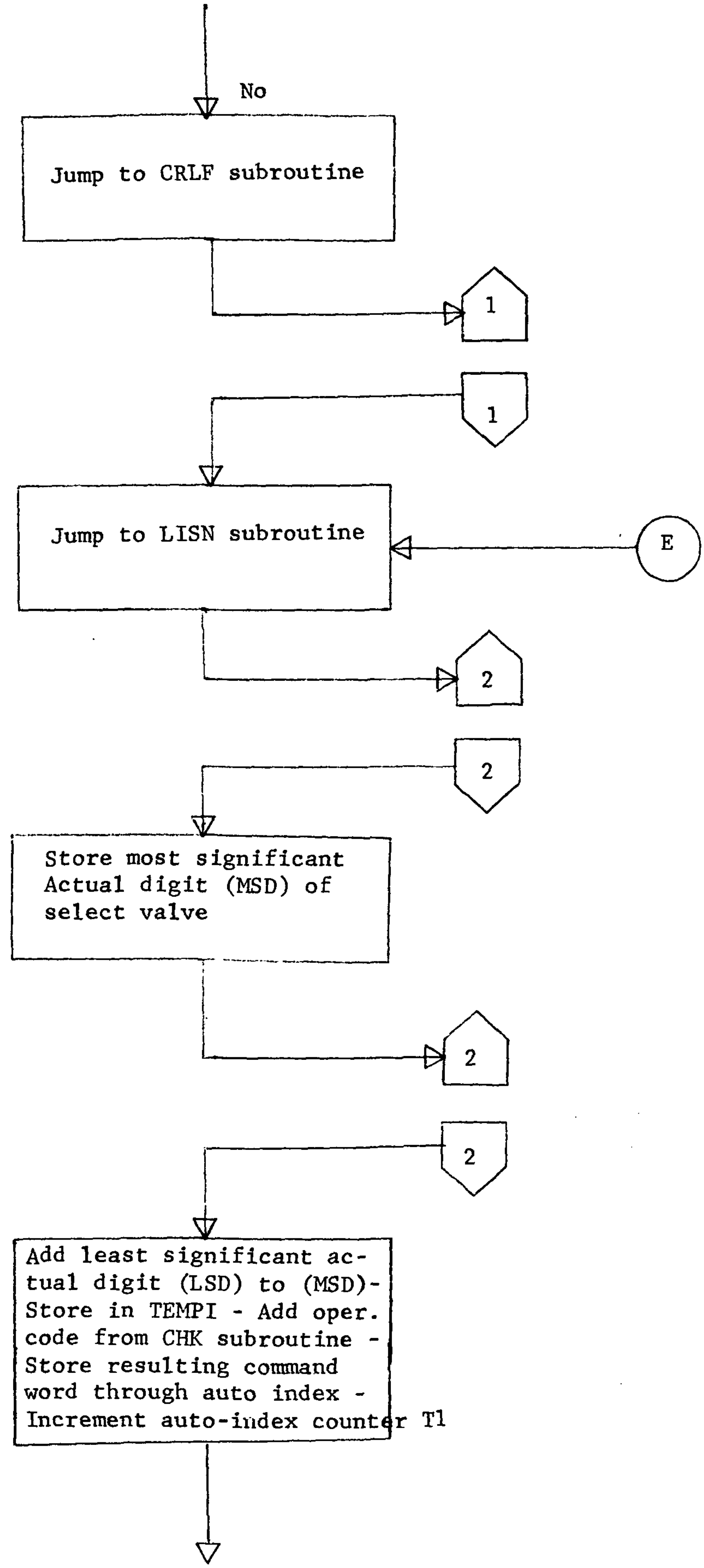
B. The Omni-Axis Test Routine

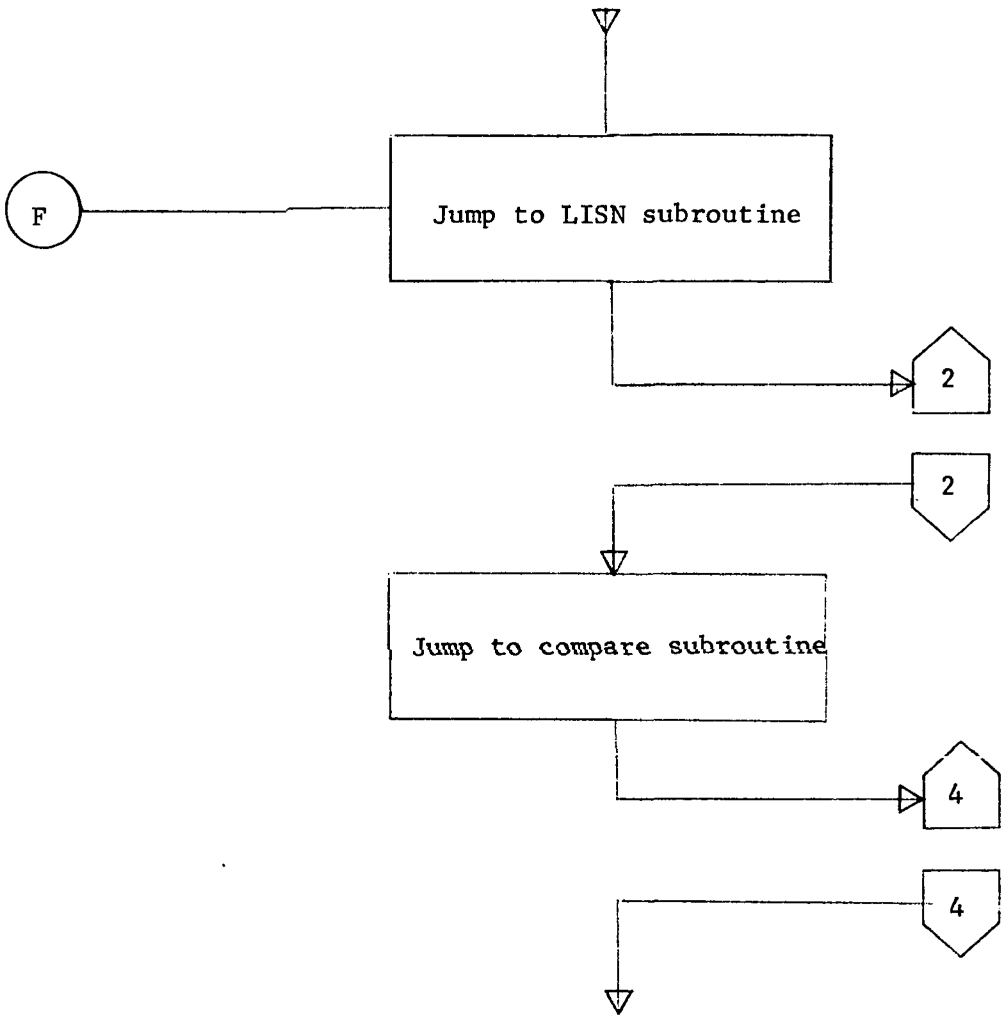
The Test Routine provides a simplified method of operator control of the system and a quick means of verifying that all portions of the hardware are working properly. The program is operated through the ASR keyboard and an interactive operator/controller mode provides separate operation of all circuits in the interface panel and operation of all valves and pressure switches of the nozzle assembly. The operator may open (O) or shut (S) any valve or any sequence of valves at his discretion. He may further interrogate all pressure switches to determine true valve status. An additional check of the analog to digitol converter contained in the interface panel is provided by this routine. Following is a flow diagram of this routine and a program listing.

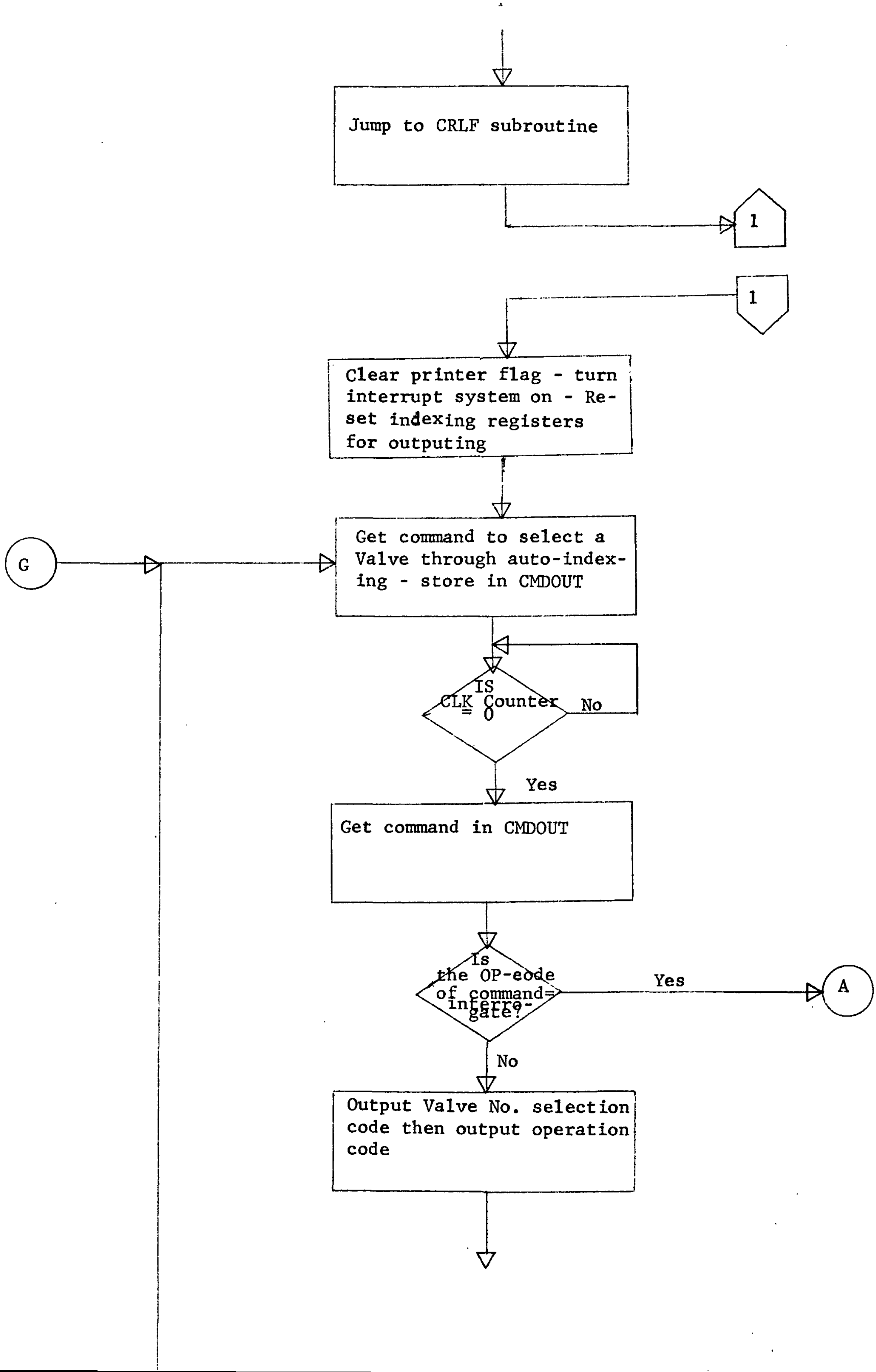
FLOW CHART

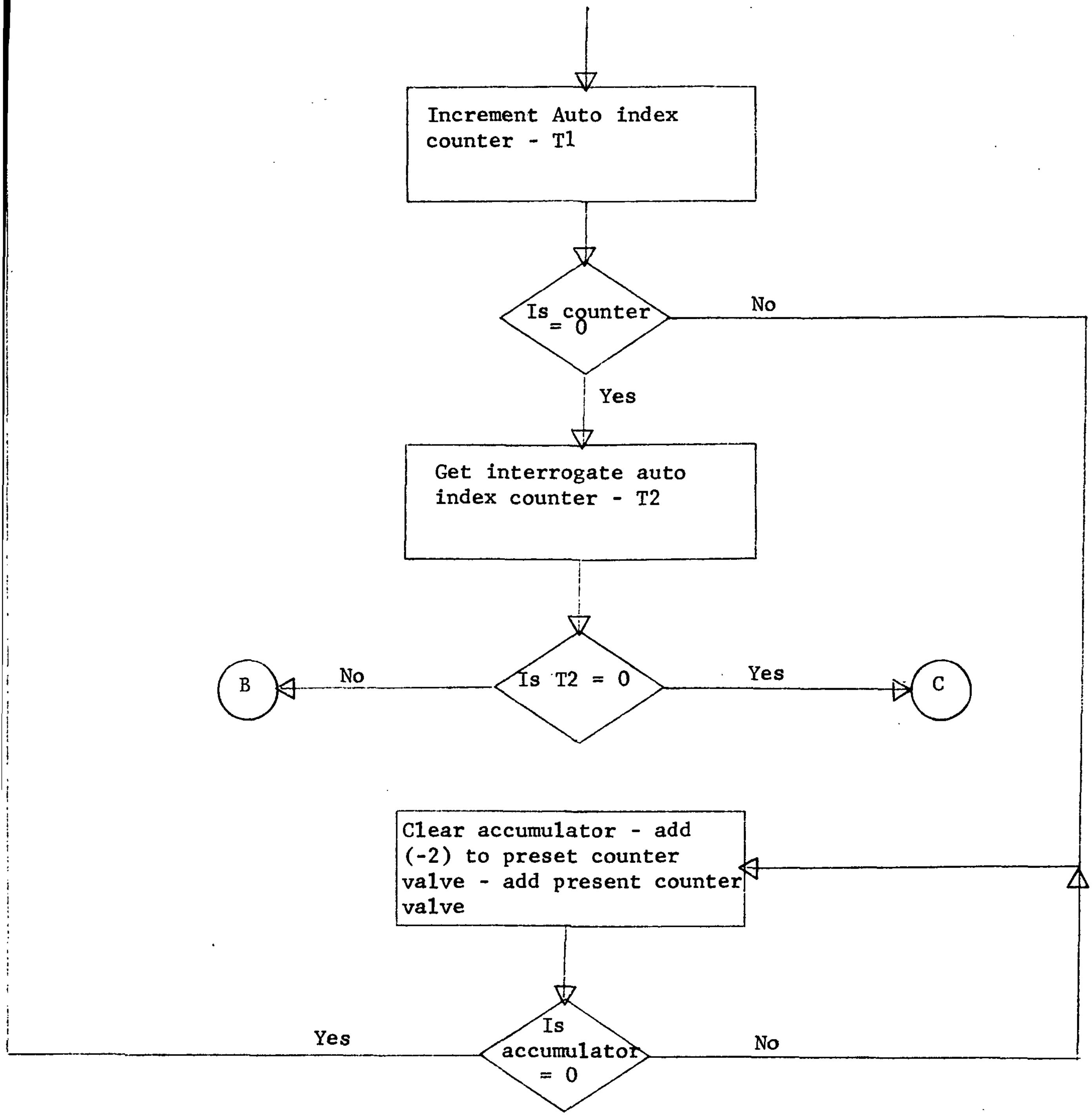
TEST ROUTINE



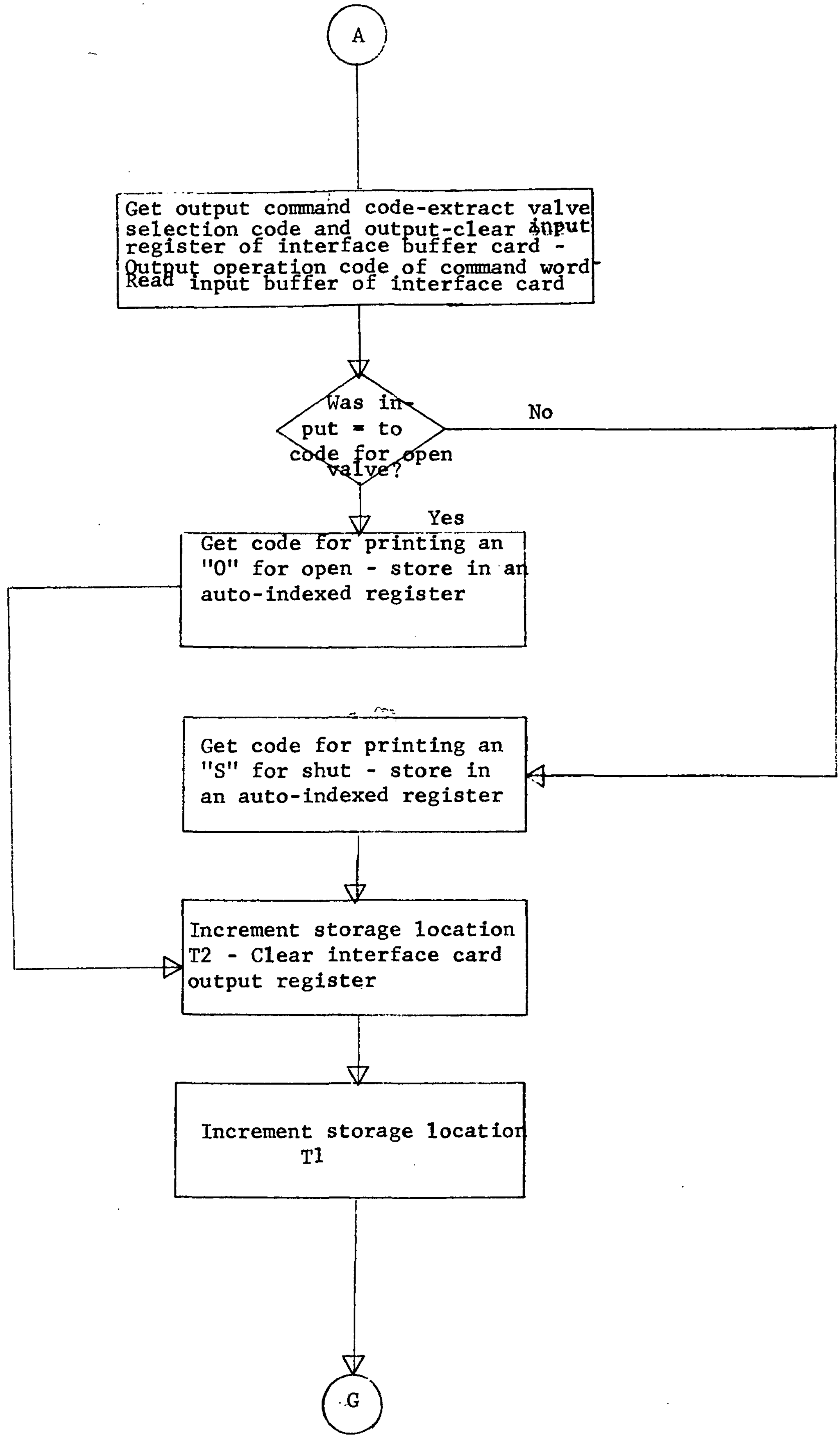

No
Jump to CRLF subroutine
1
1
Jump to LISN subroutine
E
2
2
Store most significant Actual digit (MSD) of select valve
2
2
Add least significant actual digit (LSD) to (MSD)- Store in TEMPI - Add oper. code from CHK subroutine - Store resulting command word through auto index - Increment auto-index counter T1

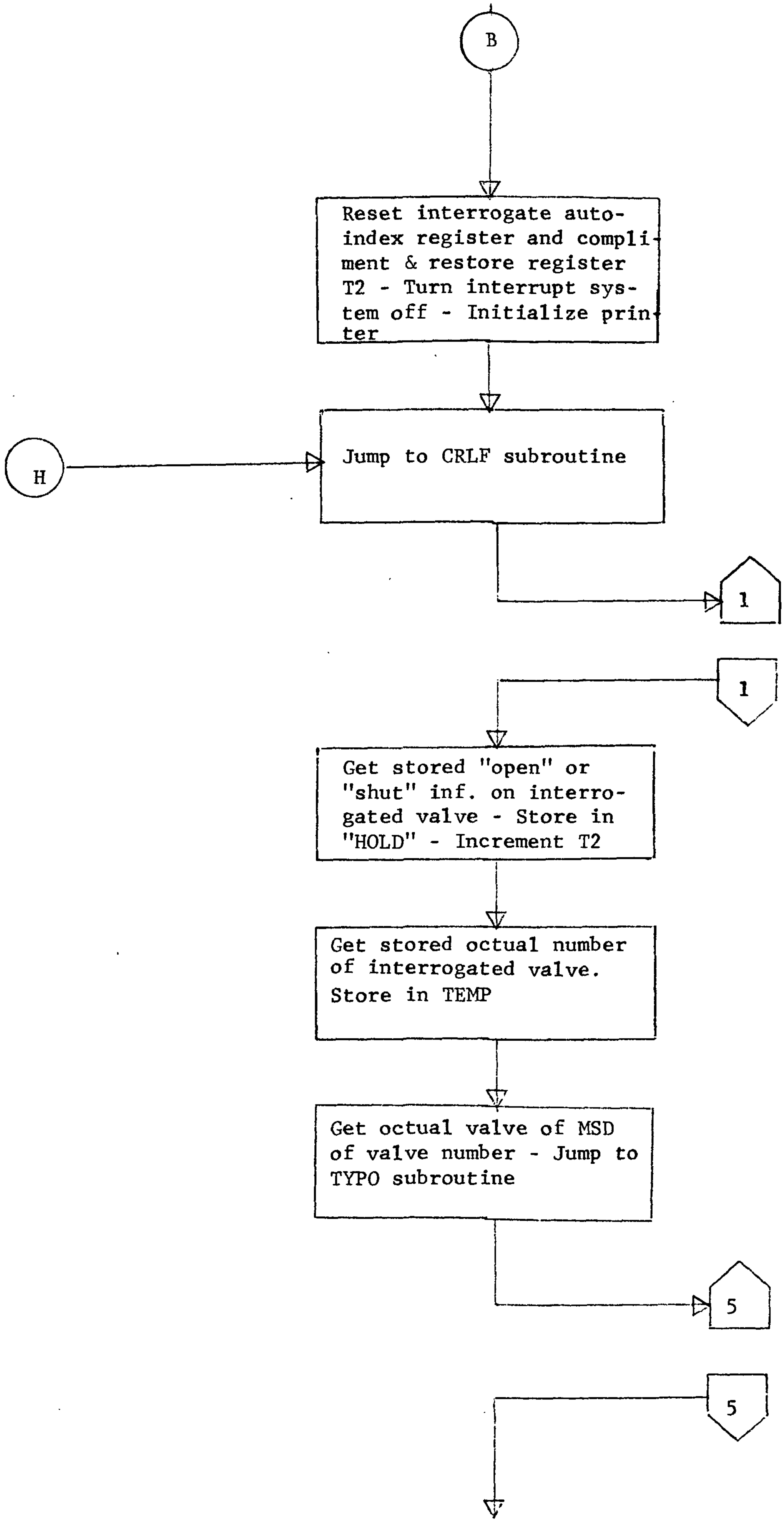

F
Jump to LISN subroutine
2
2
Jump to compare subroutine
4
4

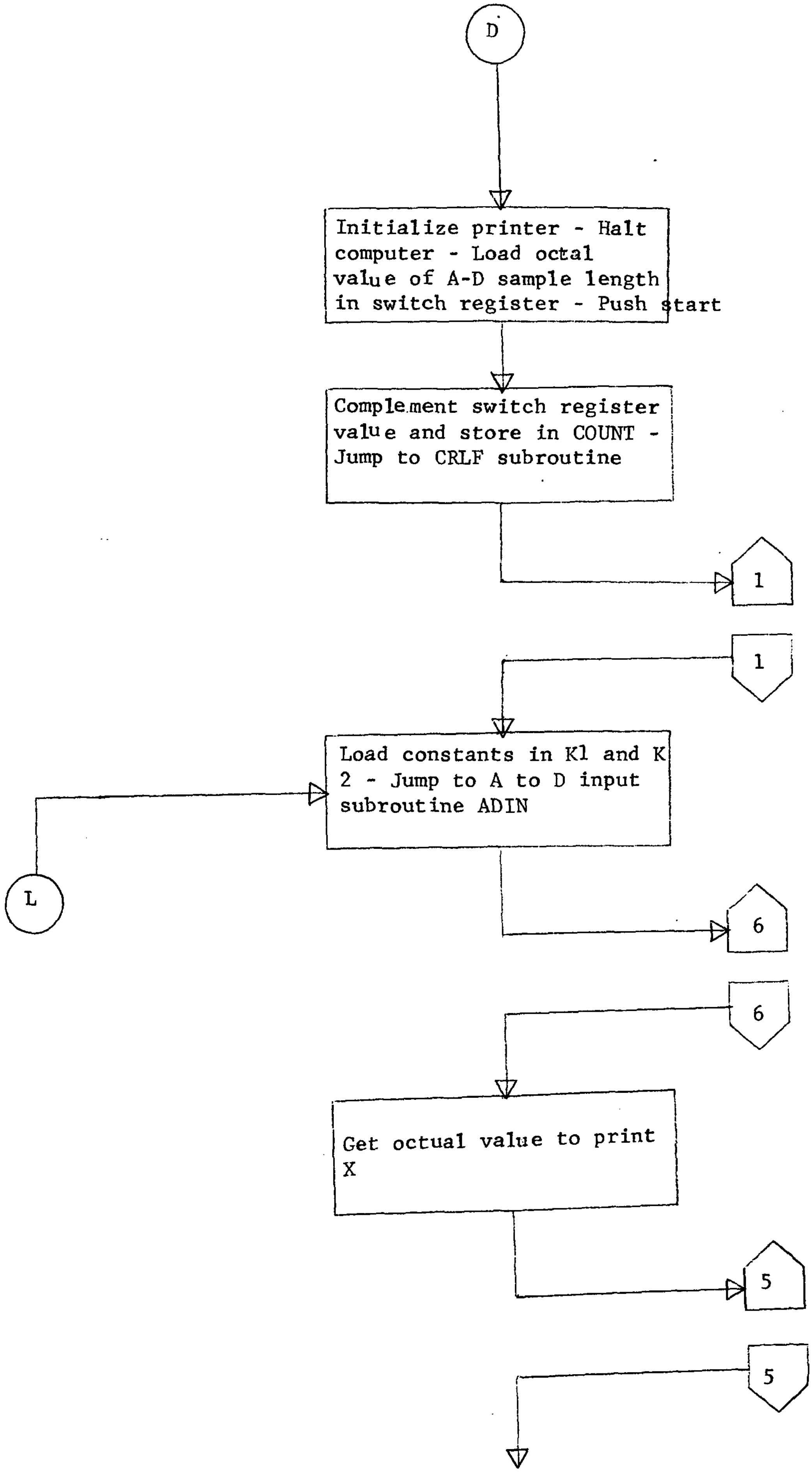

Jump to CRLF subroutine
1
1
Clear printer flag - turn interrupt system on - Reset indexing registers for outputing
G
Get command to select a Valve through auto-indexing - store in CMDOUT
IS CLK Counter = 0
No
Yes
Get command in CMDOUT
Is the OP-code of command= interro-gate?
Yes
A
No
Output Valve No. selection code then output operation code

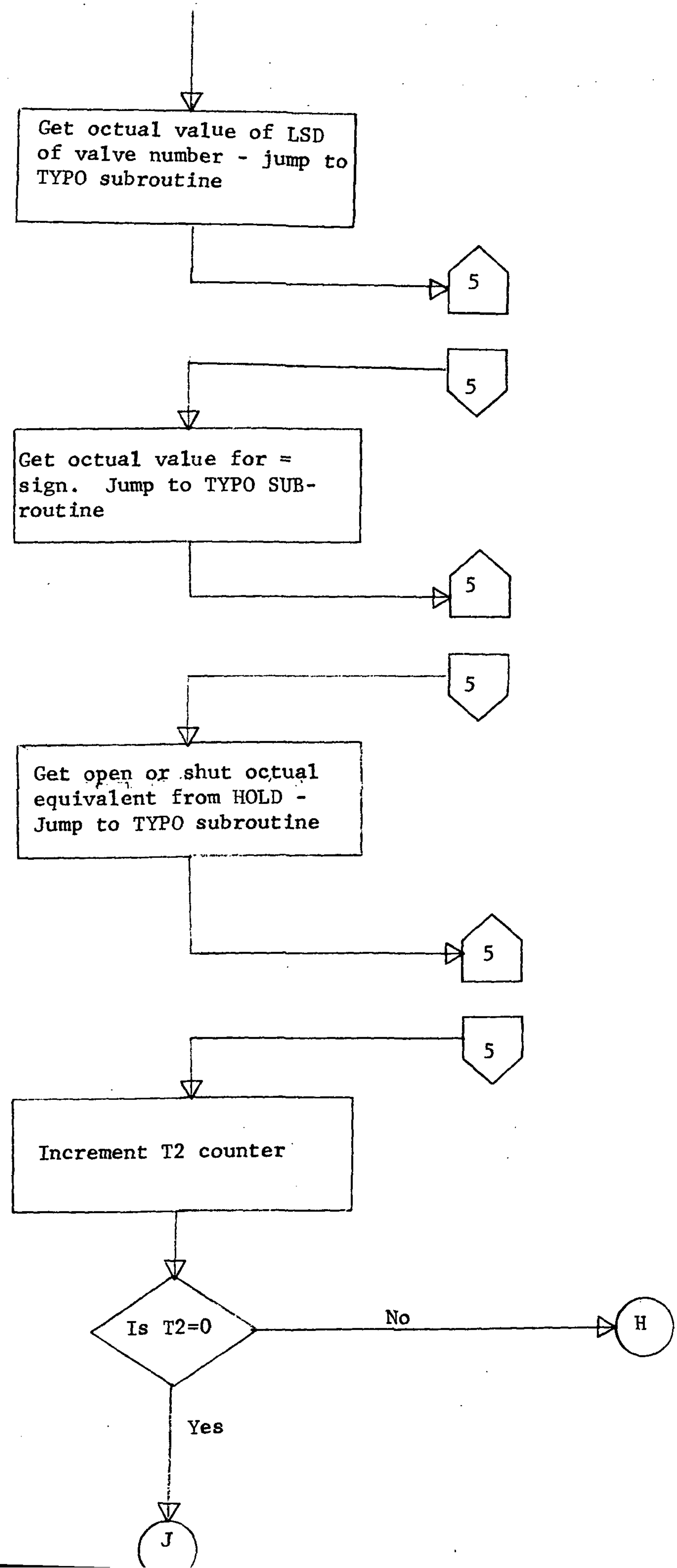


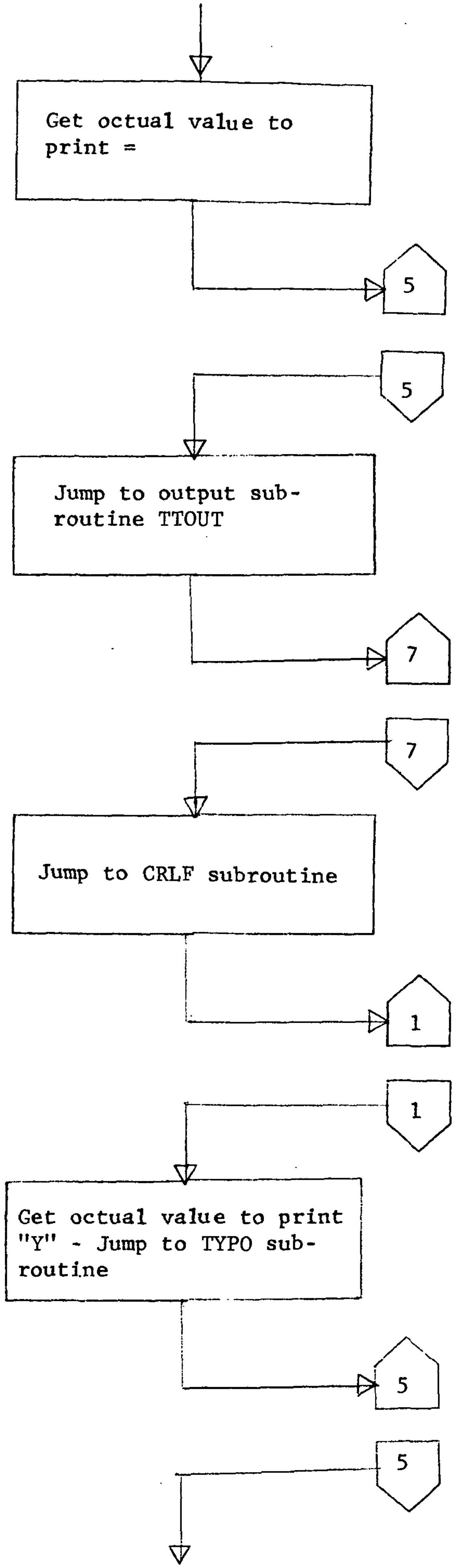
Increment Auto index counter - T1
Is counter = 0
No
Yes
Get interrogate auto index counter - T2
Is T2 = 0
No
B
Yes
C
Clear accumulator - add (-2) to preset counter valve - add present counter valve
Is accumulator = 0
Yes
No

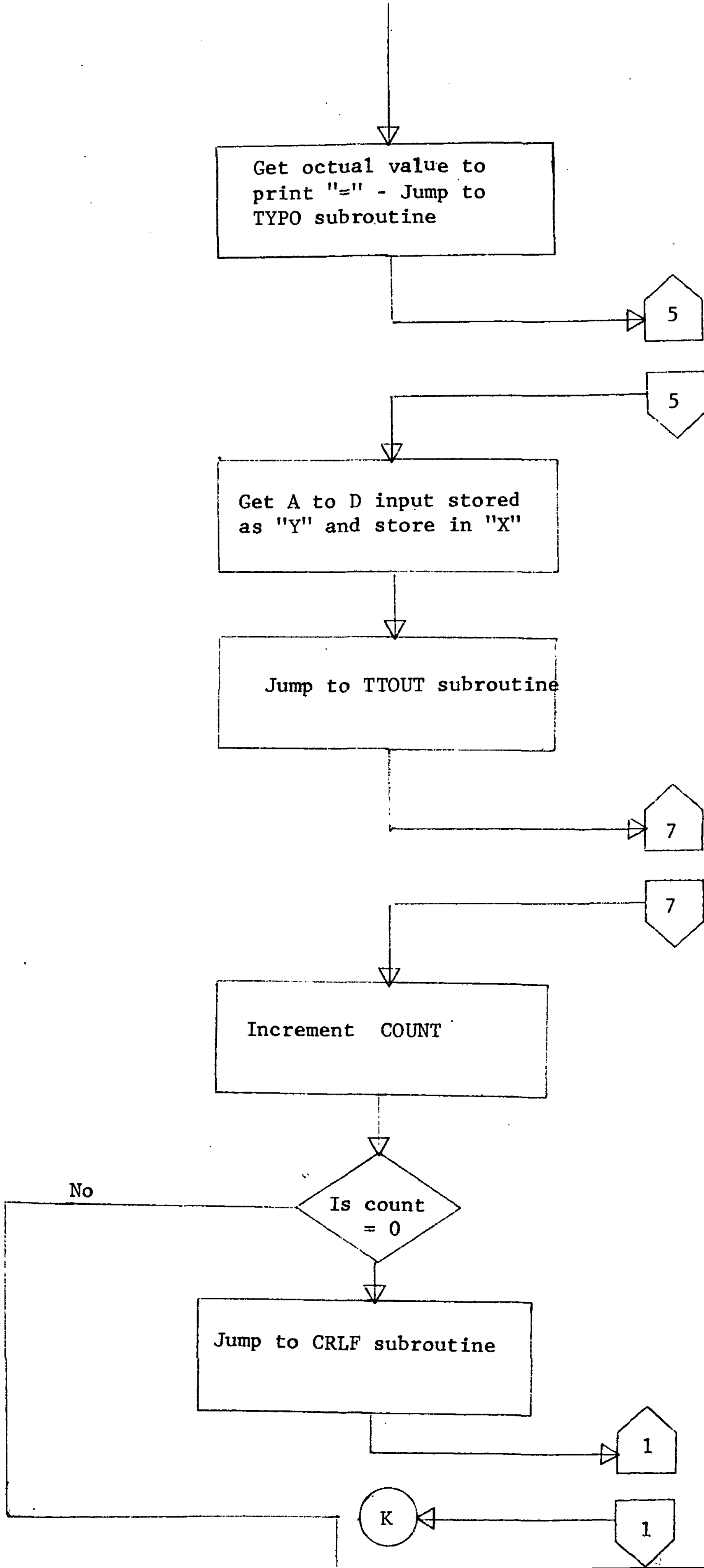

A
Get output command code-extract valve selection code and output-clear input register of interface buffer card - Output operation code of command word- Read input buffer of interface card
Was input = to code for open valve?
No
Yes
Get code for printing an "O" for open - store in an auto-indexed register
Get code for printing an "S" for shut - store in an auto-indexed register
Increment storage location T2 - Clear interface card output register
Increment storage location T1
G

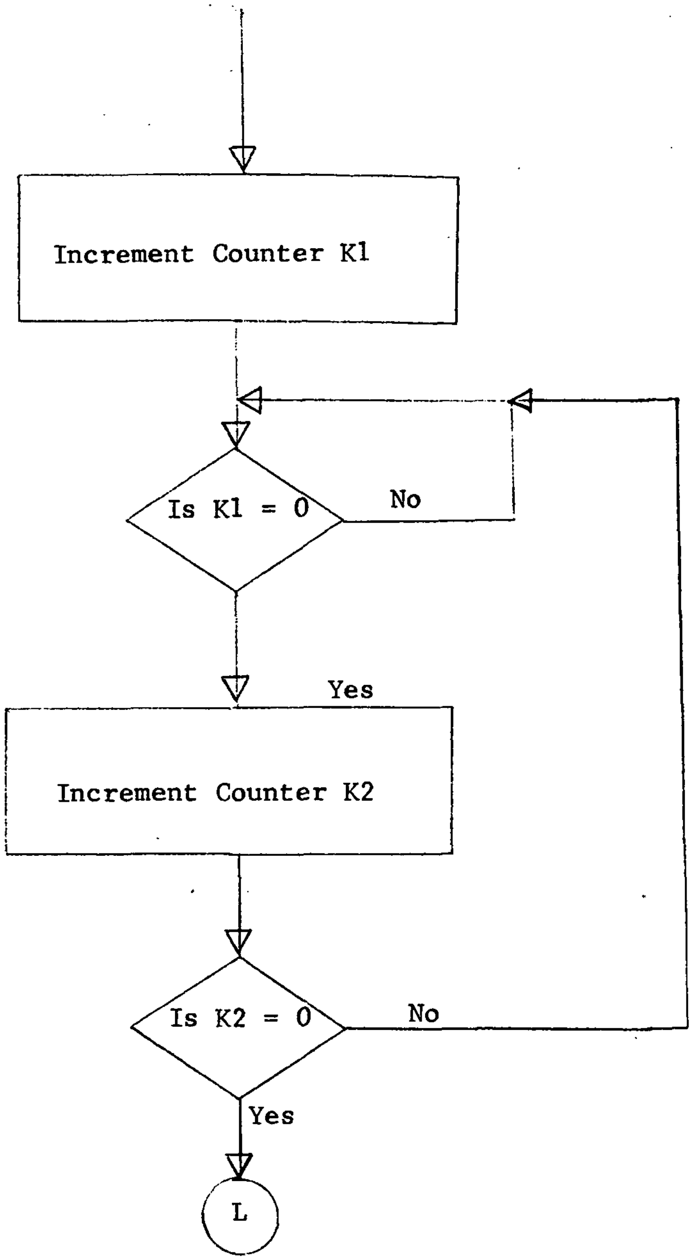

B
Reset interrogate auto-index register and compliment & restore register T2 - Turn interrupt system off - Initialize printer
H
Jump to CRLF subroutine
1
1
Get stored "open" or "shut" inf. on interrogated valve - Store in "HOLD" - Increment T2
Get stored octual number of interrogated valve. Store in TEMP
Get octual valve of MSD of valve number - Jump to TYPO subroutine
5
5

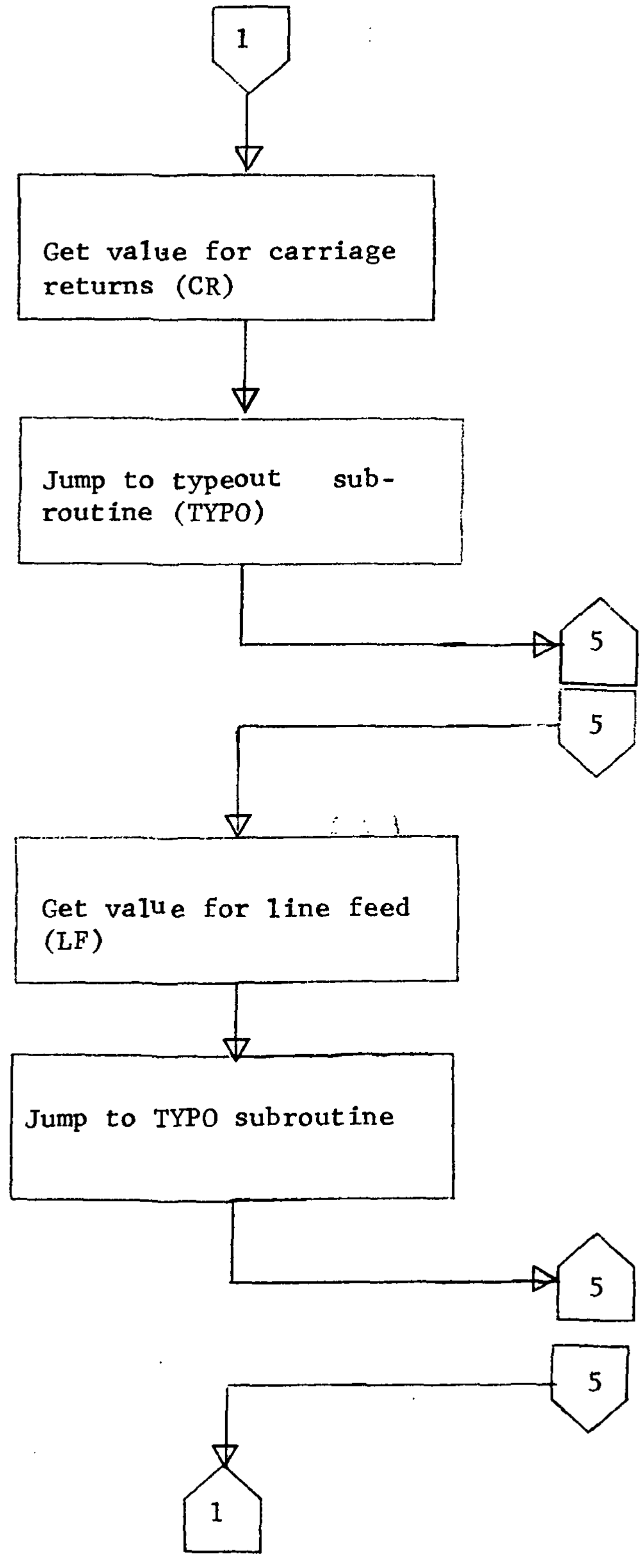

D
Initialize printer - Halt computer - Load octal value of A-D sample length in switch register - Push start
Complement switch register value and store in COUNT - Jump to CRLF subroutine
1
1
Load constants in K1 and K 2 - Jump to A to D input subroutine ADIN
L
6
6
Get octual value to print X
5
5

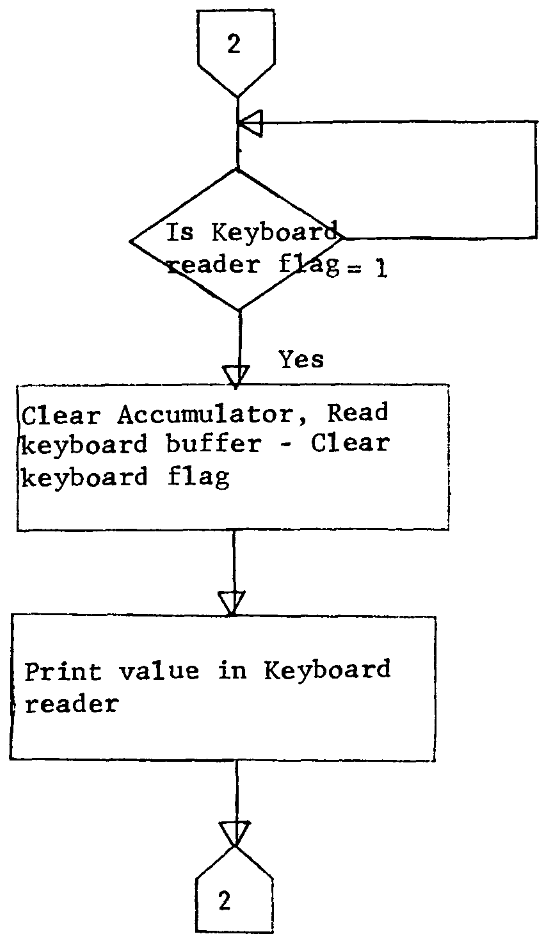

Get octual value of LSD of valve number - jump to TYPO subroutine
5
5
Get octual value for = sign. Jump to TYPO SUB-routine
5
5
Get open or shut octual equivalent from HOLD - Jump to TYPO subroutine
5
5
Increment T2 counter
Is T2=0
No
H
Yes
J

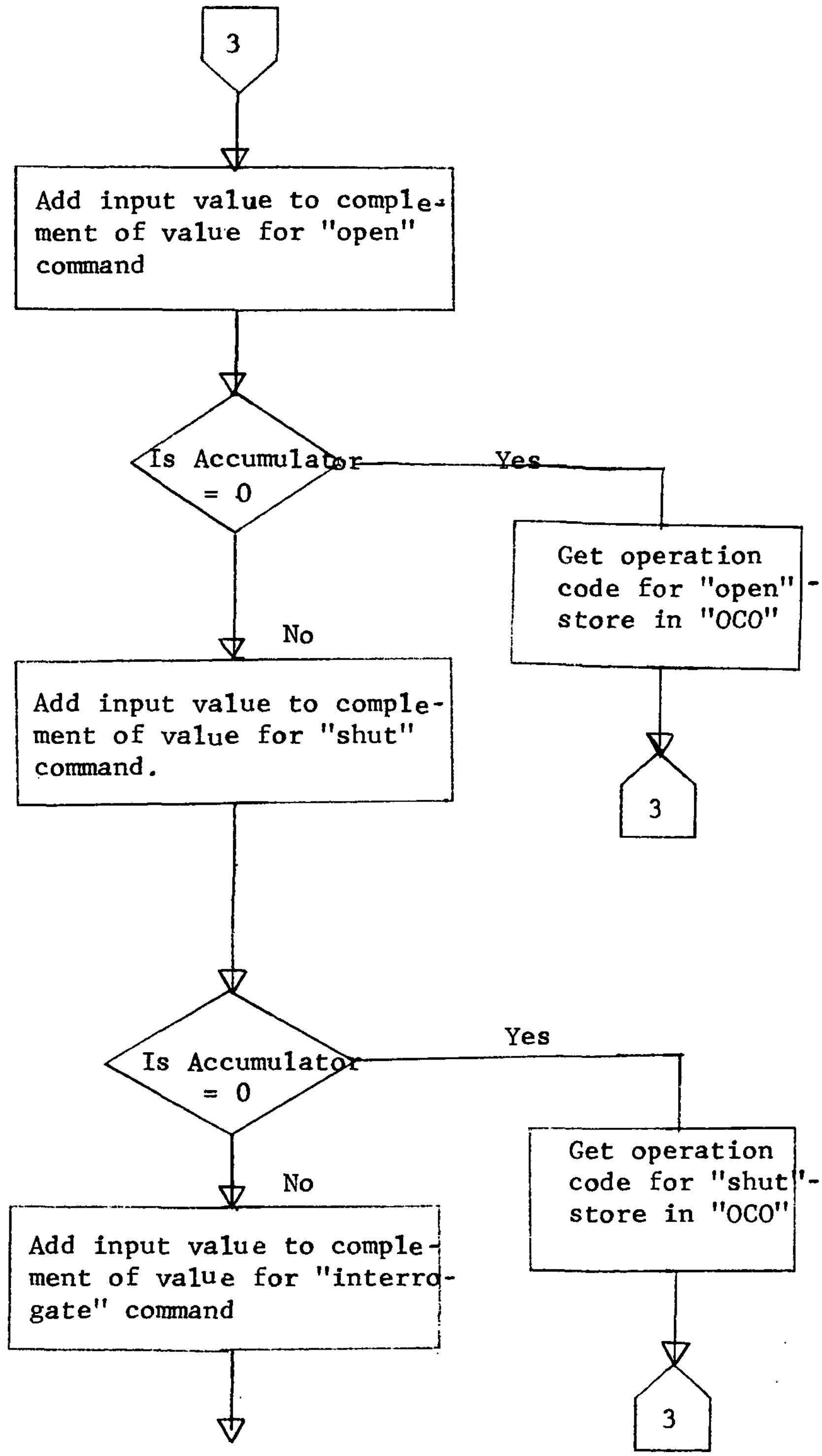

Get octual value to print =
5
5
Jump to output sub-routine TTOUT
7
7
Jump to CRLF subroutine
1
1
Get octual value to print "Y" - Jump to TYPO sub-routine
5
5

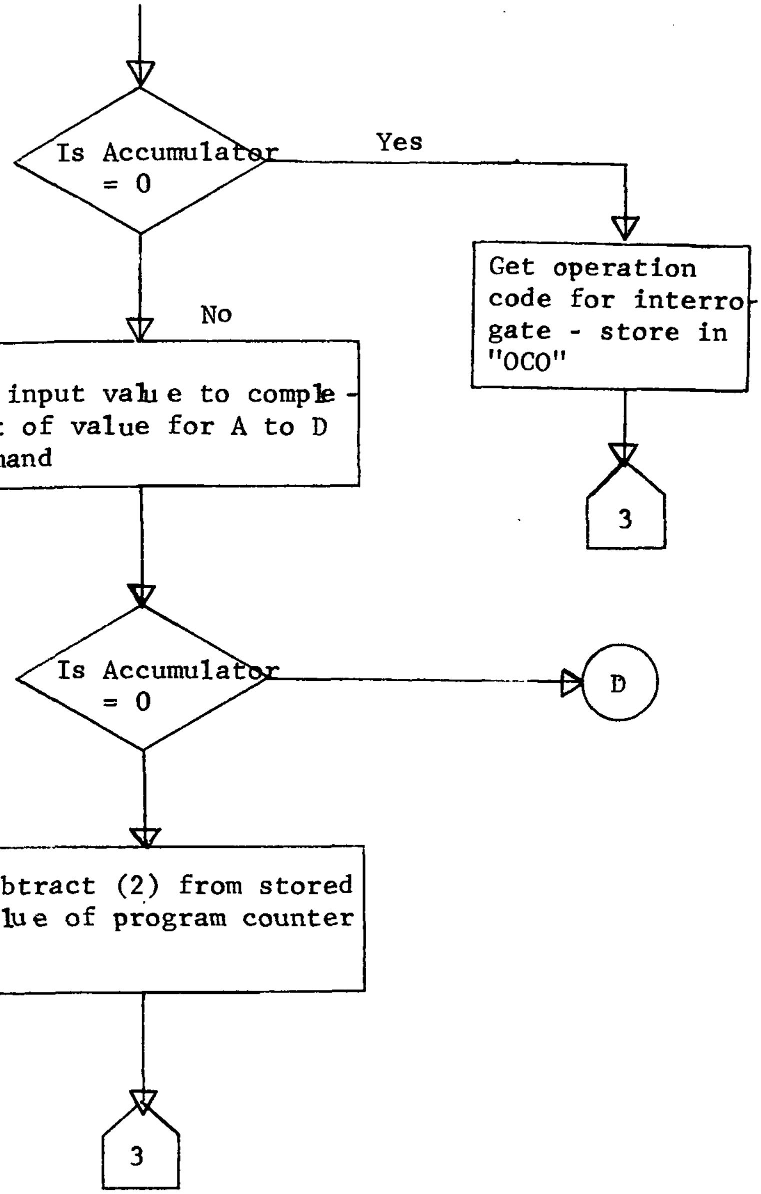

Get octual value to print "=" - Jump to TYPO subroutine
5
5
Get A to D input stored as "Y" and store in "X"
Jump to TTOUT subroutine
7
7
Increment COUNT
No
Is count = 0
Jump to CRLF subroutine
1
K
1

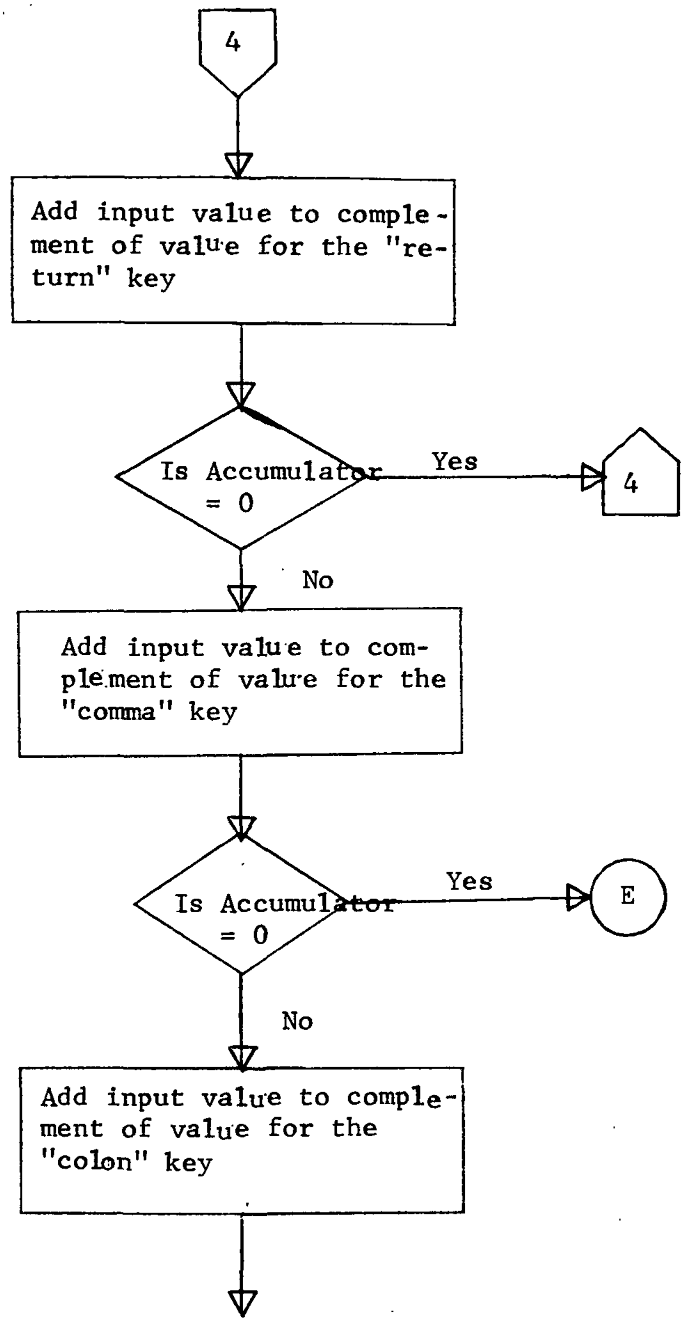

Increment Counter K1
Is K1 = 0
No
Yes
Increment Counter K2
Is K2 = 0
No
Yes
L

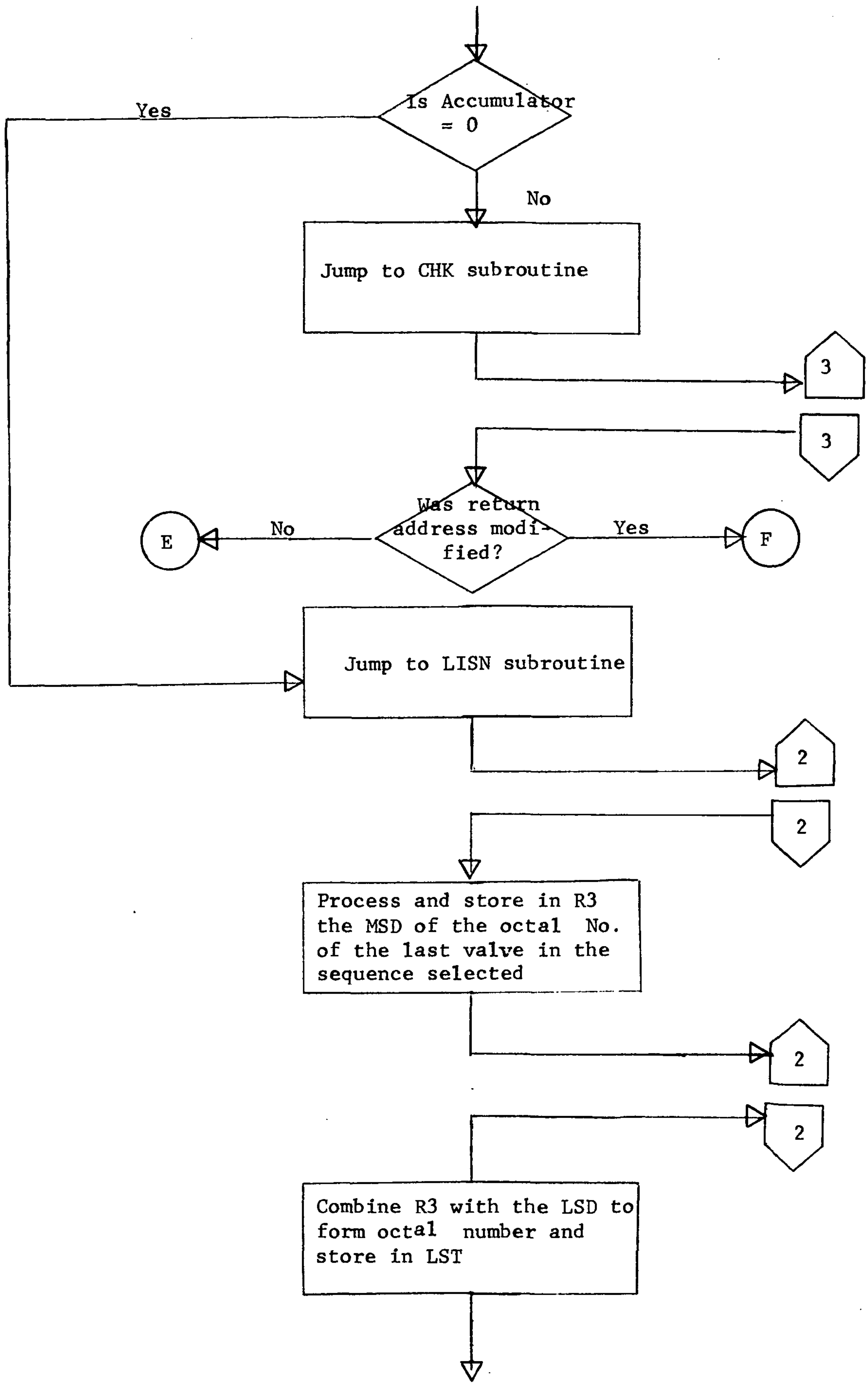

1
Get value for carriage returns (CR)
Jump to typeout sub-routine (TYPO)
5
5
Get value for line feed (LF)
Jump to TYPO subroutine
5
5
1

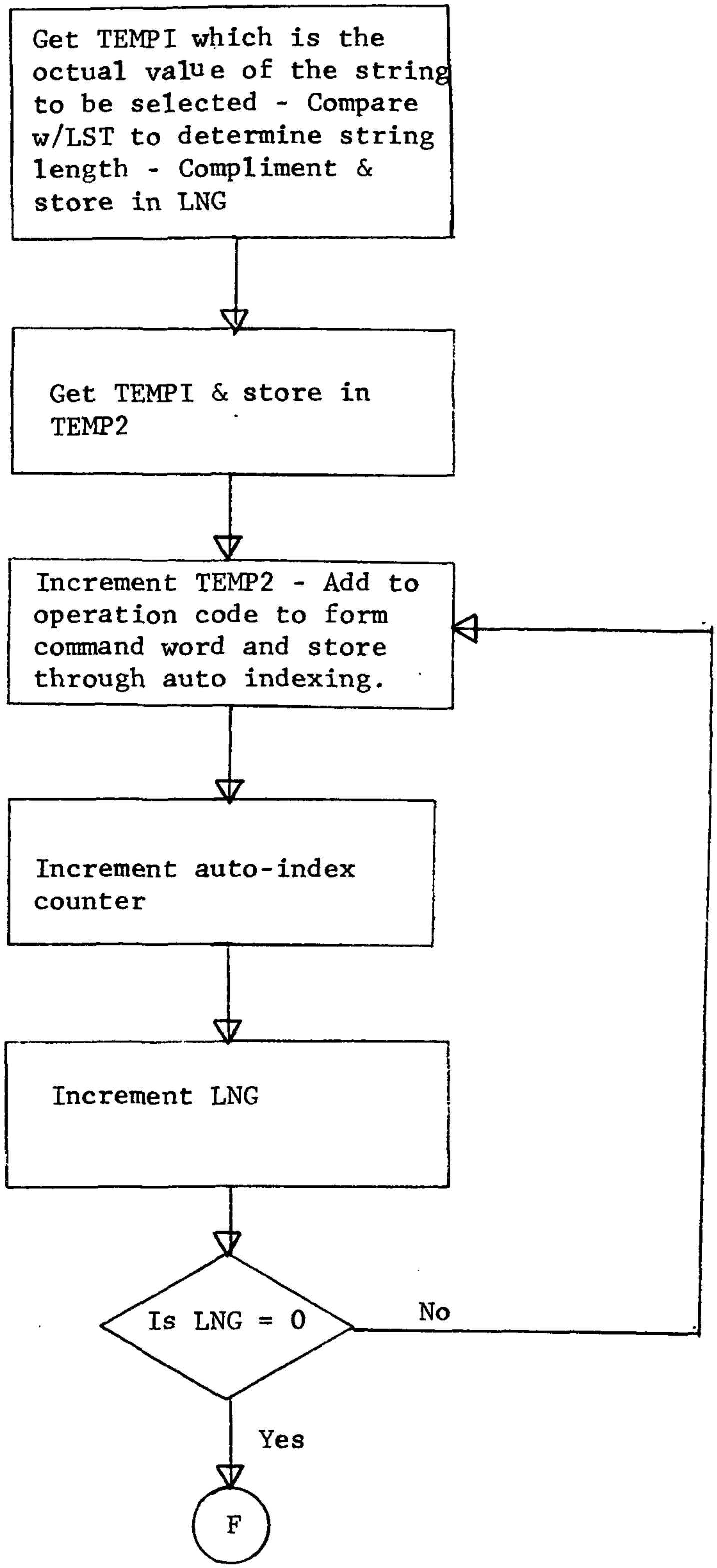

2
Is Keyboard reader flag = 1
Yes
Clear Accumulator, Read keyboard buffer - Clear keyboard flag
Print value in Keyboard reader
2

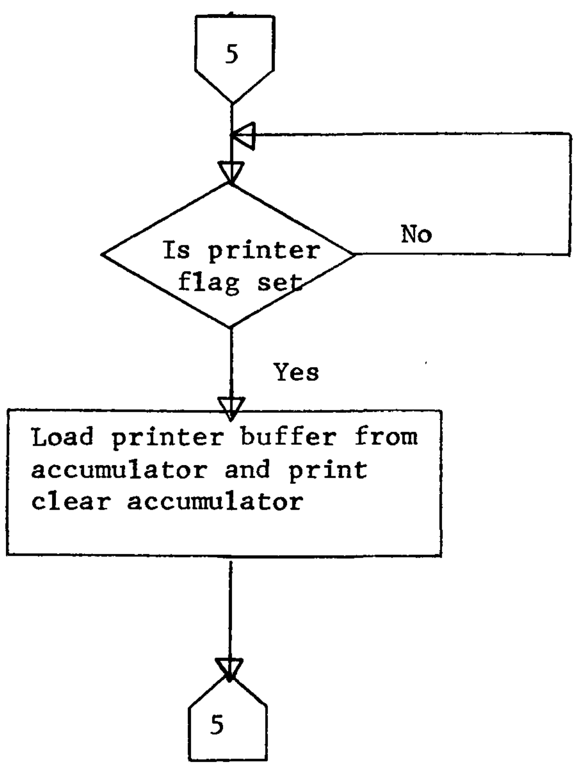

3
Add input value to complement of value for "open" command
Is Accumulator = 0
Yes
Get operation code for "open" - store in "OCO"
3
No
Add input value to complement of value for "shut" command.
Is Accumulator = 0
Yes
Get operation code for "shut" - store in "OCO"
3
No
Add input value to complement of value for "interrogate" command

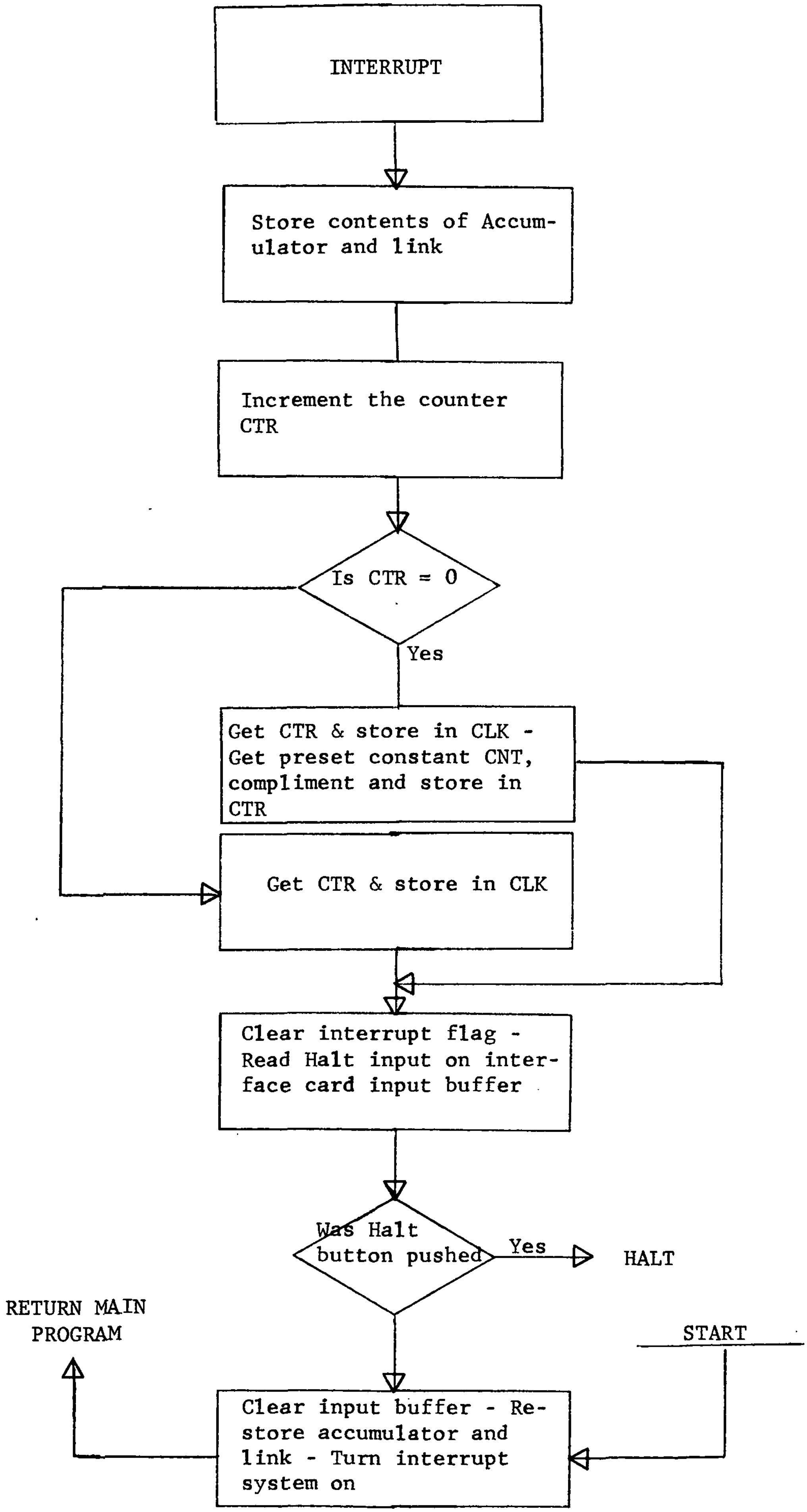

Is Accumulator = 0
Yes
Get operation code for interrogate - store in "OCO"
3
No
Add input value to complement of value for A to D command
Is Accumulator = 0
D
Subtract (2) from stored value of program counter
3


4
Add input value to complement of value for the "return" key
Is Accumulator = 0
Yes
4
No
Add input value to complement of value for the "comma" key
Is Accumulator = 0
Yes
E
No
Add input value to complement of value for the "colon" key


Is Accumulator = 0
Yes
No
Jump to CHK subroutine
3
3
Was return address modified?
No
Yes
E
F
Jump to LISN subroutine
2
2
Process and store in R3 the MSD of the octal No. of the last valve in the sequence selected
2
2
Combine R3 with the LSD to form octal number and store in LST


Get TEMPI which is the octual value of the string to be selected - Compare w/LST to determine string length - Compliment & store in LNG
Get TEMPI & store in TEMP2
Increment TEMP2 - Add to operation code to form command word and store through auto indexing.
Increment auto-index counter
Increment LNG
Is LNG = 0
No
Yes
F


5
Is printer flag set
No
Yes
Load printer buffer from accumulator and print clear accumulator
5


INTERRUPT
Store contents of Accumulator and link
Increment the counter CTR
Is CTR = 0
Yes
Get CTR & store in CLK - Get preset constant CNT, compliment and store in CTR
Get CTR & store in CLK
Clear interrupt flag - Read Halt input on interface card input buffer
Was Halt button pushed
Yes
HALT
RETURN MAIN PROGRAM
START
Clear input buffer - Restore accumulator and link - Turn interrupt system on

PROGRAM LIST

OMNI-AXIS
TEST ROUTINE

```
                              *0000
0000          0000            ZERO,          0
0001          3100                           DCA STOR1
0002          7010                           RAR
0003          3101                           DCA STOR2
0004          5405                           JMP I XSUB
0005          0400            XSUB,          SUB
                              *10
0010          0000            X10,           0000
0011          0000            X11,           0000
                              *100
0100          0000            STOR1,         0000
0101          0000            STOR2,         0000
0102          0000            CTR,           0000
0103          0000            CLK,           0000
0104          1000            CNT,           1000
0105          0600            XCHK,          CHK
0106          0216            XOPCD,         OPCD
0107          0215            CR,            0215
0110          0212            LF,            0212
0111          0000            OCO,           0000
0112          2200            RESET2,        2200
0113          0007            MASKH,         0007
0114          7770            MASKJ,         7770
0115          0000            TEMP1,         0000
                              *120
0120          0000            LISN,          0
0121          6031                           KSF
0122          5121                           JMP .-1
0123          6036                           KRB
0124          6046                           TLS
0125          5520                           JMP I LISN
0126          0000            CRLF,          0000
0127          1107                           TAD CR
0130          4134                           JMS TYPO
0131          1110                           TAD LF
0132          4134                           JMS TYPO
0133          5526                           JMP I CRLF
0134          0000            TYPO,          0000
0135          6041                           TSF
0136          5135                           JMP .-1
0137          6046                           TLS
0140          7200                           CLA
0141          5534                           JMP I TYPO
                              *200
0200          6046            START,         TLS
0201          7300            FIRST,         CLA CLL
```

```
0202    6002              IOF
0203    1104              TAD CNT
0204    7041              CIA
0205    3102              DCA CTR
0206    3331              DCA T1
0207    3103              DCA CLK
0210    3737              DCA I XT2
0211    4126              JMS CRLF
0212    1332              TAD RESET1
0213    3010              DCA X10
0214    1112              TAD RESET2
0215    3011              DCA X11
0216    4120    OPCD,     JMS LISN
0217    4505              JMS I XCHK
0220    4126              JMS CRLF
0221    4120    AGN1,     JMS LISN
0222    7100              CLL
0223    0333              AND MASK1
0224    7006              RTL
0225    7004              RAL
0226    3334              DCA R1
0227    4120              JMS LISN
0230    0333              AND MASK1
0231    1334              TAD R1
0232    7001              IAC
0233    3115              DCA TEMP1
0234    1115              TAD TEMP1
0235    7002              BSW
0236    1111              TAD OCO
0237    3410              DCA I X10
0240    2331              ISZ T1
0241    4120    LOOP,     JMS LISN
0242    4726              JMS I XCMPR
0243    4126              JMS CRLF
0244    6041              TSF
0245    5244              JMP .-1
0246    6042              TCF
0247    6001              ION
0250    7300    OUTPUT,   CLA CLL
0251    1332              TAD RESET1
0252    3010              DCA X10
0253    1331              TAD T1
0254    7041              CIA
0255    3331              DCA T1
0256    1410    GET,      TAD I X10
0257    3335              DCA CMDOUT
0260    7200    WAIT1,    CLA
0261    1103              TAD CLK
0262    7440              SZA
0263    5260              JMP .-3
0264    7240              CLA CMA
0265    6505              DBCOO
0266    7200              CLA
0267    1335    CMD,      TAD CMDOUT
```

```
0270    0113                AND MASKH
0271    3330                DCA CODE
0272    1330                TAD CODE
0273    1336                TAD C5
0274    7440                SZA
0275    7410                SKP
0276    5725                JMP I XINTO
0277    7300                CLA CLL
0300    1335                TAD CMDOUT
0301    0114                AND MASKJ
0302    6506                DBS00
0303    1330                TAD CODE
0304    6506                DBS00
0305    7240                CLA CMA
0306    6505                DBC00
0307    7200                CLA
0310    2331    ISZT,       ISZ T1
0311    5316                JMP WAIT2
0312    1737                TAD I XT2
0313    7440                SZA
0314    5727                JMP I XINTOT
0315    5200                JMP START
0316    7305    WAIT 2,     CLA CLL IAC RAL
0317    7041                CIA
0320    1104                TAD CNT
0321    1102                TAD CTR
0322    7440                SZA
0323    5316                JMP WAIT2
0324    5256                JMP GET
0325    1400    XINTO,      INTO
0326    1200    XCMPR,      CMPR
0327    1433    XINTOT,     INTOT
0330    0000    CODE,       0000
0331    0000    T1,         0000
0332    1600    RESET1,     1600
0333    0007    MASK1,      0007
0334    0000    R1,         0000
0335    0000    CMDOUT,     0000
0336    7774    C5,         7774
0337    1504    XT2,        T2
                *400
0400    2102    SUB,        ISZ CTR
0401    5210                JMP .+7
0402    1102                TAD CTR
0403    3103                DCA CLK
0404    1104                TAD CNT
0405    7041                CIA
0406    3102                DCA CTR
0407    5212                JMP OUT
0410    1102                TAD CTR
0411    3103                DCA CLK
0412    7300    OUT,        CLA CLL
```

```
0413    6142            CLCK
0414    6504            DBRIO
0415    0232            AND MASKS
0416    7440            SZA
0417    5230            JMP HALT
0420    7240    CLR,    CLA CMA
0421    6503            DBCIO
0422    7200            CLA
0423    1101            TAD STOR2
0424    7004            RAL
0425    1100            TAD STOR1
0426    6001            ION
0427    5400            JMP I ZERO
0430    7402    HALT,   HLT
0431    5220            JMP CLR
0432    0004    MASKS,  0004
                *600
0600    0000    CHK,    0
0601    3244            DCA IN
0602    1244            TAD IN
0603    1245            TAD C1
0604    7640            SZA CLA
0605    5211            JMP CHK1
0606    1246            TAD OP
0607    3111            DCA OCO
0610    5600            JMP I CHK
0611    1244    CHK1,   TAD IN
0612    1253            TAD C2
0613    7440            SZA
0614    5220            JMP CHK2
0615    1247            TAD SH
0616    3111            DCA OCO
0617    5600            JMP I CHK
0620    7200    CHK2,   CLA
0621    1244            TAD IN
0622    1250            TAD CINT
0623    7440            SZA
0624    5230            JMP CHK3
0625    1251            TAD INT
0626    3111            DCA OCO
0627    5600            JMP I CHK
0630    7200    CHK3,   CLA
0631    1244            TAD IN
0632    1252            TAD CA
0633    7440            SZA
0634    7410            SKP
0635    5643            JMP I XATD
0636    7305            CLA CLL IAC RAL
0637    7041            CIA
0640    1200            TAD CHK
0641    3200            DCA CHK
0642    5600            JMP I CHK
0643    1000    XATD,   ATD
0644    0000    IN,     0000
0645    7461    C1,     7461
0646    0001    OP,     0001
```

```
0647    0002    SH,      0002
0650    7467    CINT,    7467
0651    0004    INT,     0004
0652    7477    CA,      7477
0653    7455    C2,      7455
                *1000
1000    6046    ATD,     TLS
1001    7402             HLT
1002    7404             OSR
1003    7041             CIA
1004    3247             DCA COUNT
1005    4126             JMS CRLF
1006    1245    RETR,    TAD SK1
1007    3243             DCA K1
1010    1246             TAD SK2
1011    3244             DCA K2
1012    4126             JMS CRLF
1013    4265             JMS ADIN
1014    1250             TAD XA
1015    4134             JMS TYPO
1016    1251             TAD EQ
1017    4134             JMS TYPO
1020    4316             JMS TTOUT
1021    4126             JMS CRLF
1022    1252             TAD YA
1023    4134             JMS TYPO
1024    1251             TAD EQ
1025    4134             JMS TYPO
1026    1253             TAD Y
1027    3254             DCA X
1030    4316             JMS TTOUT
1031    2247             ISZ COUNT
1032    5235             JMP 1035
1033    4126             JMS CRLF
1034    5506             JMP I XOPCD
1035    7300             CLA CLL
1036    2243             ISZ K1
1037    5236             JMP .-1
1040    2244             ISZ K2
1041    5236             JMP .-3
1042    5206             JMP RETR
1043    0000    K1,      0000
1044    0000    K2,      0000
1045    0001    SK1,     0001
1046    7700    SK2,     7700
1047    0000    COUNT,   0000
1050    0330    XA,      0330
1051    0275    EQ,      0275
1052    0331    YA,      0331
1053    0000    Y,       0000
1054    0000    X,       0000
1055    0004    RESET,   0004
1056    0002    CONVRT,  0002
1057    4777    MASKE,   4777
1060    7000    MASKA,   7000
1061    0700    MASKB,   0700
1062    0070    MASKC,   0070
```

```
1063    0007    MASKD,   0007
1064    0260    X26,     0260
1065    0000    ADIN,    0
1066    7240             CLA CMA
1067    6515             DBC01
1070    7300             CLA CLL
1071    1255             TAD RESET
1072    6516             DBS01
1073    6515             DBC01
1074    7300             CLA CLL
1075    4302             JMS CYCLE
1076    3254             DCA X
1077    4302             JMS CYCLE
1100    3253             DCA Y
1101    5665             JMP I ADIN
1102    0000    CYCLE,   0
1103    1256             TAD CONVRT
1104    6516             DBS01
1105    6515             DBC01
1106    7240             CLA CMA
1107    6513             DBCI1
1110    6512             DBSK1
1111    5310             JMP .-1
1112    6514             DBRI1
1113    7500             SMA
1114    0257             AND MASKE
1115    5702             JMP I CYCLE
1116    0000    TTOUT,   0
1117    7100             CLL
1120    1254             TAD X
1121    0260             AND MASKA
1122    7002             BSW
1123    7012             RTR
1124    7010             RAR
1125    1264             TAD X26
1126    4134             JMS TYPO
1127    1254             TAD X
1130    0261             AND MASKB
1131    7002             BSW
1132    1264             TAD X26
1133    4134             JMS TYPO
1134    1254             TAD X
1135    0262             AND MASK C
1136    7012             RTR
1137    7010             RAR
1140    1264             TAD X26
1141    4134             JMS TYPO
1142    1254             TAD X
1143    0263             AND MASKD
1144    1264             TAD X26
1145    4134             JMS TYPO
1146    5716             JMP I TTOUT
```

```
                                *1200
1200    0000                    CMPR,       0000
1201    3270                                DCA R2
1202    1270                                TAD R2
1203    1264                                TAD CRET
1204    7440                                SZA
1205    7410                                SKP
1206    5600                                JMP I CMPR
1207    7300                                CLA CLL
1210    1270                                TAD R2
1211    1265                                TAD CMMA
1212    7440                                SZA
1213    7410                                SKP
1214    5672                                JMP I XAGN1
1215    7300                                CLA CLL
1216    1270                                TAD R2
1217    1274                                TAD COLN
1220    7640                                SZA CLA
1221    5301                                TMP 1301
1222    5226                                JMP STRNG
1223    5671                                JMP I XLOOP
1224    4505                                JMS I XCHK
1225    5672                                JMP I XAGN1
1226    4120                    STRNG,      JMS LISN
1227    7100                                CLL
1230    0266                                AND MASK10
1231    7006                                RTL
1232    7004                                RAL
1233    3263                                DCA R3
1234    4120                                JMS LISN
1235    0266                                AND MASK10
1236    1263                                TAD R3
1237    7001                                IAC
1240    3261                                DCA LST
1241    1115                                TAD TEMP1
1242    7041                                CIA
1243    1261                                TAD LST
1244    7041                                CIA
1245    3262                                DCA LNG
1246    1115                                TAD TEMP1
1247    3267                                DCA TEMP2
1250    1267                    INCR,       TAD TEMP2
1251    5275                                JMP 1275
1252    7002                                BSW
1253    1111                                TAD OCO
1254    3410                                DCA I X10
1255    2673                                ISZ I ZT1
1256    2262                                ISZ LNG
1257    5250                                JMP INCR
1260    5671                                JMP I XLOOP
1261    0000                    LST,        0000
1262    0000                    LNG,        0000
1263    0000                    R3,         0000
1264    7563                    CRET,       7563
1265    7524                    CMMA,       7524
1266    0007                    MASK10,     0007
```

```
1267    0000    TEMP2,    0000
1270    0000    R2,       0000
1271    0241    XLOOP,    LOOP
1272    0221    XAGN1,    AGN1
1273    0331    ZT1,      T1
1274    7506    COLN,     7506
1275    7001              IAC
1276    3267              DCA TEMP2
1277    1267              TAD TEMP2
1300    5252              JMP 1252
1301    1270              TAD R2
1302    5224              JMP 1224
                *1400
1400    1706    INTO,     TAD I XCMDOT
1401    0114              AND MASKJ
1402    6506              DBSOO
1403    7240              CLA CMA
1404    6503              DBCIO
1405    7200              CLA
1406    1706              TAD I XCMDOT
1407    6506              DBSOO
1410    6504              DBRIO
1411    0276              AND MASK2
1412    7440              SZA
1413    5217              JMP .+4
1414    1303              TAD X317
1415    3411              DCA I X11
1416    5222              JMP .+4
1417    7200              CLA
1420    1302              TAD X323
1421    3411              DCA I X11
1422    2304              ISZ T2
1423    1706              TAD I XCMDOT
1424    3411              DCA I X11
1425    2304              ISZ T2
1426    7240              CLA CMA
1427    6505              DBCOO
1430    7200              CLA
1431    2705              ISZ I XT1
1432    5674              JMP I XGET
1433    1112    INTOT,    TAD RESET2
1434    3011              DCA X11
1435    1304              TAD T2
1436    7041              CIA
1437    3304              DCA T2
1440    6002              IOF
1441    6046              TLS
1442    4126    MORE,     JMS CRLF
1443    1411              TAD I X11
1444    3277              DCA HOLD
1445    2304              ISZ T2
1446    7000              NOP
```

```
1447    1411                  TAD I X11
1450    5312                  JMP 1512
1451    3310                  DCA TEMP
1452    1310                  TAD TEMP
1453    7010                  RAR
1454    7012                  RTR
1455    0311                  AND MASKF
1456    1307                  TAD OT26
1457    4134                  JMS TYPO
1460    1310                  TAD TEMP
1461    0311                  AND MASKF
1462    1307                  TAD OT26
1463    4134                  JMS TYPO
1464    1701                  TAD I XEQ
1465    4134                  JMS TYPO
1466    1277                  TAD HOLD
1467    4134                  JMS TYPO
1470    2304                  ISZ T2
1471    5242                  JMP MORE
1472    5673                  JMP I XFIRST
1473    0201    X FIRST,      FIRST
1474    0256                  X GET
1475    0400    C6,           0400
1476    7776    MASK2,        7776
1477    0000    HOLD,         0000
1500    0310    XISZT,        ISZT
1501    1051    XEQ,          EQ
1502    0323    X323,         0323
1503    0317    X317,         0317
1504    0000    T2,           0000
1505    0331    XT1,          T1
1506    0335    XCMDOT,       XMDOUT
1507    0260    OT26,         0260
1510    0000    TEMP,         0000
1511    0007    MASKF,        0007
1512    7002                  BSW
1513    1315                  TAD ONE
1514    5251                  JMP 1451
1515    7777                  MONE

ADIN    1065
AGN1    0221
ATD     1000
CA      0652
CAL     1577
CHK     0600
CHK1    0611
CHK2    0620
CHK3    0630
CINT    0650
CLK     0103
CLR     0420
CMD     0267
CMDOUT  0335
CMMA    1265
CMPR    1200
CNT     0104
```

CODE	0330
COLN	1274
CONVRT	1056
COUNT	1047
CR	0107
CRET	1264
CRLF	0126
CTR	0102
CYCLE	1102
C1	0645
C2	0653
C5	0336
C6	1475
EQ	1051
FIRST	0201
GET	0256
HALT	0430
HOLD	1477
IN	0644
INCR	1250
INT	0651
INTO	1400
INTOT	1433
ISZT	0310
K1	1043
K2	1044
LF	0110
LISN	0120
LNG	1262
LOOP	0241
LST	1261
MASKA	1060
MASKB	1061
MASKC	1062
MASKD	1063
MASKE	1057
MASKF	1511
MASKH	0113
MASKJ	0114
MASKS	0432
MASK1	0333
MASK10	1266
MASK2	1476
MORE	1442
OCO	0111
OP	0646
OPCD	0216
OT26	1507
OUT	0412
OUTPUT	0250
RESET	1055

RESET1	0332
RESET2	0112
RETR	1006
R1	0334
R2	1270
R3	1263
SH	0647
SK1	1045
SK2	1046
START	0200
STOR1	0100
STOR2	0101
STRNG	1226
SUB	0400
TEMP	1510
TEMP1	0115
TEMP2	1267
TTOUT	1116
TYPO	0134
T1	0331
T2	1504
WAIT1	0260
WAIT2	0316
X	1054
XA	1050
XAGN1	1272
XATD	0643
XCHK	0105
XCMDOT	1506
XCMPR	0326
XEQ	1501
XFIRST	1473
XGET	1474
XINTO	0325
XINTOT	0327
XISZT	1500
XLOOP	1271
XOPCD	0106
XSUB	0005
XT1	1505
XT2	0337
X10	0010
X11	0011
X26	1064
X317	1503
X323	1502
Y	1053
YA	1052
ZERO	0000
ZT1	1273

SECTION FIVE

V. HARDWARE DESCRIPTION

Figure 1-1 of this report shows all of the hardware developed for the program. The nozzle assembly which contains 30 solenoid valves and 30 pressure switches as shown in figure 5-1. This assembly is connected to the interface panel by a cable. The interface panel is shown in figures 5-2 and 5-3. Connection between the interface panel and the PDP-8 process controller is accomplished through normal I/O cabling of the PDP-8.

A. Axis Nozzle

The Nozzle Assembly (drawings 5049-001 through -005) consists of a torus-formed plenum supplied from a compressed air source and connected to 30 injector ports through 30 Skinner solenoid valves. In the pressure chamber between the valve and its injection port, an automobile brakeline pressure switch was installed to sense whether each valve was open or closed. The drawings used to fabricate this nozzle assembly follow.

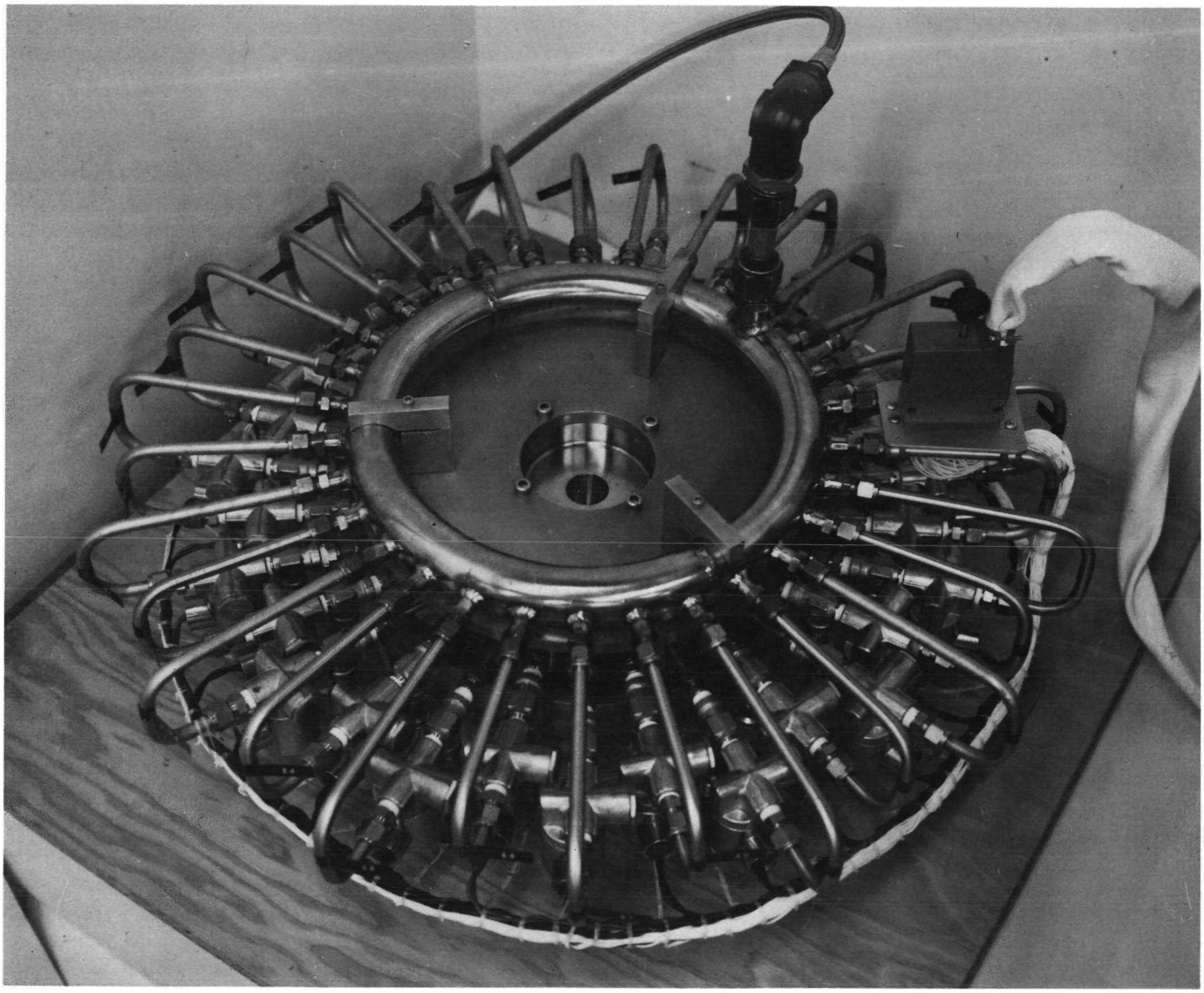
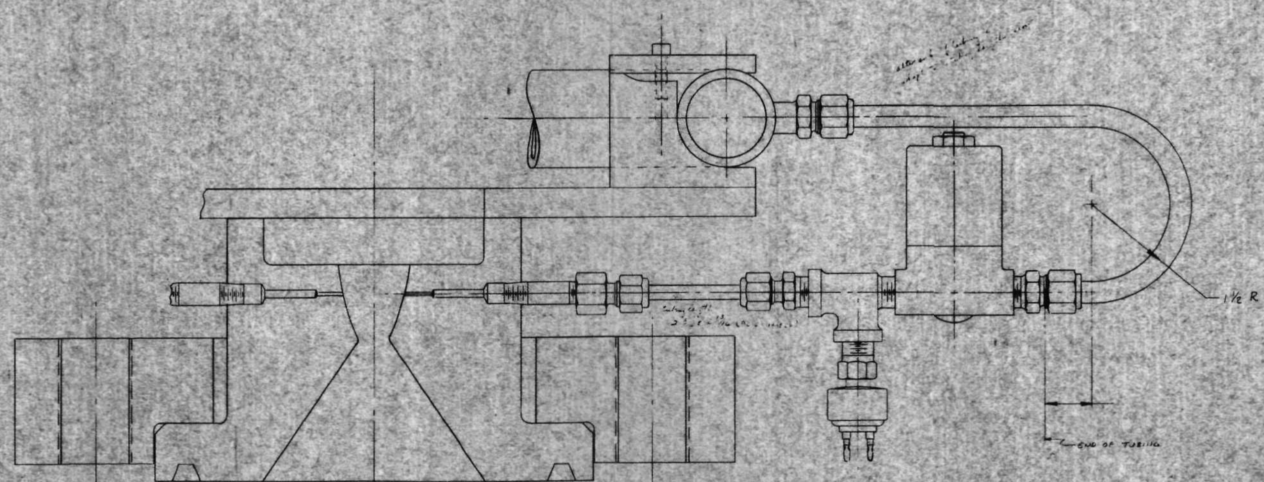


FIGURE 5-1
NOZZLE ASSEMBLY



REVISIONS

ZONE	LTR.	DESCRIPTION	DATE	APPROVED

QUANTITY REQUIRED	ZONE	ITEM	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

CONTRACT NO
PROJ ENGR
MECH
ELEC
MFG PROC ENGR
STRUCT
GROUP APP
CHECKED BY
DRAWN BY 9-26-72
APPROVED DATE
APPROVED BY (OTHERS) DATE

NEXT ASSEMBLY | USED ON | QTY PER NEXT ASSY | MATERIAL

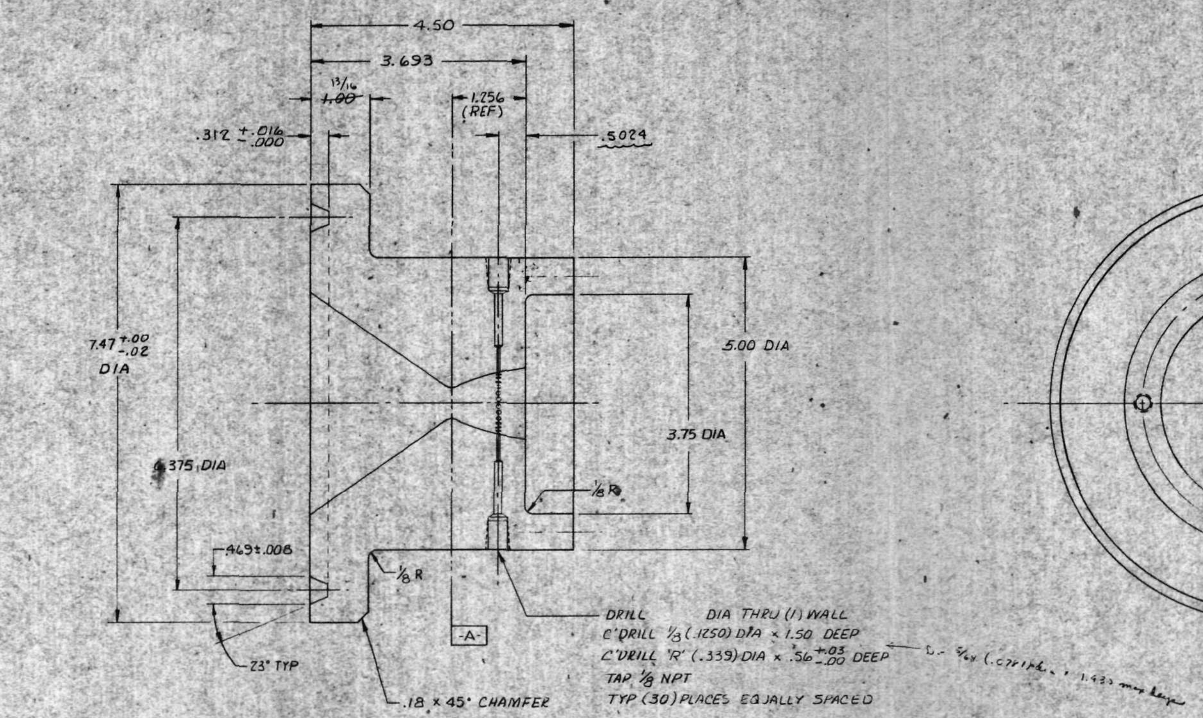
ELECTROSYSTEMS | MONTEK

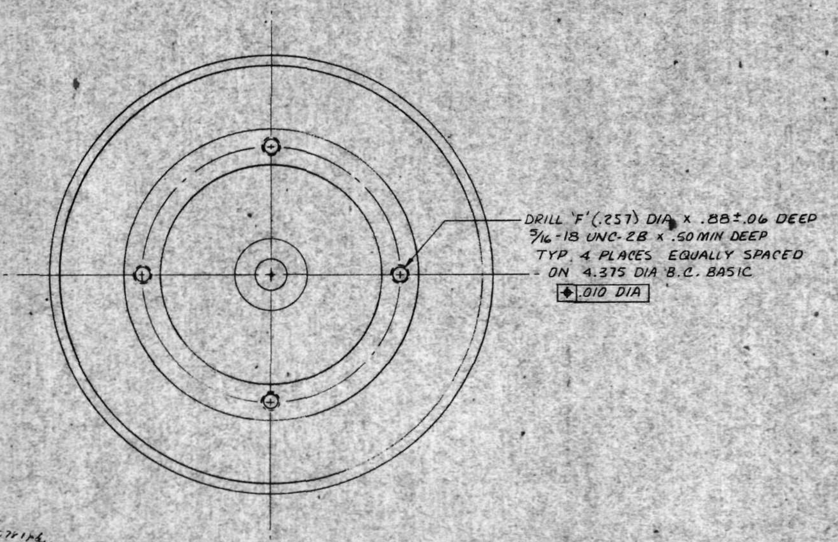
OMNI-AXIS TVC
COLD GAS - SUB SCALE
TEST FIXTURE

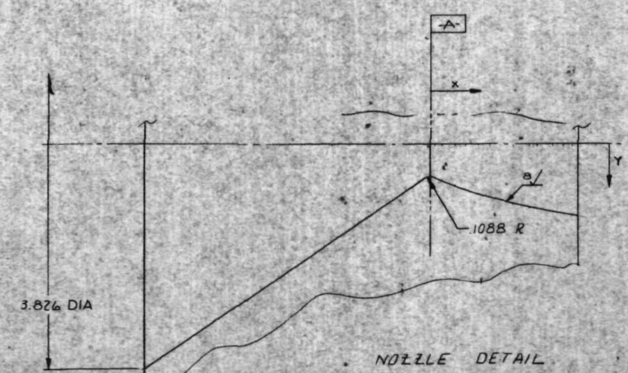
SIZE E | CODE IDENT NO. 19156 | 5019-0001 | REV
SCALE: | SHEET

FOLDOUT FRAME 1

FOLDOUT FRAME 2







NOZZLE DETAIL

X	Y
0.0000	.2120
0.0350	.2178
0.0663	.2886
0.1009	.3011
0.1360	.3144
0.1724	.3281
0.2110	.3428
0.2531	.3589
0.2997	.3761
0.3525	.3954
0.4131	.4164
0.4840	.4401
0.5680	.4662
0.6696	.4950
0.9092	.5524
1.1331	.5939
1.2560	.6120

QUANTITY REQUIRED	ZONE	ITEM	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE

LIST OF MATERIAL OR PARTS LIST

NEXT ASSEMBLY | USED ON | QTY PER MAJOR ASSY | MATERIAL

UNLESS OTHERWISE SPECIFIED

CONTRACT NO
PROJ ENGR
MECH
ELEC
STRUCT
GROUP APP
CHECKED BY
DRAWN BY Williams 9-26-72
APPROVED DATE
APPROVED BY (OTHERS) DATE

ELECTROSYSTEMS INC. | MONTEK

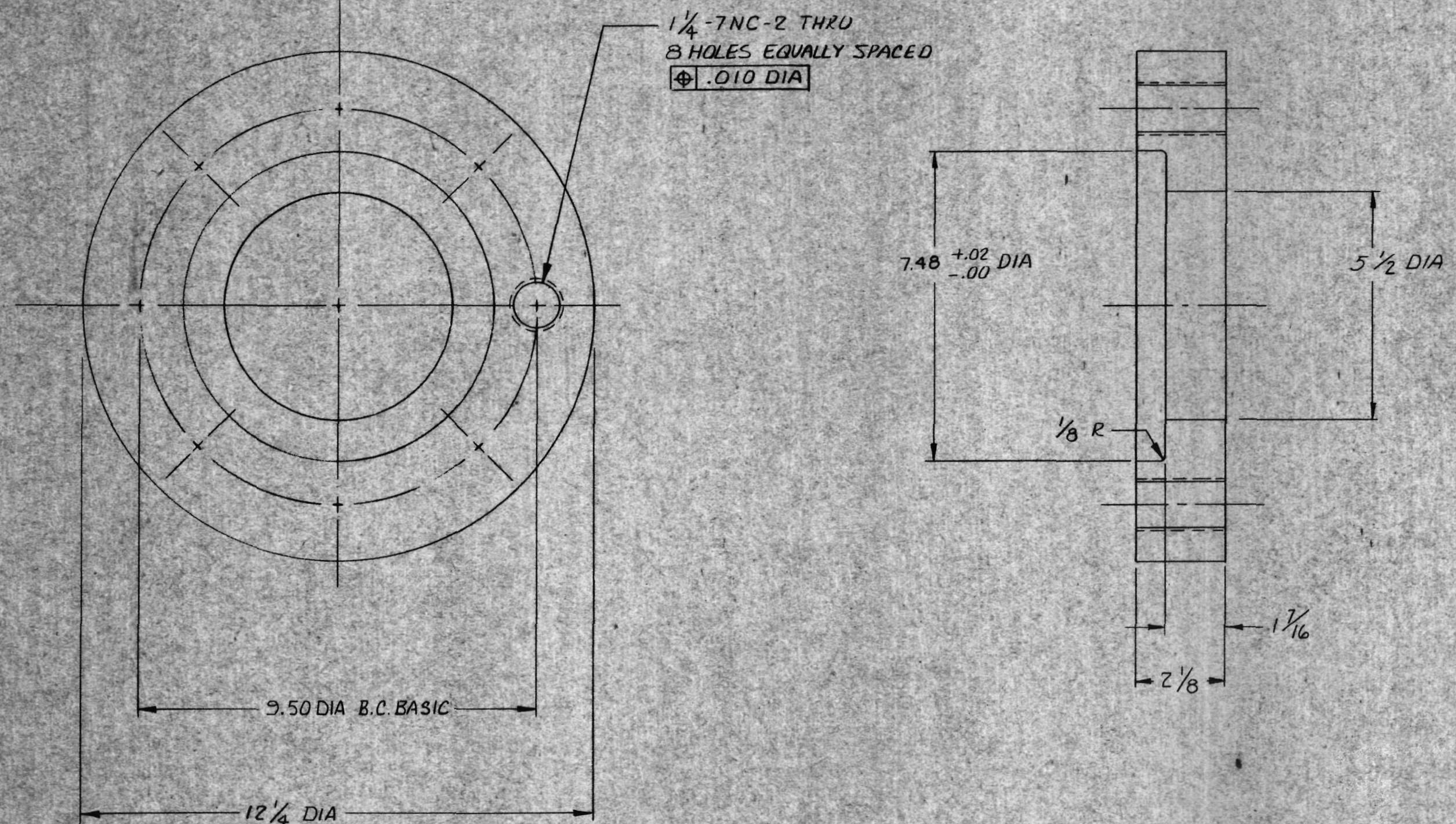
NOZZLE

SIZE E | CODE IDENT NO. 19156 | 5049-002 | REV

SCALE: | SHEET

FOLDOUT FRAME 1

FOLDOUT FRAME 2



REVISIONS

ZONE	LTR.	DESCRIPTION	DATE	APPROVED

QUANTITY REQUIRED	ZONE	ITEM	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE
		2					
		1					

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

TOLERANCES ON:
2 PLACE DEC ±.02 — 3 PLACE DEC ±.010 — FRACTIONAL ±1/32
ANGLES: MACHINED ±0°15' — FORMED ±1° — SHEARED ±0°30'
HOLE TOLERANCE PER AND 10387
SURFACE ROUGHNESS PER MIL-STD-10
MACHINED SURFACE FINISH 125 ✓
DIMENSIONING AND TOLERANCING PER USASI Y14.5
ECCENTRICITY BETWEEN ANY DIA(S) ON THE SAME CENTERLINE SHALL NOT EXCEED .010 TOTAL INDICATOR READING. ALL DIM. ARE IN INCHES & INCLUDE APPLIED FINISH
WELD SYMBOLS PER AWS A2.0-68, RIVET CODE PER NAS 523, THREADS PER MIL-S-8879, MARK PER MIL-STD-130.
REMOVE ALL BURRS AND SHARP EDGES.

CONTRACT NO	
PROJ ENGR	
MECH	
ELEC	
MAT'L / PROC ENGR	
STRUCT	
GROUP APP	
CHECKED BY	
DRAWN BY	Williams 9-26-72
APPROVED	DATE
APPROVED BY (OTHERS)	DATE

NEXT ASSEMBLY | USED ON | QTY PER MAJOR ASSY | MATERIAL

LTV ELECTROSYSTEMS INC | MONTEK

FLANGE

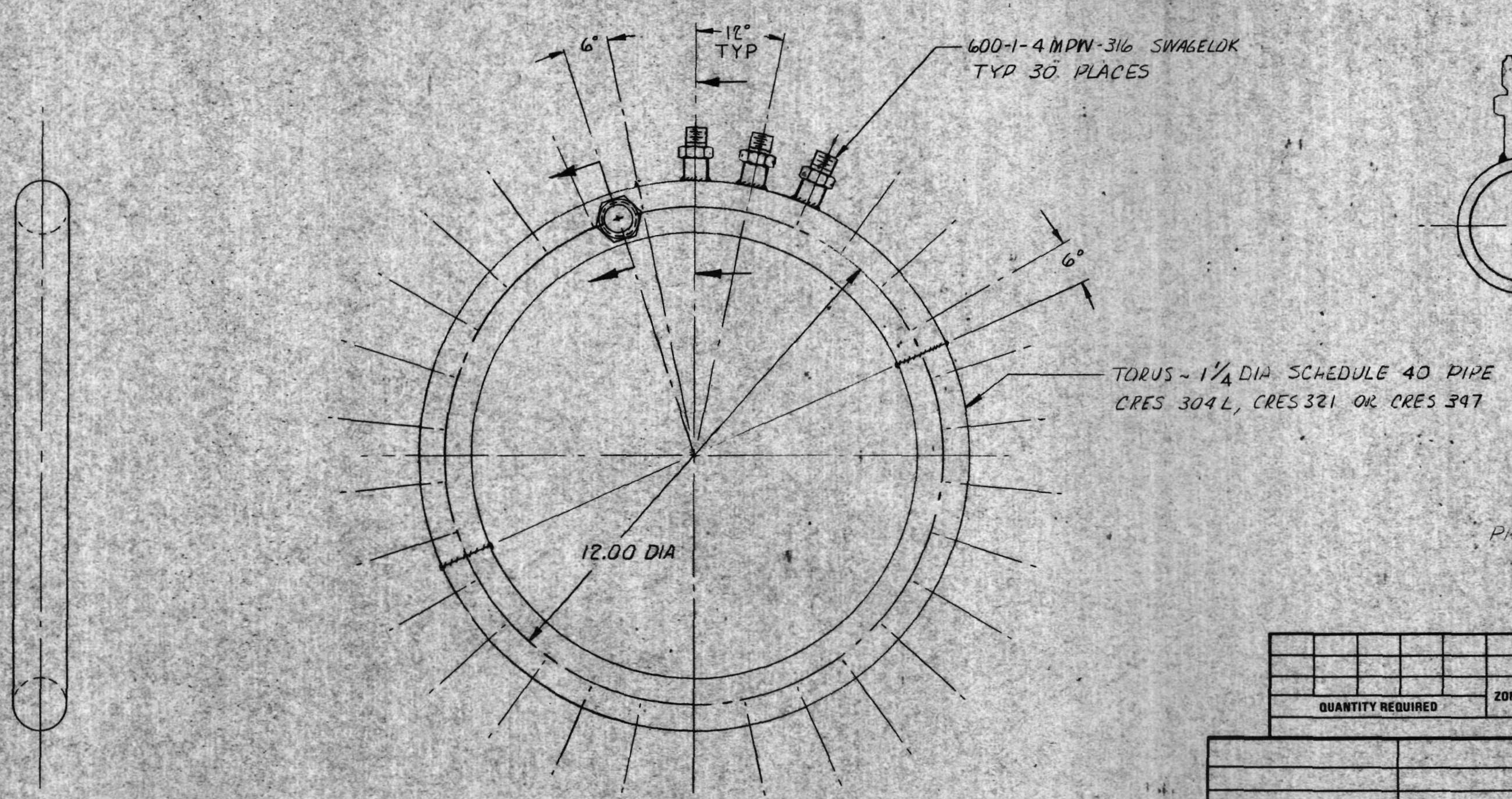
SIZE	CODE IDENT NO.		REV
D	19156	5049-003	

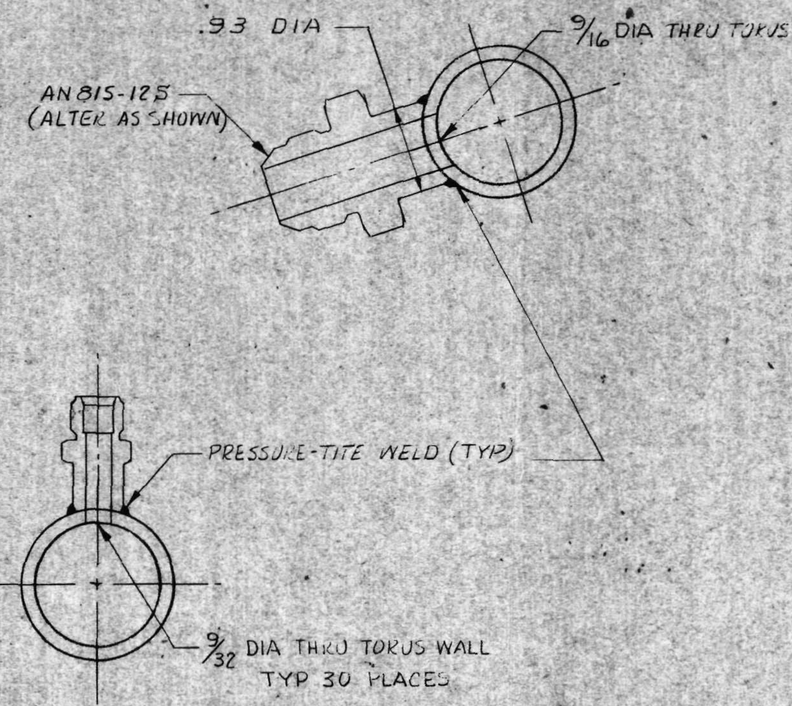
SCALE: | SHEET

DWG. NO.

FOLDOUT FRAME 1

FOLDOUT FRAME 2





PRESSURE TEST TO 2000 PSI

REVISIONS				
ZONE	LTR.	DESCRIPTION	DATE	APPROVED

QUANTITY REQUIRED	ZONE	ITEM	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE
		2					
		1					

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

TOLERANCES ON:
2 PLACE DEC ±.02; 3 PLACE DEC ±.010; FRACTIONAL ±1/32
ANGLES: MACHINED ±0°15'; FORMED ±1°; SHEARED ±0°30'
HOLE TOLERANCE PER AND 10387
SURFACE ROUGHNESS PER MIL-STD-10
MACHINED SURFACE FINISH 125 ✓
DIMENSIONING AND TOLERANCING PER USASI Y14.5
ECCENTRICITY BETWEEN ANY DIA(S) ON THE SAME CENTERLINE SHALL NOT EXCEED .010 TOTAL INDICATOR READING. ALL DIM. ARE IN INCHES & INCLUDE APPLIED FINISH

WELD SYMBOLS PER AWS A2.0-68, RIVET CODE PER NAS 523, THREADS PER MIL-S-8879, MARK PER MIL-STD-130. REMOVE ALL BURRS AND SHARP EDGES.

CONTRACT NO	
PROJ ENGR	
MECH	
ELEC	
MAT'L/PROC ENGR	
STRUCT	
GROUP APP	
CHECKED BY	
DRAWN BY	Williams 9-26-72
APPROVED	DATE
APPROVED BY (OTHERS)	DATE

NEXT ASSEMBLY | USED ON | QTY PER MAJOR ASSY | MATERIAL

ELECTROSYSTEMS | MONTEK

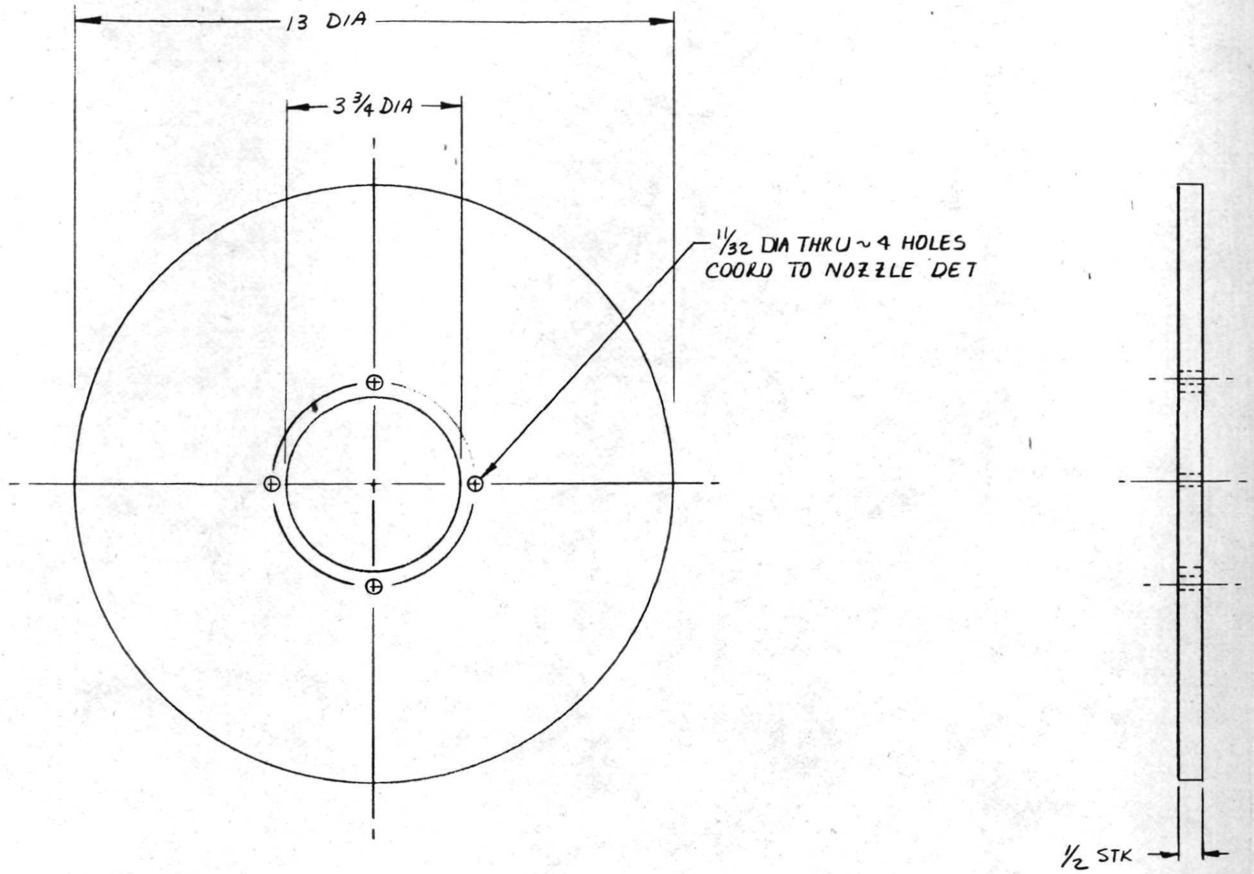
MANIFOLD
OMNI-AXIS TVC
SUB SCALE COLD GAS TEST FIXTURE

SIZE: D | CODE IDENT NO. 19156 | 5049-004 | REV

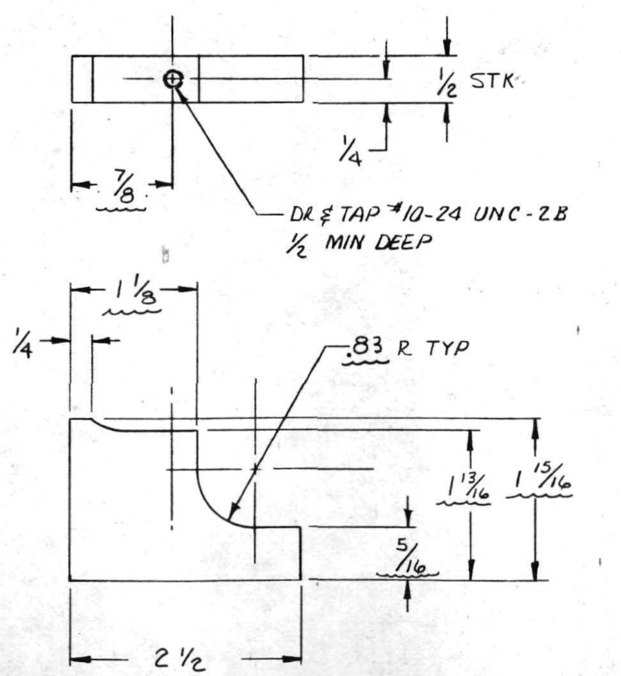
SCALE: | SHEET

FOLDOUT FRAME 1

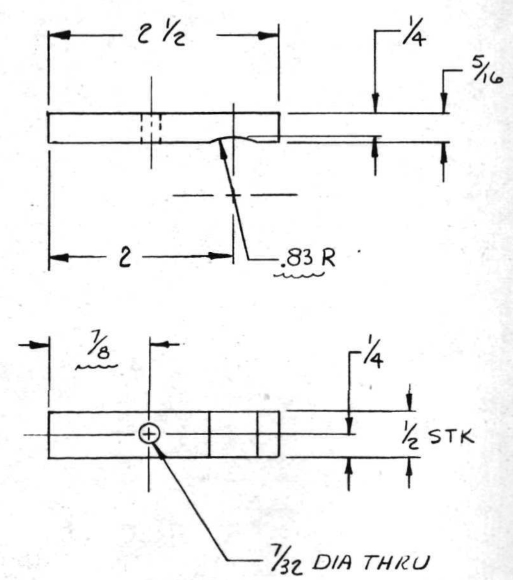
FOLDOUT FRAME 2



TORUS SUPPORT PLATE DETAIL
1/2 SCALE



TORUS SUPPORT BLOCK DETAIL
4 REQD PER N/A



TORUS CLAMP DETAIL
4 REQD PER N/A

REVISIONS				
ZONE	LTR.	DESCRIPTION	DATE	APPROVED

QUANTITY REQUIRED	ZONE	ITEM	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE
		2					
		1					

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

CONTRACT NO / PROJ ENGR / MECH / ELEC / MAT'L PROC ENGR / STRUCT / GROUP APP / CHECKED BY / DRAWN BY WILLIAMS 9-26-72 / APPROVED DATE / APPROVED BY (OTHERS) DATE

NEXT ASSEMBLY | USED ON | QTY PER MAJOR ASSY | MATERIAL

ELECTROSYSTEMS | MONTEK

TORUS SUPPORT DETAILS

SIZE D | CODE IDENT NO. 19156 | 5049-005 | REV

SCALE: | SHEET

FOLDOUT FRAME 1 FOLDOUT FRAME 2

B. Interface Panel

The Interface Panel as shown in figures 5-2 and 5-3 provides the operator with an indication of the command status and actual status of each injection port. The innercircle of lights on the front of this panel represent the command and the outer circle represents the true status of each port. The front panel also provides a means of energizing the system and power supply test points. At the upper right of the panel are two (2) lights indicating the standby or run status of the PDP-8 and control switches to reset or halt a sequence.

The panel contains interface circuitry to decode the serial outputs of the PDP-8 and re-encode these command signals as commands to each valve. It further contains an analog to digital converter and a free running 1KHZ clock. The schematic diagrams used to assemble the breadboard ciruit cards and the panel assembly follow.

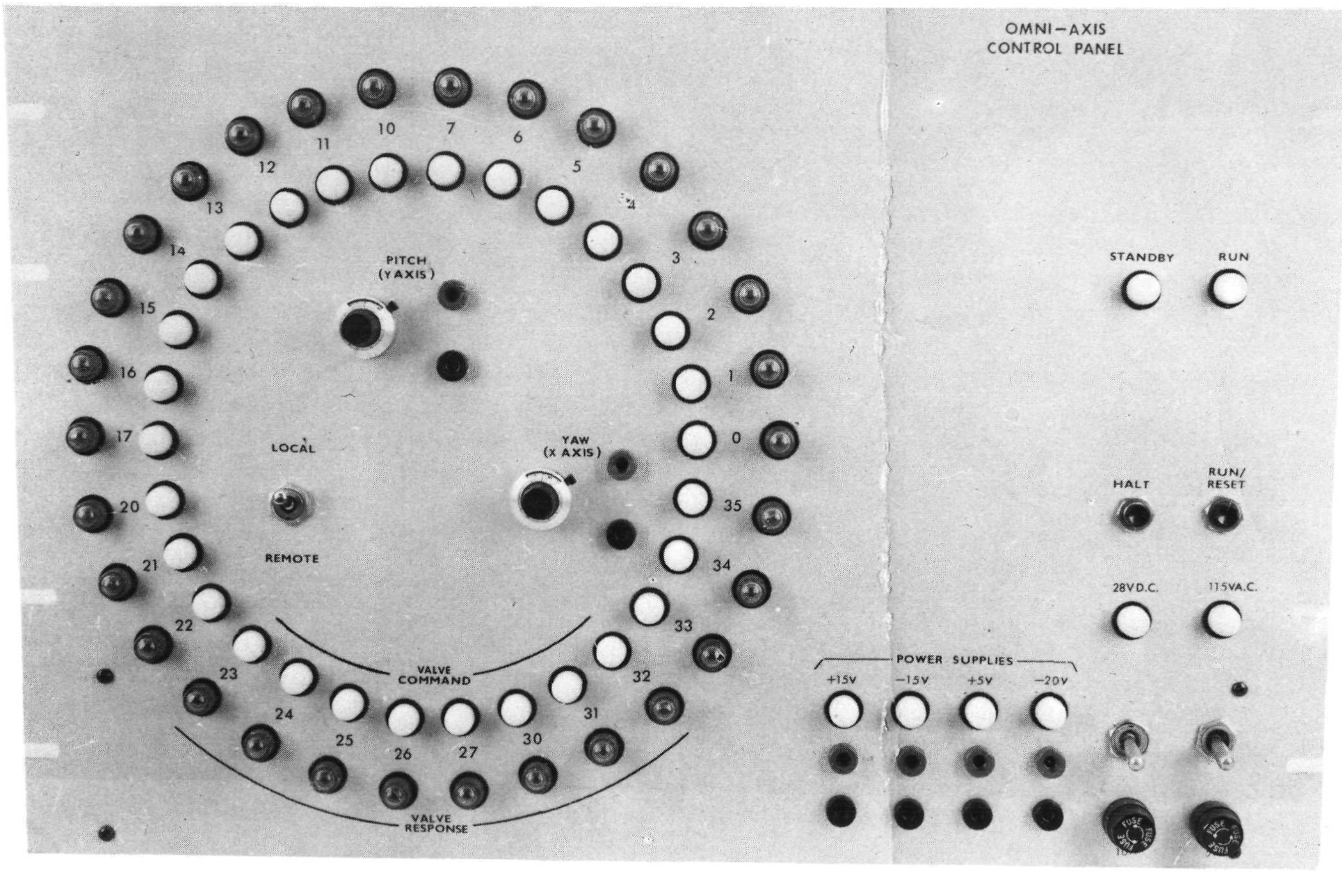


FIGURE 5-2
INTERFACE PANEL (FRONT VIEW)

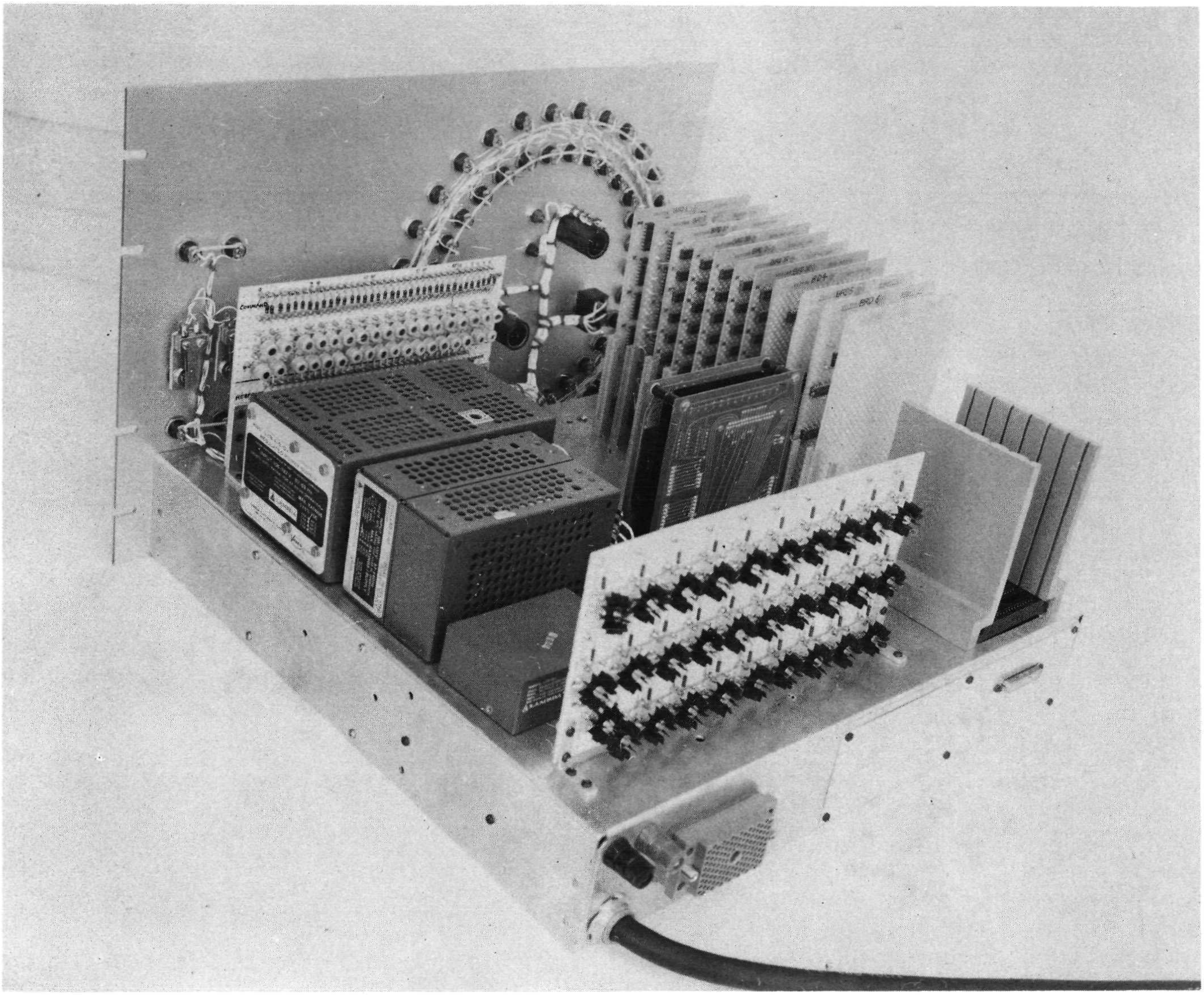
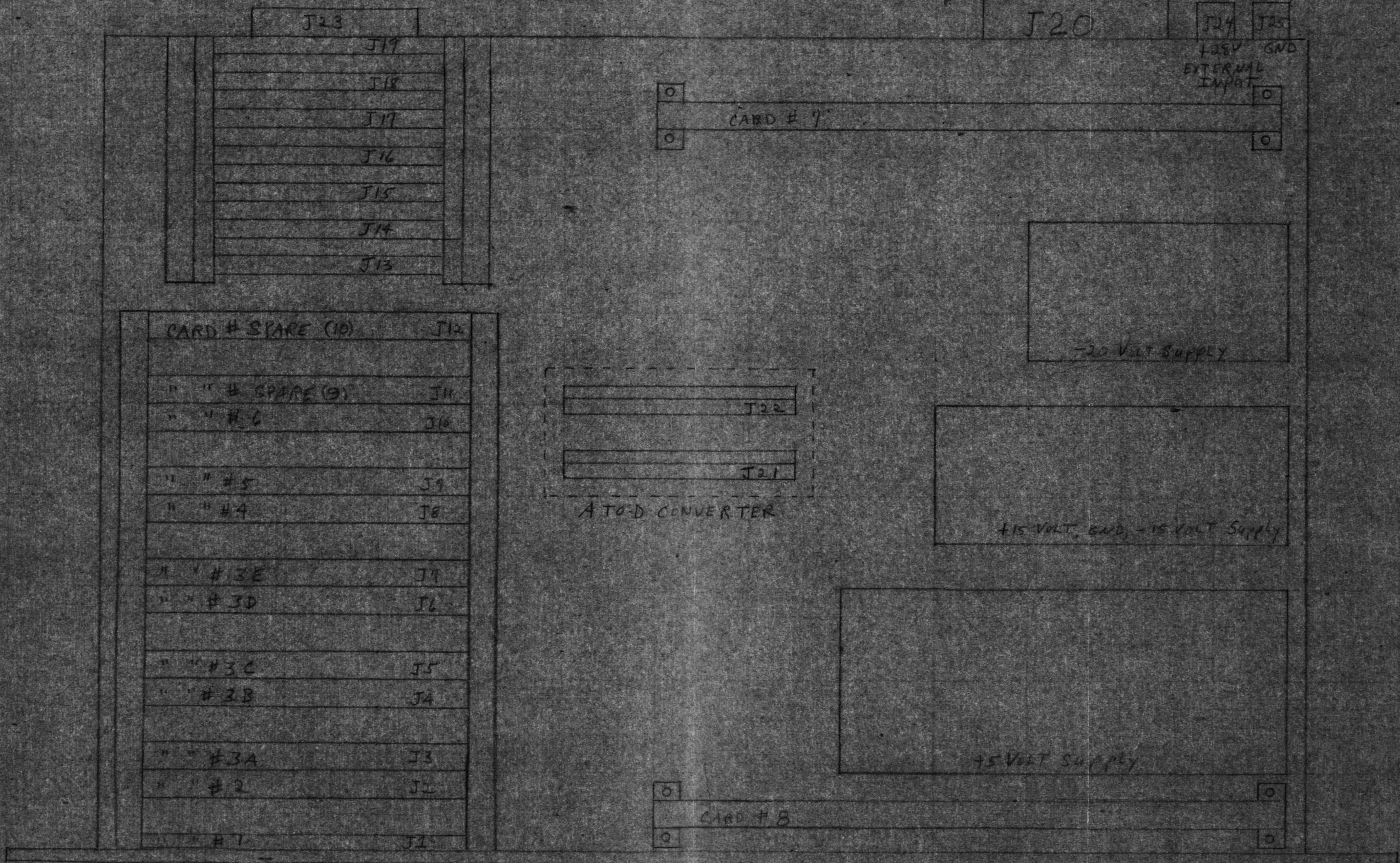


FIGURE 5-3
INTERFACE PANEL (REAR VIEW)

FOLDOUT FRAME 1

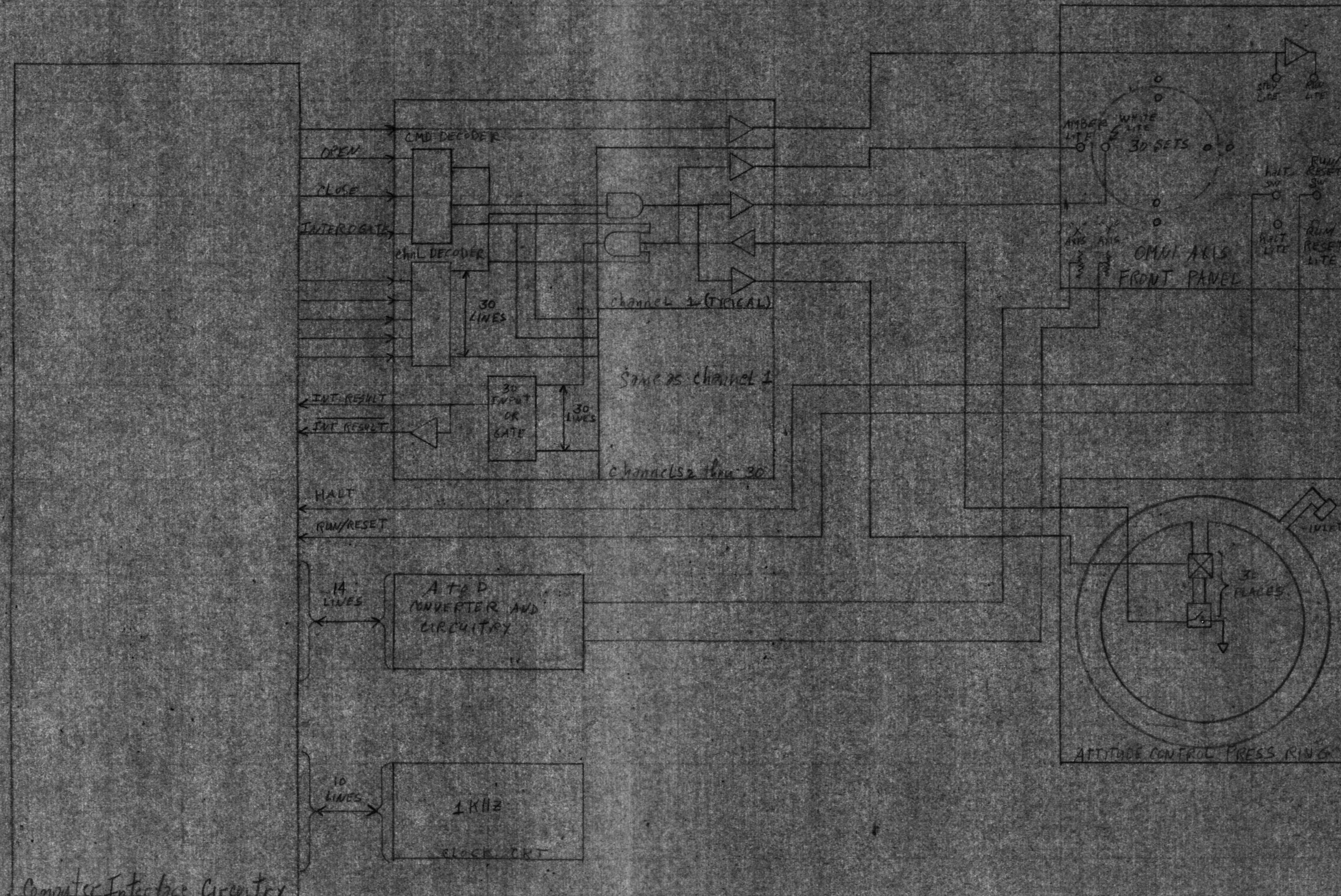
FOLDOUT FRAME 2



OMNI CHASSIS LOCATOR DIAGRAM

FOLDOUT FRAME 1

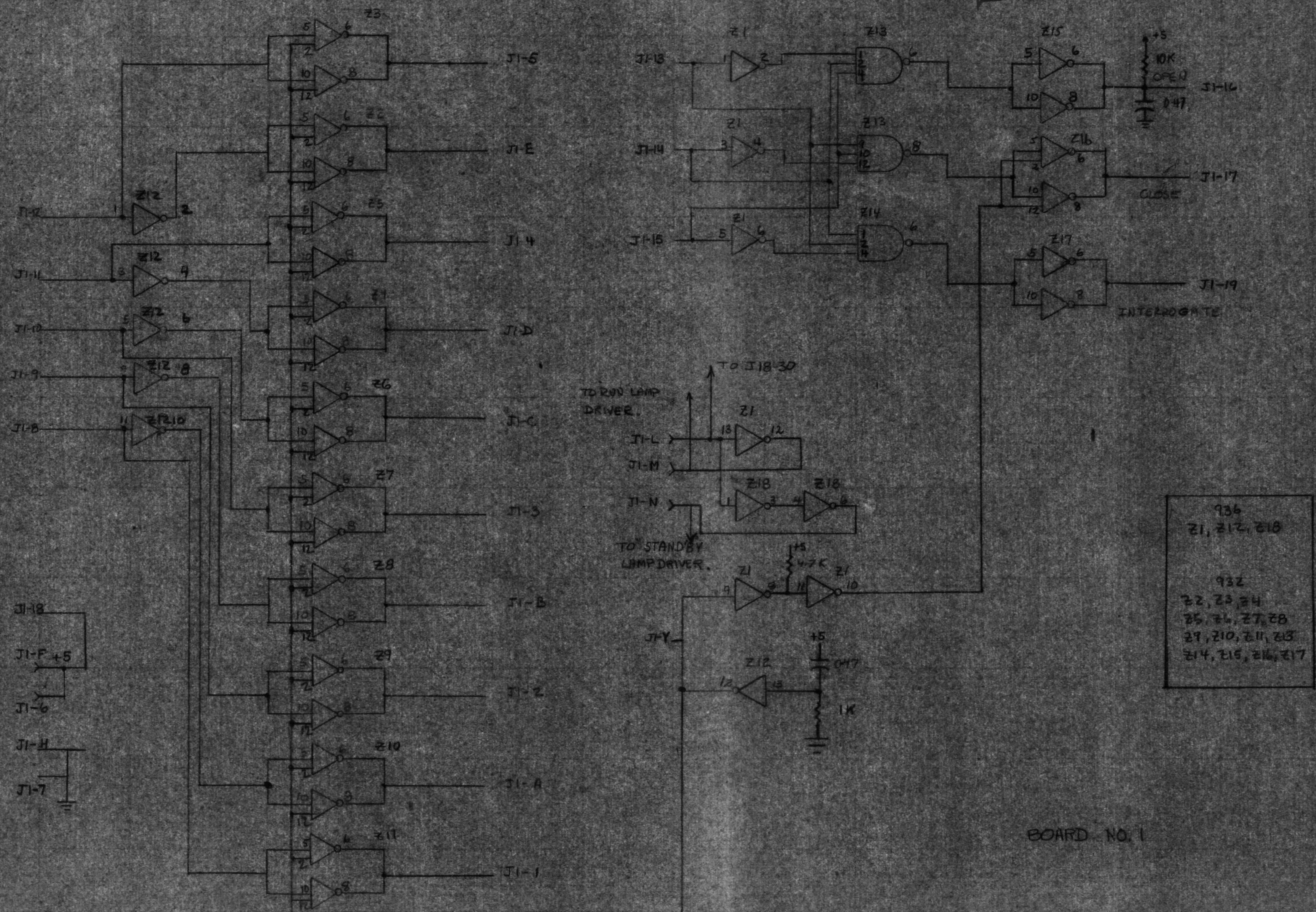
FOLDOUT FRAME 2



OMNI AXIS BLOCK DIAGRAM

FOLDOUT FRAME 1

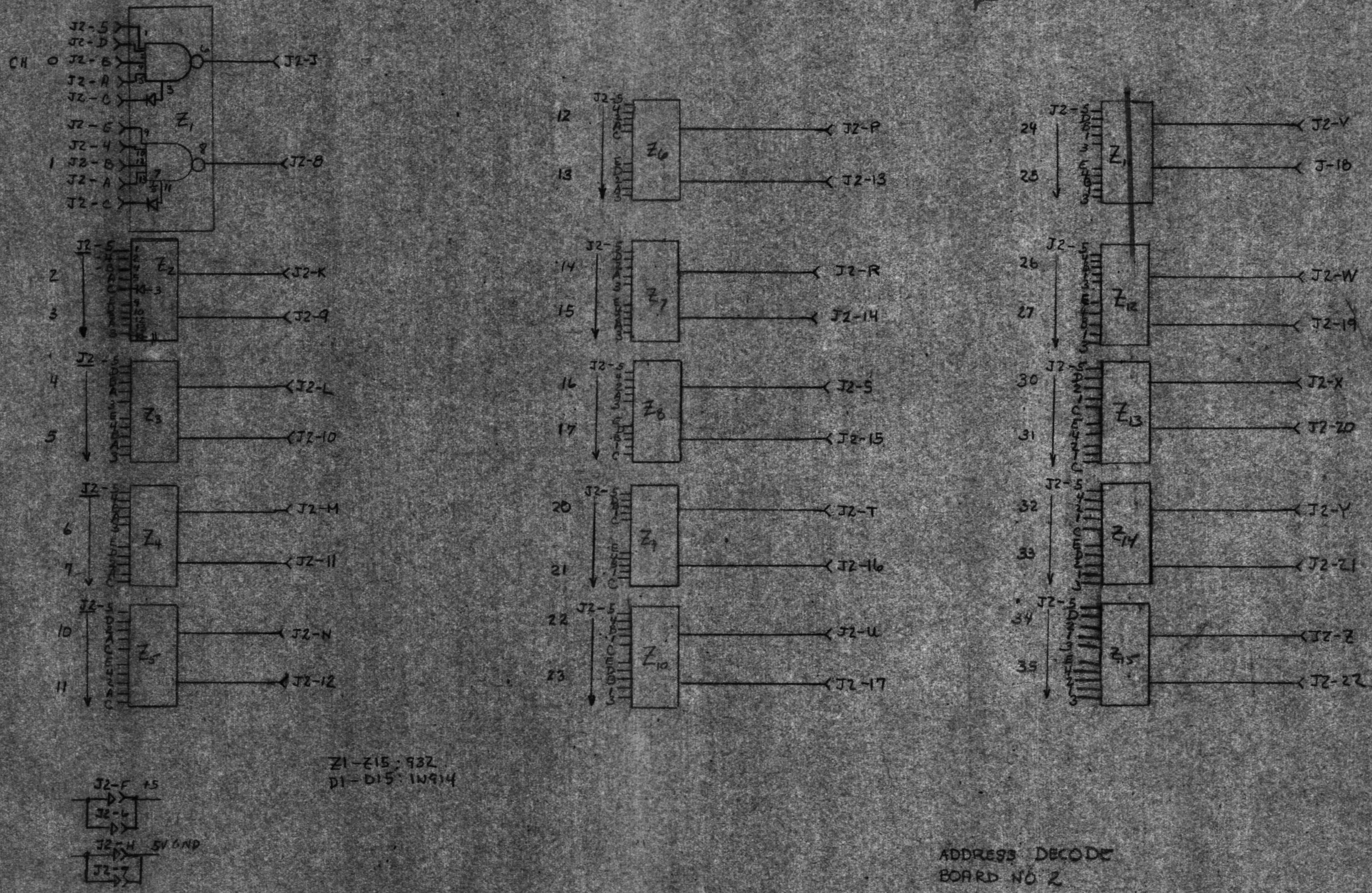
FOLDOUT FRAME 2



BOARD NO. 1

FOLDOUT FRAME 1

FOLDOUT FRAME 2

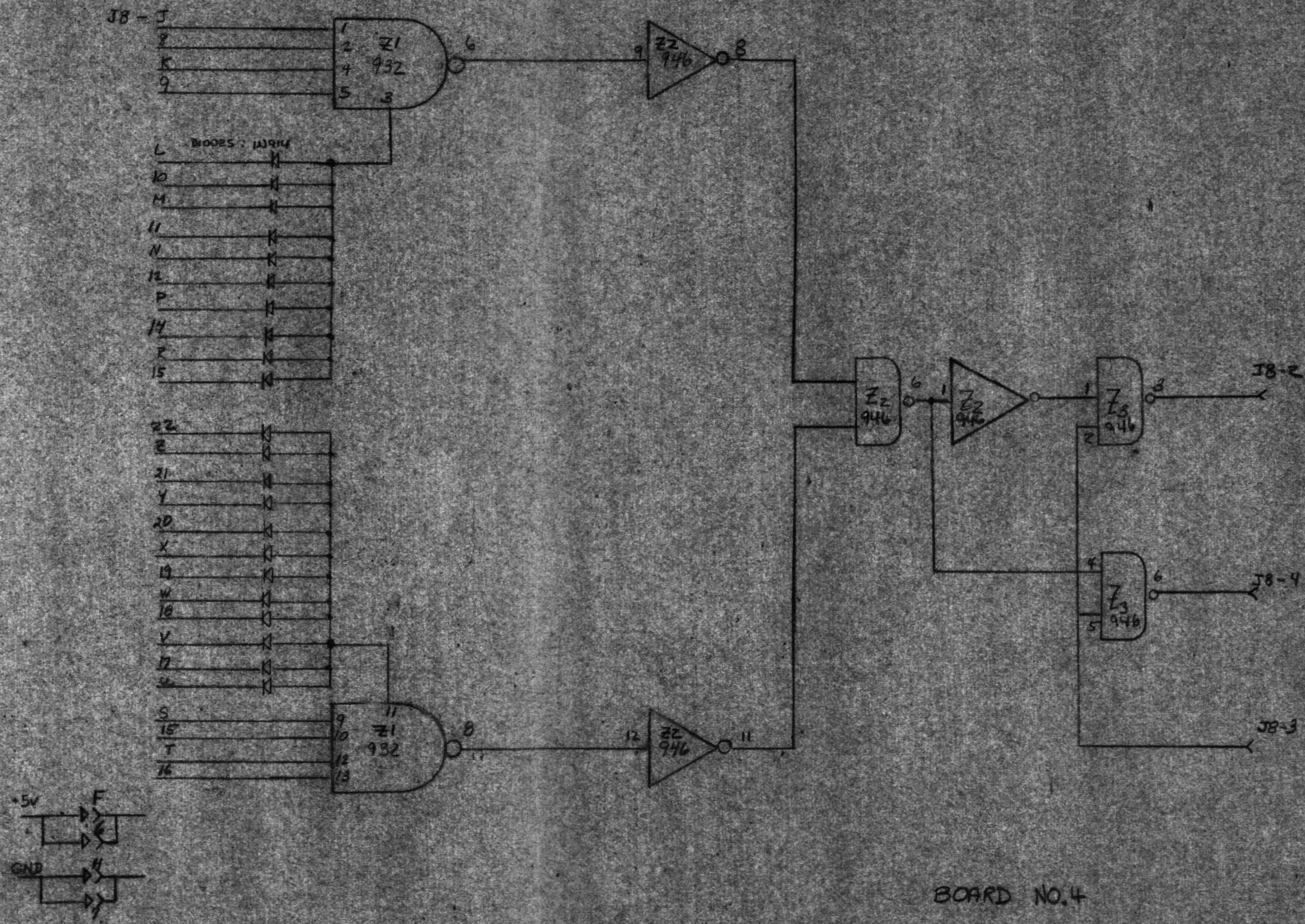


Z1-Z15 : 932
D1-D15 : 1N914

ADDRESS DECODE
BOARD NO 2

FOLDOUT FRAME 1

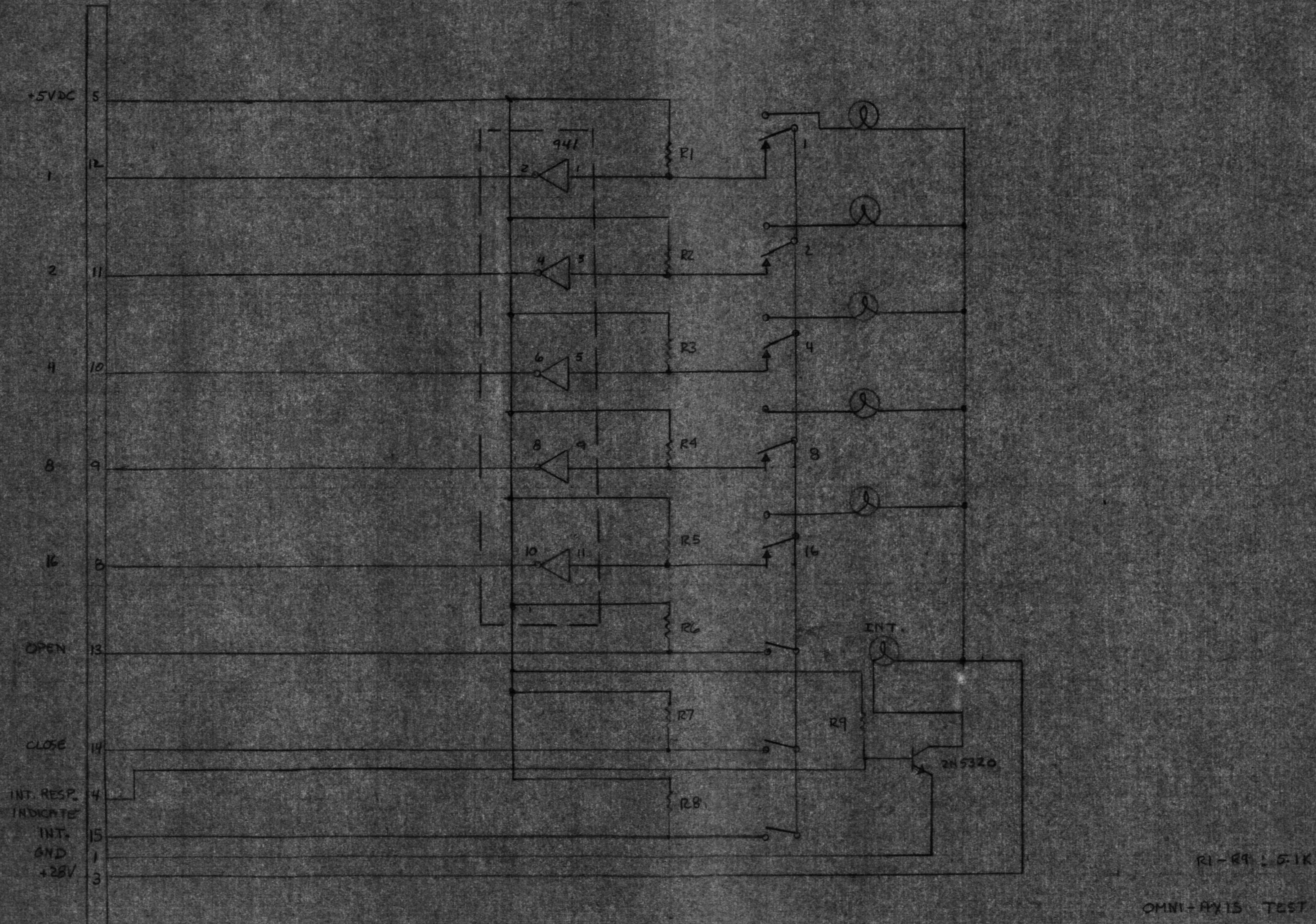
FOLDOUT FRAME 2



BOARD NO. 4

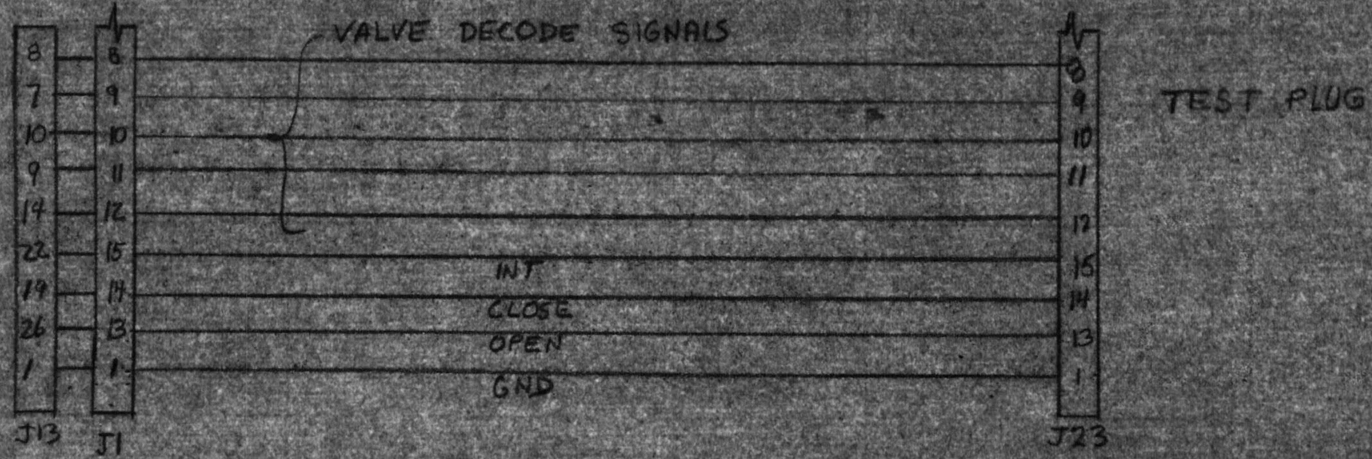
FOLDOUT FRAME 1

FOLDOUT FRAME 2



OMNI-AXIS TEST BOX

FOLDOUT FRAME 1



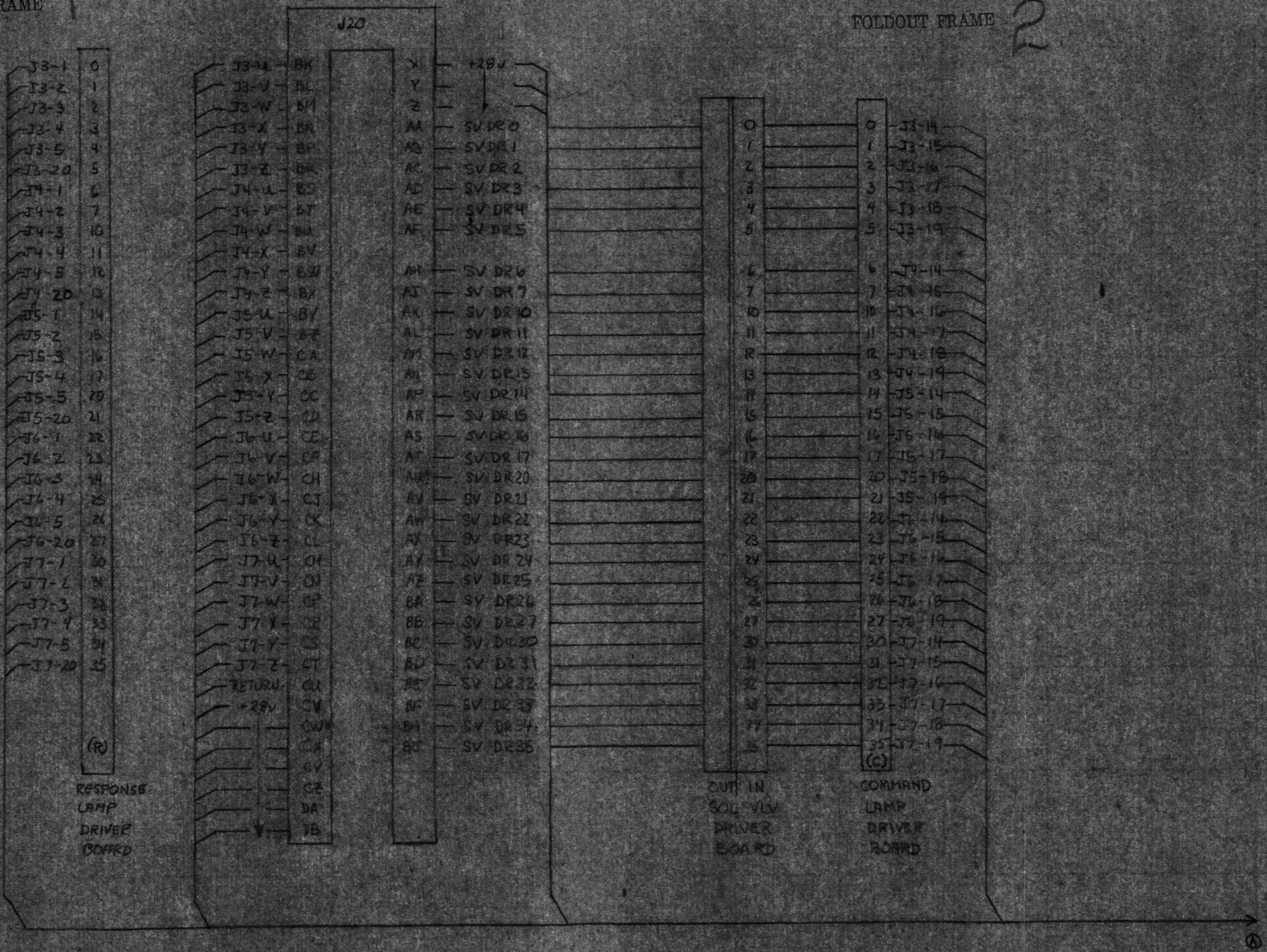
CLOCK CKT PARTS LIST

R1	511Ω
R2	523Ω
R3	10K
R4	2.7K
R5	1.5M
R6	10K
R7	100K
R8	4.7K
C1	9PF
C2	0.01μF
D1,D2	1N753
Q1	2N2222
Z1	709
Z2	741
Z3	932
Z4	946

FOLDOUT FRAME 2

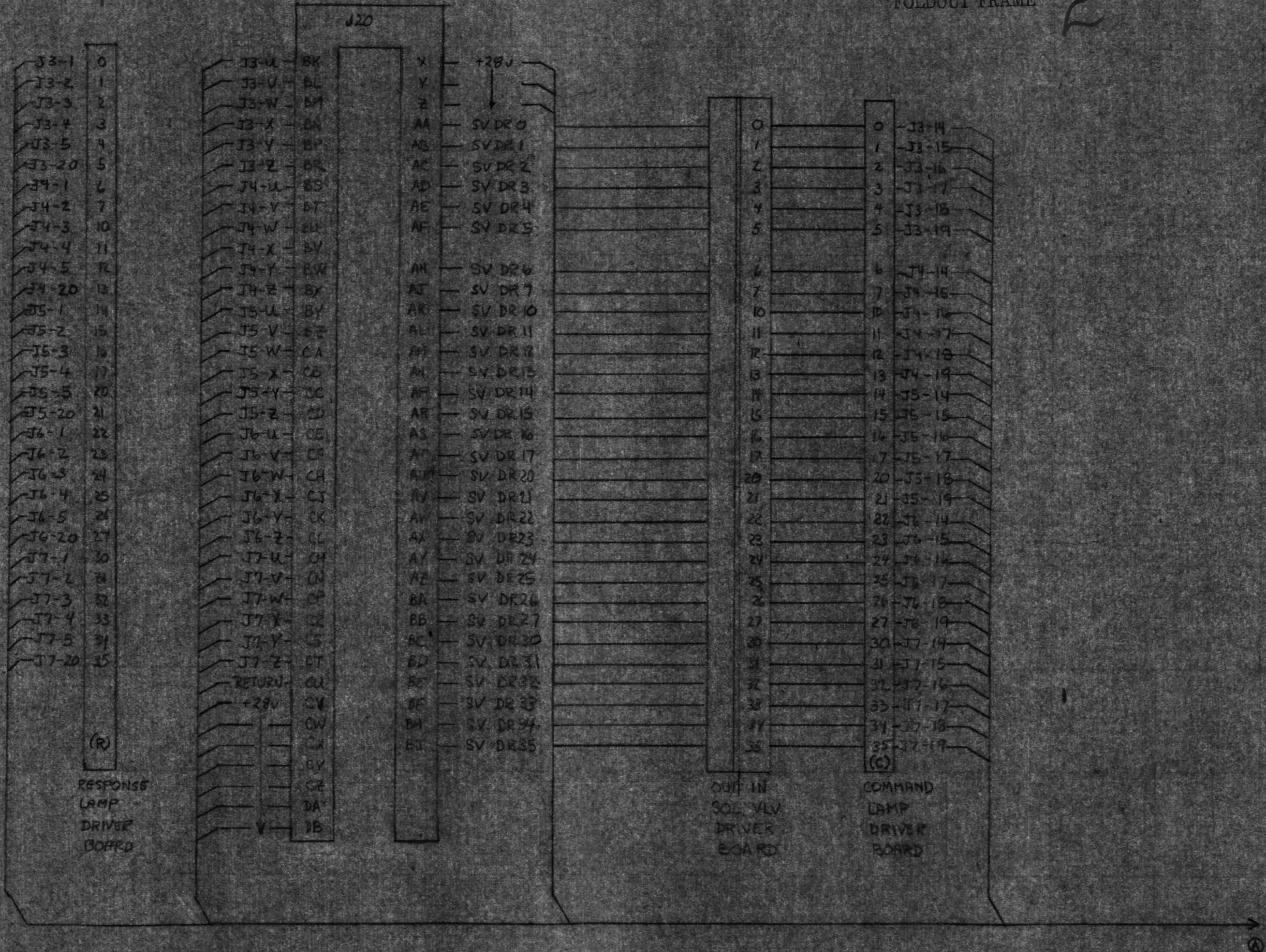
FOLDOUT FRAME 1

FOLDOUT FRAME 2



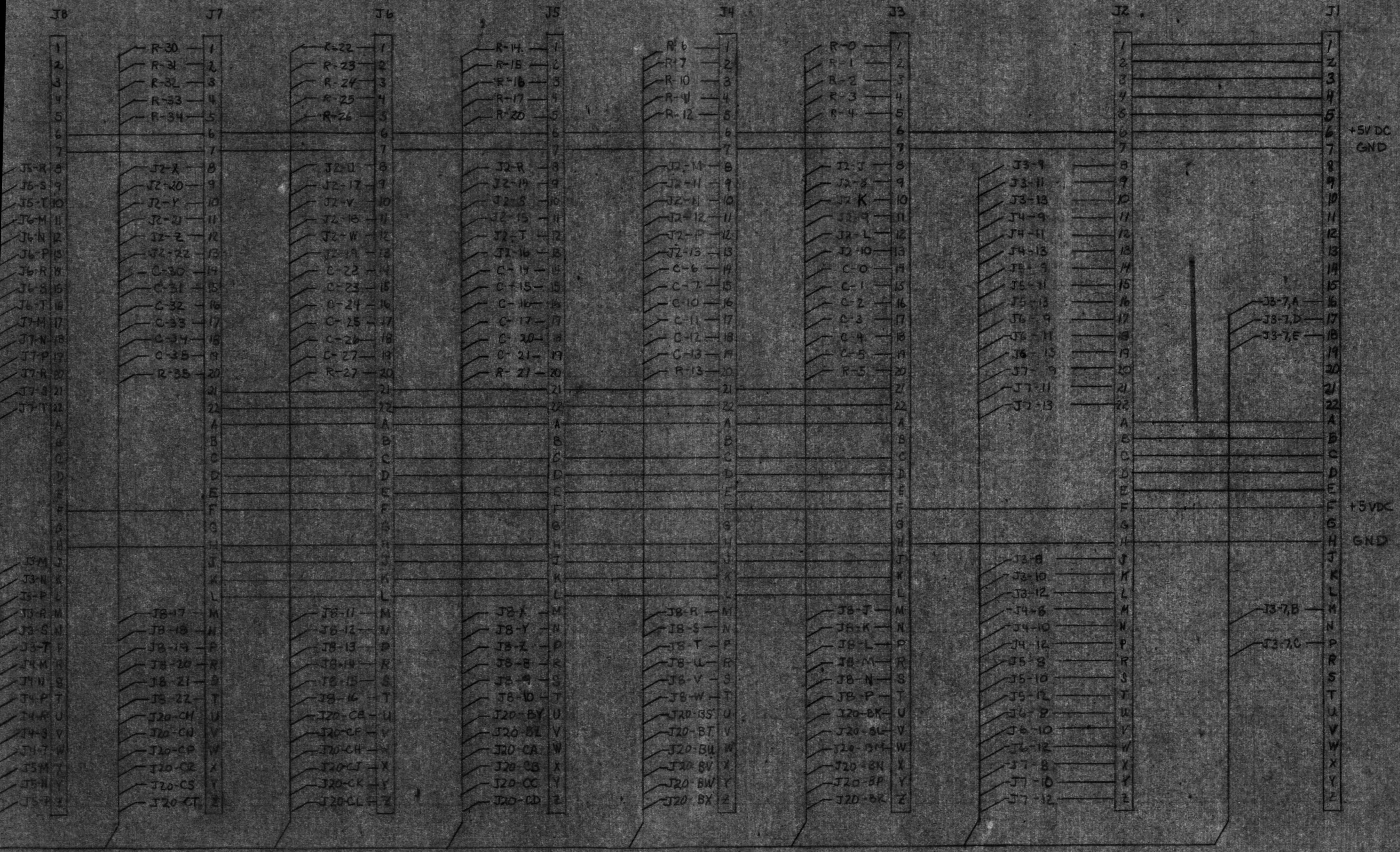
FOLDOUT FRAME 1

FOLDOUT FRAME 2



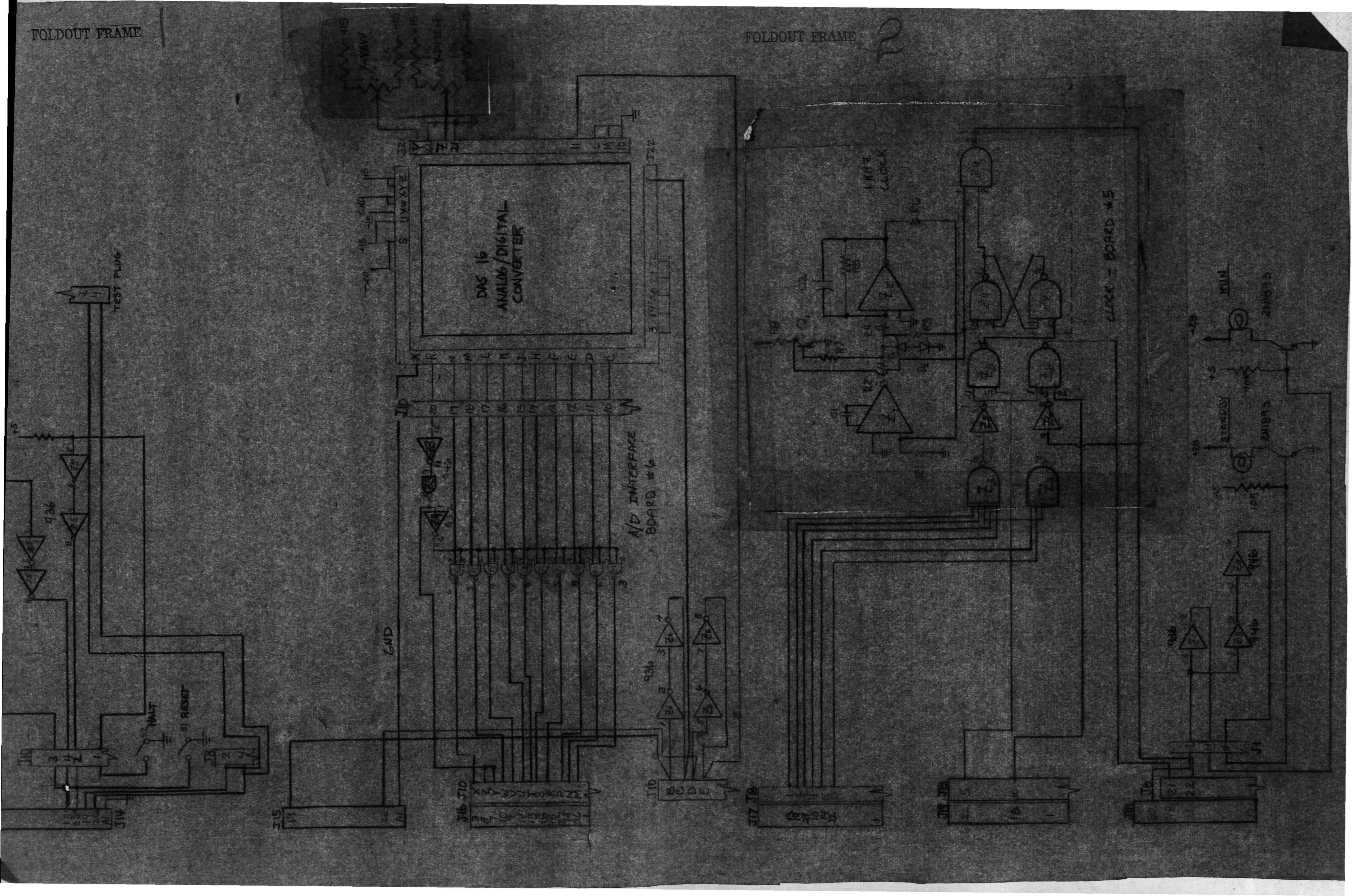
FOLDOUT FRAME 1

FOLDOUT FRAME 2



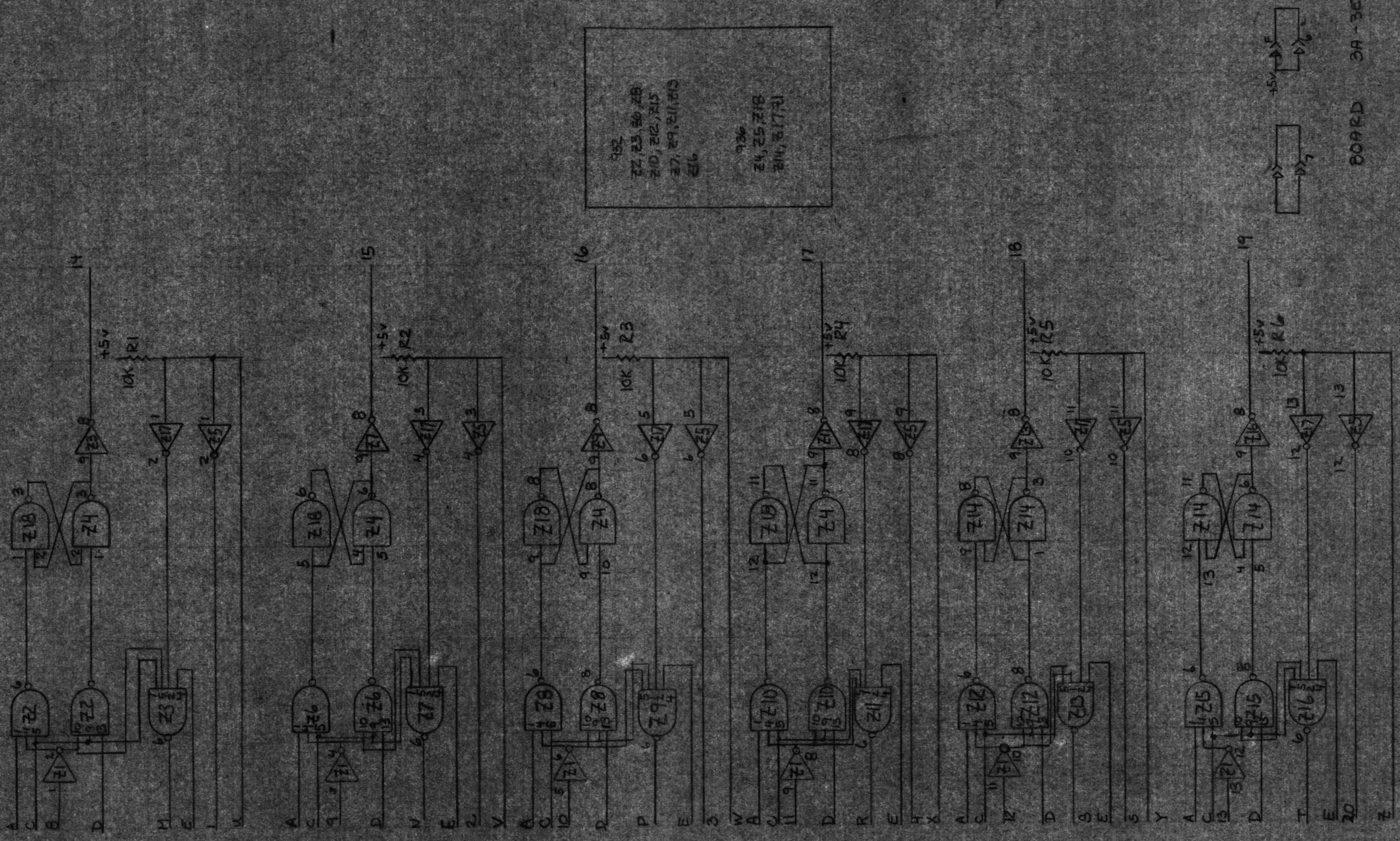
FOLDOUT FRAME 1

FOLDOUT FRAME 2



FOLDOUT FRAME 1

FOLDOUT FRAME 2



SECTION SIX

VI. OPERATING THE OPERATIONAL ROUTINE

A. The Keyboard Monitor

Control of the operational routine resides in the Keyborad Monitor. When the program is loaded and started at location 200 in Field 0, a "@" will be printed at the left margin of the teleprinter. Whenever this character is printed, the program is in the Keyboard Monitor Command Mode waiting for an operator command at the teletype.

There are four (4) commands under Keyboard Monitor which will be discussed in detail. These are:

"M" - Mode Select

"PS" - Program Select

"PE" - Program Execute

"PL" - Program List

The teleprinter will respond with a "?" and return to Keyboard Monitor for any character typed while in Keyboard Monitor other than the above listed commands and two special characters to be discussed.

Whenever the operator wishes to return to Keyboard Monitor control, he types a CTRL/U (produced by pressing the CTRL key and U key simultaneously). The teleprinter echoes a "↑U" and returns to Keyboard Monitor indicated by a "@" at the left margin.

If this thrust control test program is used under DEC OS/8 control, a return to the OS/8 Keyboard Monitor is accomplished by typing a CTRL/C (produced by pressing the CTRL key and C key simultaneously). The teleprinter echoes a "↑C" and transfers program control to location 7600 in Field 0 - i.e. the OS/8 Keyboard Monitor return point. (WARNING: Do NOT type CTRL/C if you are not under the OS/8 monitor.)

B. "M" - Mode Select Instruction

When an "M" is typed under Keyboard Monitor, the teleprinter responds by typing the question "MODE(R,S):". The operator then responds by typing an "R" (remote mode) or an "S" (sequence mode). For any other character (except CTRL/U or CTRL/C) the teleprinter responds with a "?" and asks again "MODE(R,S):".

The "M" instruction selects the mode under which the test program will operate. It affects the subsequent use of the "PS" and "PE" instructions.

"R" - Remote Mode: This means that all X,Y input to the test program will take place from a sampling of the analog to digital converter. It is used when one desires to control the X,Y input by hand (i.e. through pots) or by an external signal generator.

"S" - Sequence Mode: This means that all X,Y input to the test program will take place from a reading of X,Y sequence stacks (in core memory) that were loaded via the teletype prior to execution and under the program select ("PS") instruction.

C. "PS" - Program Select Instruction

(Under Remote Mode) When a "PS" is typed under Keyboard Monitor the teleprinter will respond with the question "STEP:". An integer (from 1 to 2000) is then entered via the keyboard. This represents the transitional step distance of Figure 3-10 discussed earlier. The actual transitional step distance is slightly smaller than this since the transition step count is found by

$$STPCNT \leftarrow (DSTNC/STEPDT)+1$$

to insure a step of at least one. (See the Program Listing for further details).

Next the question "R(C,V): C" is asked. "V" stands for variable, "C" for constant. In remote mode the transition rate R is always a constant. It represents the time lapse between valve state commands and is measured in units of approximately one msec. R should generally not be under 50 to accomodate the computer time spent in calculations. If R is much smaller than 50, the time lapse between valve state commands will be governed by the program computation time. After the operator types in a value for R the final question asked is "T= ". "T" stands for "termination point" and is equal in absolute time units to the product of T and R. When there is no change in an X,Y input for a period of T times R the program considers X,Y to be a terminal state (albeit temporarily) and enters a compensate routine to account for valves stuck open or closed. If a valve is found to be stuck open, the 180 degree opposite valve is opened to neutralize its effect. If a valve is found to be stuck closed (i.e. it was commanded to open but remained closed), the nearest closed valve to the stuck one is then opened.

After entering a value for T the program returns to Keyboard Monitor.

(Under Sequence Mode) When a "PS" is typed under Keyboard Monitor the teleprinter will respond with the question "STEP:".

Next the question "CD(I,F):" (cycle duration) is asked. "I" stands for infinite, "F" for finite. If an I is typed, the subsequent program execution will cycle through the X,Y,R stacks indefinitely - until a CTRL/U is typed or the "HALT" button is pushed. If an F is typed, it must be followed by an integer representing the number of times the program will cycle through the X,Y,R stacks under program execution before returning to Keyboard Monitor.

The next question asked is "R(C,V):". If a C is typed, it must be followed by an integer. It also inhibits the program from asking for an R when the X,Y stacks are being loaded. The designated constant is automatically loaded into the R stack each time an X,Y pair is selected.

The following questions asked by the program are a repetitive sequence of the three questions "X=", "Y=", and "R=" (R is only asked if a "V" was typed in response to the "R(C,V):" question.) The X,Y,R sequence stacks are loaded from this question. Only 127 values each are allowed for X,Y and R due to stack size limitations. X and Y must be in the range from -512 to +511. A return to Keyboard Monitor is accomplished by filling the stacks or returning via a CTRL/U.

D. <u>"PE" - Program Execute Instruction</u>

When a "PE" is typed under Keyboard Monitor, the program begins the execution selected under the "M" and "PS" instructions. A return to keyboard monitor may be accomplished via the CTRL/U at the teletype or the "HALT" button.

Every valve command or valve inquiry is recorded in a program listing file in core. This is later used as documentation of the actual program execution. When this listing buffer is full, no more program execution documentation will be recorded even though the program execution may continue. The buffer has a capacity for 213 individual commands (or inquiries).

E. <u>"PL" - Program List Instruction</u>

When a "PL" is typed under Keyboard Monitor, a documentation listing of the previous program execution is given. The heading for this listing is as follows:

VALVE	VALVE COMMAND	VALVE STATE	ABSOLUTE TIME

The valve number in octal is given under "VALVE". Either "O" for an open command, "C" for a close command, or "I" for an inquiry is given under "VALVE COMMAND". The "VALVE

STATE" column may be empty or contain a "COC" (previous state, command, current state) for a stuck closed valve, or an "OCO" for a stuck open valve. This individual valve condition is determined during the compensate routine at an X,Y termination. The "ABSOLUTE TIME" is measured in approximately one msec. units and represents the valve execution time.

F. Entering Integers

Integers are entered from the teletype whenever the program calls for them.

The "." and "," may be used as markers but are ignored by the computer.

If an error is made while entering an integer the error flag "←" may be typed followed by the correct integer. This error flag may be used as many times as necessary.

Typing the minus sign "-" will cause the integer to be entered negatively in 2's complementary arithmetic. The "+" character may, but need not be used.

Any other non-digit character will terminate the integer input and return control to the program. A "carriage return" is usually used for this.

Internally the program identifies the valves from 1 to 36.

External identification of the valves ranges from 0 to 35.