AFAPL-TR-76-43 VOLUME I

AIRCRAFT HYDRAULIC SYSTEMS DYNAMIC ANALYSIS

VOLUME I
TRANSIENT ANALYSIS (HYTRAN)
COMPUTER PROGRAM USER MANUAL

MCDONNELL AIRCRAFT COMPANY
MCDONNELL DOUGLAS CORPORATION
ST. LOUIS, MISSOURI

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AIR FORCE AERO PROPULSION LABORATORY
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Neil Pierce and Gerry Amies of McDonnell Douglas Corporation were technically responsible for the work.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The hydraulic transient analysis (HYTRAN) computer program has been developed to simulate the response of a hydraulic system to sudden changes in flow demand by the system loads.

For a selected system temperature, pump RPM, and initial steady state conditions, the program will calculate the pressures and flow amplitudes resulting from changes in flow demand or some other controller input.

It will predice transient pressures due to waterhammer and the onset of cavitation due to the opening and closing of valves.

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The engineering input data to the program is normally available to a design engineer. When specialized components are required that are not covered by existing subroutines, these may be simulated by adding to the program.

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1.0 INTRODUCTION

The hydraulic transient analysis (HYTRAN) computer program is intended for use by designers with an interest in the detailed performance of an aircraft hydraulic system or the response of a load, where the supply system is an integral part of that response.

An aircraft hydraulic system is basically a power source connected to several loads. Under steady state conditions, where only the pump and fluid are moving, the flows and pressures at various points in the system can be calculated using non-time dependent formulae. However the unsteady flow conditions which are more normal, cannot be analyzed using simple formulae. The pump is basically a closed loop servo which has a time varying output and responds continuously to system pressure changes. These changes propagate through the system at the speed of sound in hydraulic oil, which is about 4000 ft/sec. The system components respond to these pressure and flow changes, and to external load and control disturbances.

The program simulates the complete system and calculates the value of all the flows, pressures and state variables, throughout the system.

This allows the designer to study the dynamic response of any variable, such as a check valve poppet position, an actuator piston velocity, the pump swash plate acceleration, etc., since all these variables are calculated as part of the system simulation.

The program is composed of five basic parts, input, steady state calculation, line simulation, component simulation, and output.

The designer inputs data describing the lines, components and system configuration. Since the simulation is only as good as the data, some of the information required for components such as a pump, is very detailed.

Fortunately there are only a few components like this and often these are common to many systems; e.g. DC-10 pumps are used on the 747, L1011, and A300.

The steady state section of the program balances the pressures and flows in the system and calculates the initial values for all the system state variables. Once the initial values are established at zero time, the program starts by calculating for a small change in time delta T, new flows and pressures at the junction between the line segments.

The lines are divided into segments, the length of each segment being greater than or equal to the velocity of sound in the line multiplied by the time interval, delta T. There is a whole number of segments for each line. If a calculated line length segment ends up longer than the line length, the program will adjust the velocity of sound as required to achieve one whole segment and continue to run. The percent error in the velocity of sound used will be printed out.

Once the new pressures and flows have been established for the line junction, the program calculates new values for the state variables of all the components, and the flows and pressures at the junctions between the components and the lines.

The program continues to march forward in time delta T intervals, first calculating the line and then the component variables.

The output part of the program selects the variables that are required as output or output plots, at specified time steps, since it is not always necessary to plot every value that was calculated. When the program calculations are completed, the output is then printed and plotted.

The controlling input to the system will usually be a sudden load demand from a surface actuator or some similar load function. This is input as a time dependent valve motion or input demand.

The output is essentially a time history of selected system variables which have been disturbed by the controlling input.

Since the program actually advances in discrete time steps, it can be integrated into other simulations, if the cost of running can be tolerated.

This users manual describes how the program can be used, the method of inputting data and the interpretation of the output. Volume 2 contains a technical description of program, and the theory used in the calculations.

2.0 TECHNICAL SUMMARY

The HYTRAN program is intended for use by engineers with different interests. Some will be concerned with the performance of the hydraulic system as a whole, while others will be interested in the detailed performance of individual components.

HYTRAN uses a building block approach which allows the programmer to meet these needs by adding special component subroutines as required to the existing component subroutine library.

The program is supported by a number of specialized utility routines, which have been included to avoid program incompatibility with other computer systems. In the development of HYTRAN, the emphasis was placed on the performance of the hydraulic system as a whole, and its components are considered only to the extent to which they affect the total system response.

The transient analysis is a digital simulation process, which treats the fluid lines with distributed parameters, applying the concepts of wave mechanics, and including the effects of nonlinear friction. The fluid line equations are solved with the help of the method of characteristics. The dynamic equations of the components are either algebraic or ordinary differential equations. These form the boundary conditions of the lines and are solved simultaneously with the associated line characteristic equations. A numerical scheme is used to make the grid of characteristics compatible with the integration techniques used by the components.

The input to the system is normally a valve motion, which causes a disturbance to propagate through the mathematical model. The output of the program is the time histories of pressure and flows at any point in the system and other variables of interest such as actuator positions.

In the simulation of the components, the precision of the model used will depend upon its use. If the user is studying the dynamic stability of a pump system, then an accurate model is required. If, however, the user is studying an actuator out at the end of the line system, the pump response could be simulated using a simpler model; hence saving some running costs. In a similar manner, actuator friction has a significant effect on its small amplitude response, but such friction is of little interest if the actuator is being used as large demand load in the study of pump stability.

The dynamics of components such as pumps are very dependent on the dynamic properties of the connecting lines and components; hence it is important in simulations involving these components that an accurate system simulation be used.

The results which are obtained from HYTRAN are solutions of the differential and algebraic equations used to describe the system dynamics. The solutions are obtained by methods of numerical analysis, such as Runge Kutta numerical integration procedures, method of characteristics, and Lagrange interpolations. They are, therefore, subject to the errors which are inherent in numerical methods, but which can be kept small enough to be of no practical influence. Of more importance than the numerical inaccuracies are the underlying assumptions and restrictions imposed upon the basic equations.

A digital simulation has been chosen because of some important advantages over the simulation on an analog computer. These are, in particular, the high accuracy in conjunction with an almost unlimited memory capacity, the difficulty of modeling wave phenomena on analog computers.

The numerical aspects of digital simulation are described in a variety of textbooks. The concepts of the method of characteristic are explained in Appendix A and in more general terms in the description of the line subroutine.

3.0 GENERAL DESCRIPTION

The program requires a detailed description of the system conditions, lines, components, the output data required and the system layout.

The system to be investigated must be carefully described in block diagram form before the data input cards can be produced. (See Figure 3.0-1).

The elements which make up the system are split into two groups, lines (including hoses) and components.

The lines are numbered sequentially, and have designated upstream and downstream ends. For simplicity this should follow a reasonable sequence, through the system. One line number can be used to represent any number of lines in series provided the diameter, wall thickness and modulus of elasticity (or effective bulk modulus if a hose) of each line are identical.

The components which include line junctions or branches are then numbered as a separate sequence. Both sequences start at #1 and there should be no missing numbers.

Once the lines and components have been numbered, the next job is to assign numbers to the points or nodes at which the flow divides or combines under steady state flow conditions.

Node #1 is usually assigned to the pump or flow source. If the system has two pumps, the second pump is Node #2, and so on. See Section 7.0 for a description of special case nodes. Once the nodes are all numbered, the legs or flow paths between nodes, are then numbered until all the flow paths between nodes are accounted for.

The system should now have numbers assigned to all lines, components, nodes and legs. Also, component connection numbers and leg flow direction should be noted so that the proper line number and flow sign can be assigned to each specific component connection.

The preparation of the input data for each of these groups is described in the following paragraphs.

5.0 Line Data

6.0 Component Data

7.0 System Arrangement Data

8.0 Output Requirements Data

This data is needed for all system simulations and the rules for the input should be followed carefully to avoid rejected runs.

It should be noted that the current maximum number of lines (MNLINE), components (MNEL), legs (MNLEG), nodes (MNNODE), plots (MNPLOT) and line points (MNLPTS) that can be input are established in BLOCK DATA. Hence, BLOCK DATA must be changed if any of these maximums values are exceeded when inputting a system.

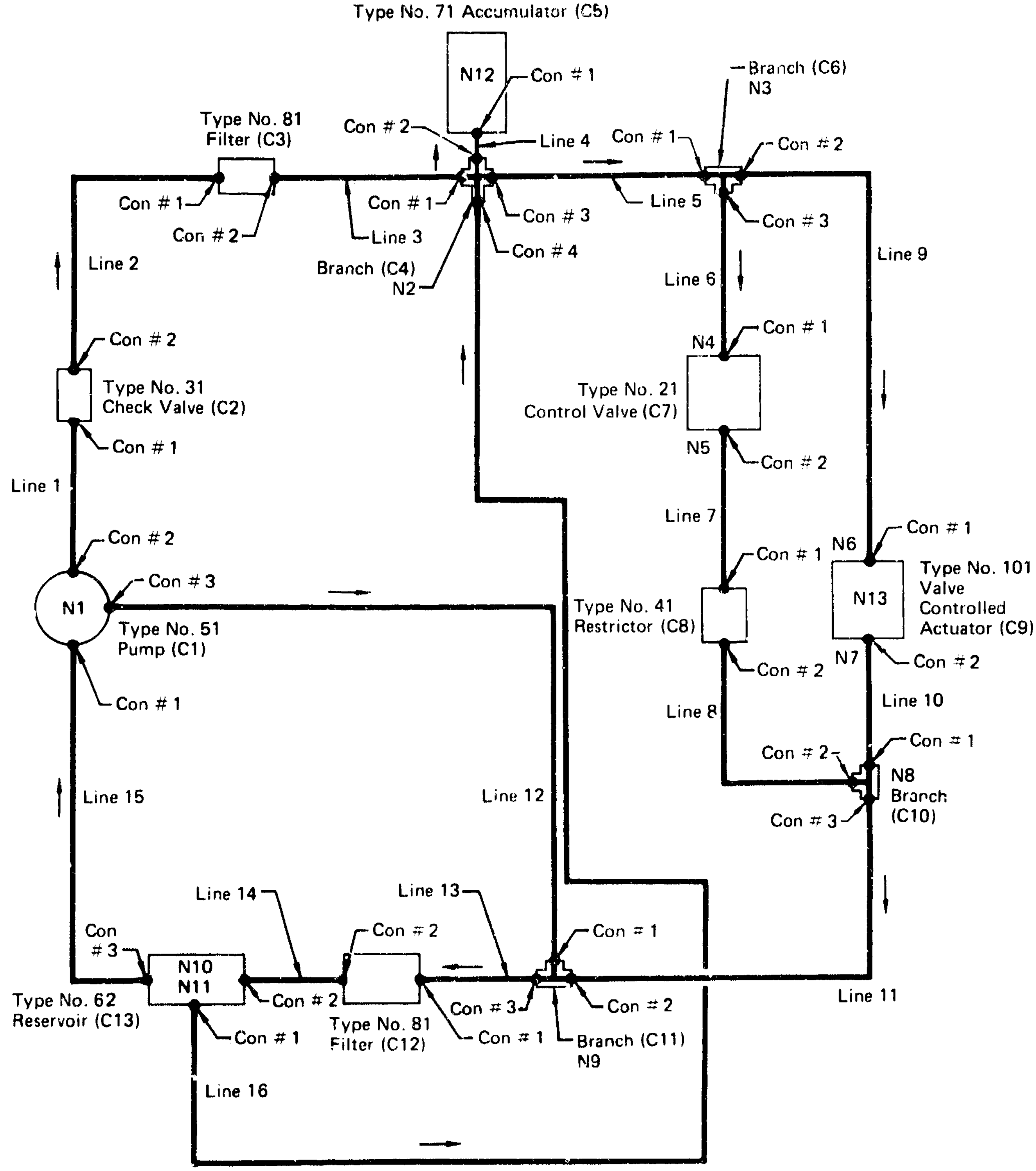


FIGURE 3.0-1
EXAMPLE SYSTEM

GP74 0773 10

Description of Figure 3.0-1

Figure 3.0-1 shows a simple hydraulic system utilizing lines and different types of components currently included in the program. This system illustrates how lines, components, connections, legs and nodes are numbered. As an aid, the integer data shown on the following example data cards have been input to reflect this system where applicable.

1. Symbol Definition

Symbol	Description
NXX	Node number XX
CYY	Component number YY

2. Assignment of Leg Numbers

Once node points are established, leg numbers are set up to represent component(s) and/or line(s) between nodes as follows.

Leg No.	Leg Goes From
1	N1 to N2
2	N2 to N3
3	N3 to N4
4	N4 to N5
5	N5 to N8
6	N3 to N6
7	N6 to N13
8	N13 to N7
9	N7 to N8
10	N8 to N9
11	N1 to N9
12	N9 to *N10
13	N10 to N1
14	*N11 to N2
15	N2 to N12

*Type 62 reservoir is unique in that its two nodes don't require a connecting leg.

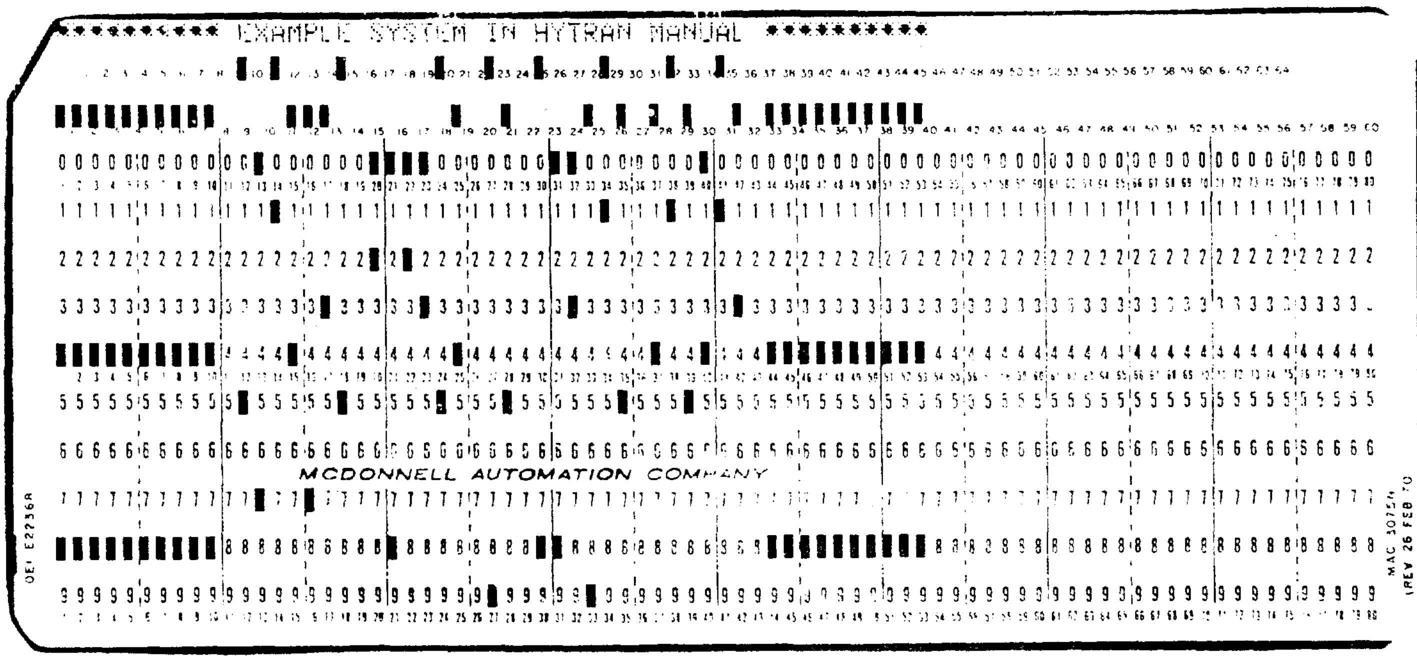
4.0 CONTROL DATA

4.1 GENERAL CONTROL DATA

This group includes three cards which set up the program title, time intervals, fluid temperature and type, number of lines and components and pressures.

Card 1 - This card inputs the program title. A maximum of 80 alphameric characters can be used in the title starting at card column 1.

Example Card:



Card 2 - This card inputs data for the calculation time interval used as the main program time step, the final time which is the time at which the calculation stops, the plotting time interval and fluid temperature.

To keep the program from adjusting the speed of sound, the following formula should be used as a guide for establishing the calculation time interval

$$\frac{\text{shortest line length in system}}{\text{calculation time interval}} \geq 60{,}000$$

The plotting time interval is selected to suit the output device, the minimum being the calculation time interval. The actual value is usually chosen to give 101 plotted points (i.e. = final time ÷ 100 or N times the calculation time interval so that every Nth calculated point is plotted).

The max system temperature is to be input along with an optional fluid temperature increment. The temperature increment allows a system to be run with each element at any one of 10 different temperatures. Once a temperature increment is selected, the program calculates and stores fluid properties for 10 equally spaced (by temperature increment) temperatures starting with max temperature and decending to lower temperature.

If columns 41 through 50 are left blank, the entire system will be run at maximum temperature.

If a temperature increment is input, specific element temperatures can then be input in columns 79 through 80 of component Card 1 and columns 39 through 40 of line cards. These temperatures are coded and are input as positive or negative values to indicate whether the element is on the supply or return side of the system, respectively (see chart below). If an element is referenced to both sides of the system (i.e., pumps, bootstrap reservoirs, etc.), either a positive or negative value may be input. If the temperature pressure code is omitted, the fluid properties for that particular element will be evaulated using maximum fluid temperature and maximum pressure.

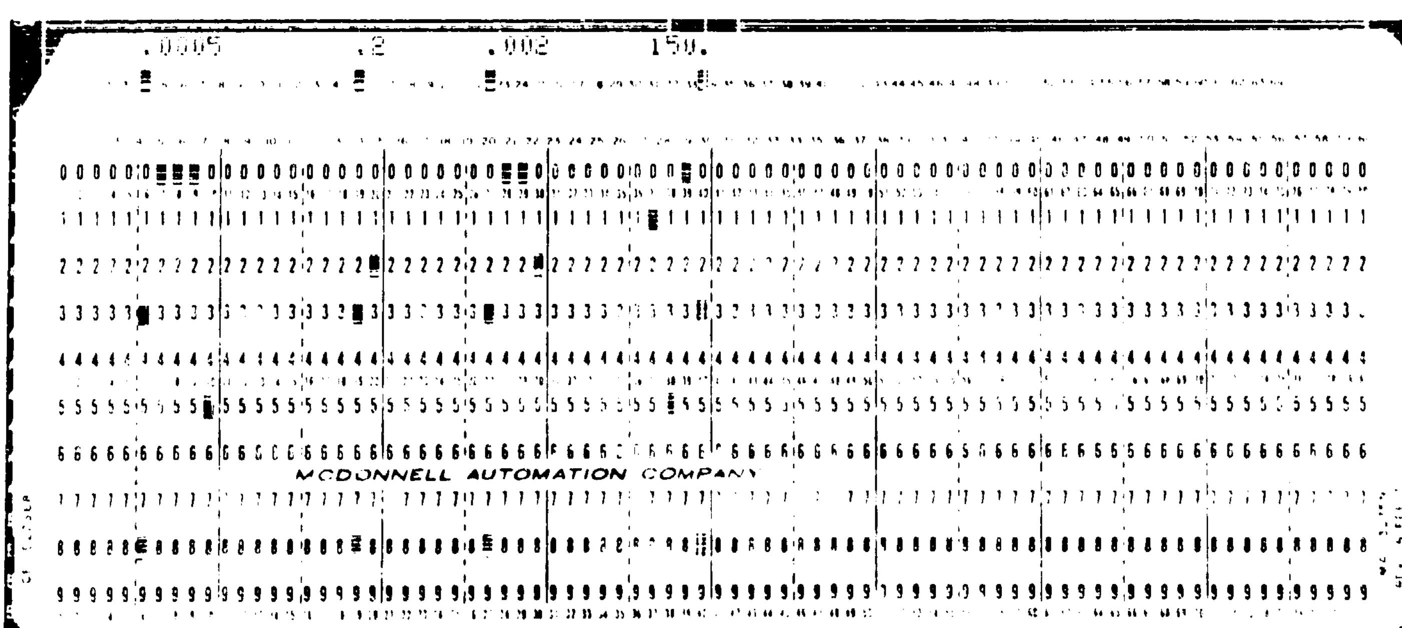
ELEMENT TEMPERATURE/PRESSURE CODE

	INPUT VALUE	
	MAX PRESS	MIN PRESS
MAX TEMPERATURE	1	-1
MAX TEMP - TEMP INCREMENT	2	-2
MAX TEMP - 2* TEMP INCREMENT	3	-3
- 3*	4	-4
- 4*	5	-5
- 5*	6	-6
- 6*	7	-7
- 7*	8	-8
- 8*	9	-9
MAX TEMP - 9* TEMP INCREMENT	10	-10

CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Calculation Time Interval	sec
11-20	E10.0	Final Time	sec
21-30	E10.0	Plotting Time Interval	sec
31-40	E10.0	Maximum Fluid Temperature	°F
41-50	E10.0	Fluid Temperature Increment	°F
51-60	E10.0	Maximum Pressure	psia
61-70	E10.0	Minimum Pressure	psia
71-80	E10.0	Atmospheric Pressure	psia

EXAMPLE CARD



Card 3. This card inputs the total number of lines, the number of components, fluid type number, optional fluid parameters (viscosity, density, bulk modulus and vapor pressure). Note: If a vapor pressure is not input the program will use a value of 2 psia. The fluid type number selects the fluid data to be used from tabulated data stored in the program and adjusts the fluid properties to the maximum and minimum pressures. The program is set up to run with either of the following fluid types at any temperature from -65°F to 300°F:

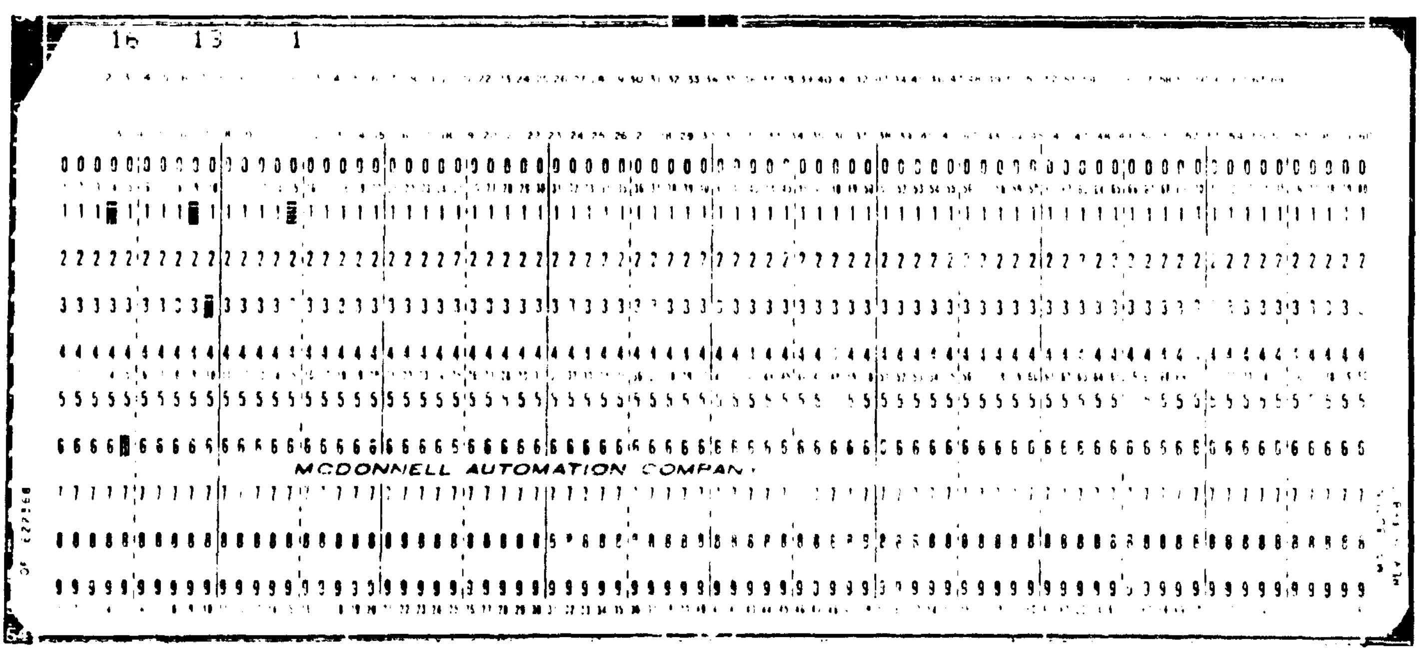
Type #1	MIL-H-5606B
Type #2	MIL-H-83282
Type #3	Skydrol 500B

In addition, the user can input fluid data for any fluid (for the maximum temperature specified on Card 2) by using a Type #0 and by inputting viscosity, density, and bulk modulus, and vapor pressure. This fluid data is not 'pressure' adjusted and is used as input. Note: Columns 21 through 50 can be left blank if fluid type #1, #2, or #3 are used.

CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-5	I5	Total Number of Lines	-
6-10	I5	Total Number of Components	-
11-15	I5	Fluid Type Number	-
16-20	I5	Not Used	-
21-30	E10.0	Fluid Viscosity	in/sec
31-40	E10.0	Fluid Density	$lb\text{-}sec^2/in^4$
41-50	E10.0	Fluid Adiabatic Bulk Modulus	psi
51-60	E10.0	Vapor Pressure	psia
61-80	E10.0	Not Used	-

EXAMPLE CARD



5.0 LINE DATA

The number of cards used in this group is equal to the number of lines entered on Card 3, and though they can be stacked in any order within the group, it is advised that the numerical order be used. An error message will be written when this condition is encountered but the program will continue. A line number may not be omitted or used twice. An error message will also be written if this condition is encountered, however the run will not stop.

A type # is used to differentiate between hard lines and hoses. As noted in Section 3.0, one line number can be used to represent any number of lines in series provided the diameter wall thickness and modulus of elasticity (effective bulk modulus if a hose) of each line are identical.

Two or more lines with different parameters may be joined together without using a branch or other component as a connection. These lines must be numbered consecutively, otherwise a 6002 error will be written and the run will stop.

Dead ended lines must have a 10 written in the type column of the line data card.

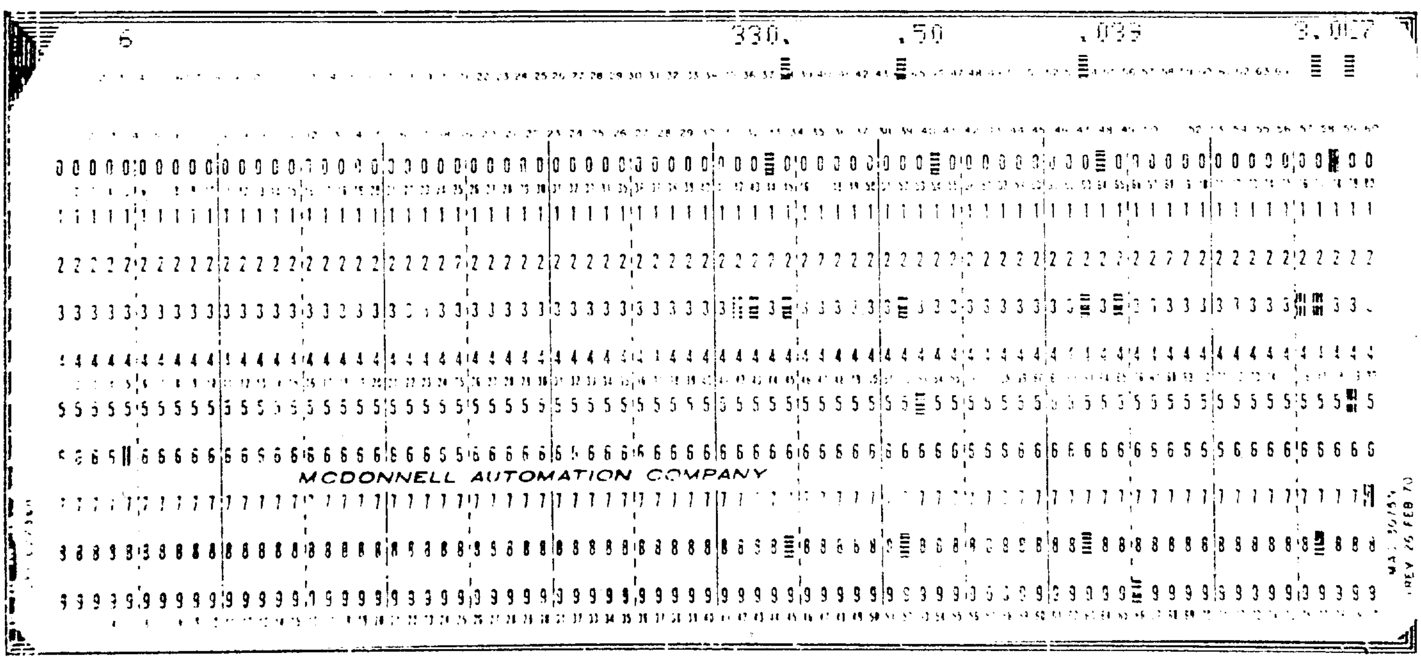
5.1 RIGID LINES

Type number zero is a rigid line. The majority of aircraft lines will fall under this category. True bend angles less than 90° are summed and input in columns 26 through 30. Angles equal to or greater than 90° are summed and input in columns 31 through 35.

CARD NUMBER 1

COLUMN	FORMAT	DATA	DIMENSIONS
1-5	I5	Line Number	-
6-10	I5	Type Number - 0 or 10 for dead ended line	-
11-15	I5	Percentage Increase in Fitting Friction	-
16-20	I5	Number of 45° Elbows	-
21-25	I5	Number of 90° Elbows	-
26-30	I5	Total of Bend Angles Less than 90°	deg
31-35	I5	Total of Bend Angles Greater Than or Equal to 90°	deg
36-40	I5	Temperature/Pressure Code (See Page 4.0-2)	-
41-50	E10.0	Total Length Including Fittings	in
51-60	E10.0	Outside Diameter	in
61-70	E10.0	Wall Thickness	in
71-80	E10.0	Modulus of Elasticity	psi

EXAMPLE CARD



5.2 FLEXIBLE HOSES

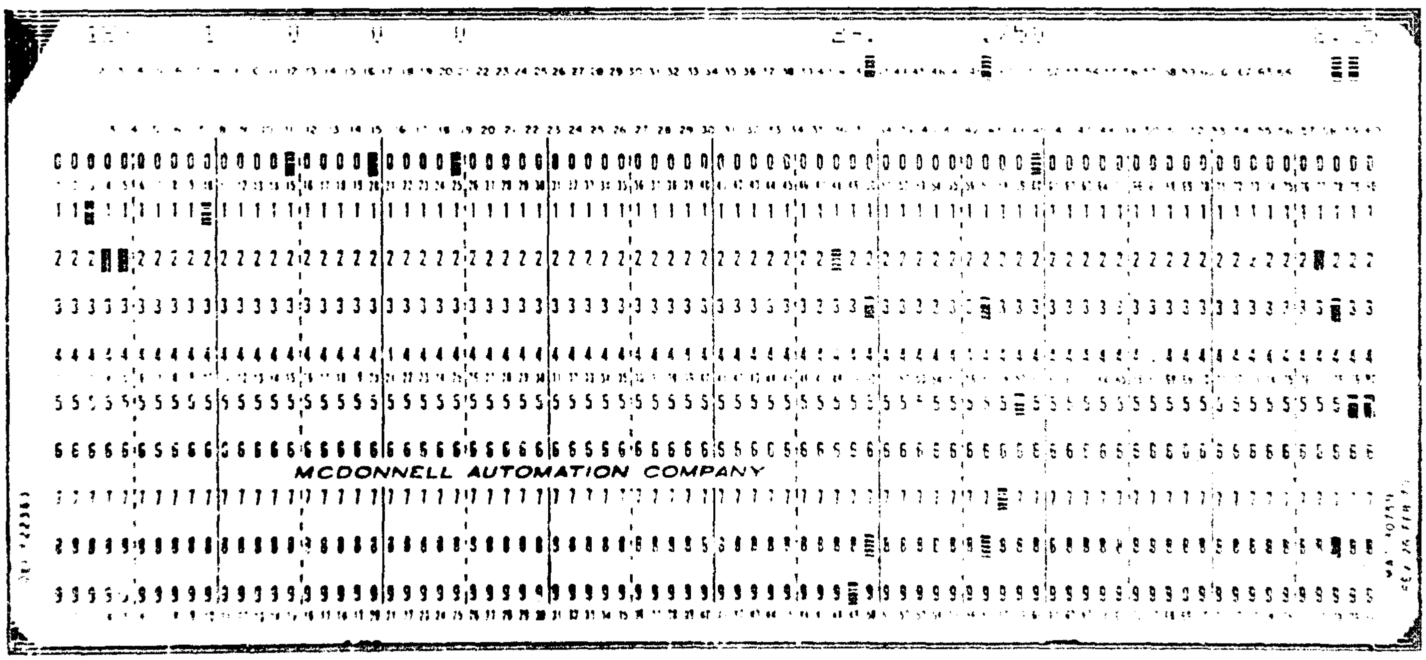
Type number 1 is a flexible hose, rigidly mounted at both ends. True bend angles are to be measured in para 5.1. Effective bulk modulus of the hose is to be determined using the follwoing formulae.

$$\text{HOSE BULK MODULUS} = \text{PRESSURE CHANGE} * \frac{\text{TOTAL HOSE VOLUME}}{\text{VOLUME CHANGE}} - \text{OIL BULK MODULUS}$$

CARD NUMBER 1

COLUMN	FORMAT	DATA	DIMENSIONS
1-5	I5	Line Number	-
6-10	I5	Type Number = 1	-
11-15	I5	Number of Straight Fittings Integral with Hose	-
16-20	I5	Number of 45° Elbows Integral with Hose	-
21-25	I5	Number of 90° Elbows Integral with Hose	-
26-30	I5	Total of Bend Angles Less Than 90°	deg
31-35	I5	Total of Bend Angles Greater than or Equal to 90°	deg
36-40	I5	Temperature/Pressure Code (See Page 4.0-2)	-
41-50	E10.0	Total Length of Hose Including Fittings	in
51-60	E10.0	Inside Diameter of Hose	in
61-70	E10.0	Not Used	
71-80	E10.0	Effective Bulk Modulus of Hose	psi

EXAMPLE CARD



6.0 COMPONENT DATA

Components are classified as anything that is not a line, and includes such things as branches, pumps, reservoirs, valves, actuators, etc.

The cards required to input the data for each component are as follows:

First Card

This card inputs the integer data which includes the component number assigned, the component type number, number of real data cards for the component, and line numbers (either negative or positive depending whether the upstream or downstream end of the line is connected tothe component). Any card data fields not required are to be left blank. All components have pre-assigned connection numbers. The input data assigns line numbers to these component connection numbers. A -ve sign in front of the line number is used if the connection is attached to the upstream end of the line. A +ve number is used to indicate that the component connection is attached to the downstream end of the line. A line number equivalent to the max number of lines (MNLINE), established in BLOCK DATA, blocks off the component connection. A line number equivalent to the MNLINE-1 opens the component connection to atmosphere.

Following Cards

These input the real data, if any, for the component. The number of real data cards to be read is specified on the first integer card in columns 11-15. Some components such as the type 11 branch may not have any real data cards.

To summarize, the component cards are input in the following order.

Component #1	Integer Card Data Cards (If any)
Component #2	Integer Card Data Cards (If any)

And so on until the number of integer cards read, equals the number of components. It is advisable to keep the component cards in order to avoid confusion and perhaps the chance of having a missing number. The program stops if a number is found to be missing. The data required for each component is described in detail in the following paragraphs.

The components are grouped under general type numbers for convenience.

Type #s	Component Types
1 - 9	Not assigned
10 - 19	Branches
20 - 29	Control Valves
30 - 39	Check Valves
40 - 49	Restrictors
50 - 59	Pumps
60 - 69	Reservoirs
70 - 79	Accumulators
80 - 89	Filters
90 - 99	Control Subroutines
100 - 119	Actuators

If a new component of any above types is to be used in a system, the following changes will have to be made to the program.

1. A new component subroutine must be created. The name should be similar to the old name except for the last digit which should be the next available digit in the sequence.
2. The new subroutine call must be added to COMP subroutine in its respective group.
3. Make any necessary changes to COMP to allow isolation and control to be passed to the new component subroutine.
4. The initialization data for the new component subroutine must be added to Block Data (See Volume II).

5. The new subroutine must then be loaded into the file being used.

Example

Newly created accumulator subroutine would be named ACUM72. COMP would be changed to the following.

```
. . . . . . . . . . .

270 CONTINUE
    GO TO (271,272,400), KTYPE-70
271 CALL ACUM71 (D(N1),D(N2),DD(N3),L(N4))
    GO TO 400
272 CALL ACUM72 (D(N1),D(N2),DD(N3),L(N4))
    GO TO 400
280 CONTINUE

. . . . . . . . . . .
```

6.10 BRANCHES

A branch is a connection used to join two or more lines or to cap off a line. The following type is currently included in the program.

Type #11 Frictionless Branch (BRAN11)

6.11 FRICTIONLESS BRANCH

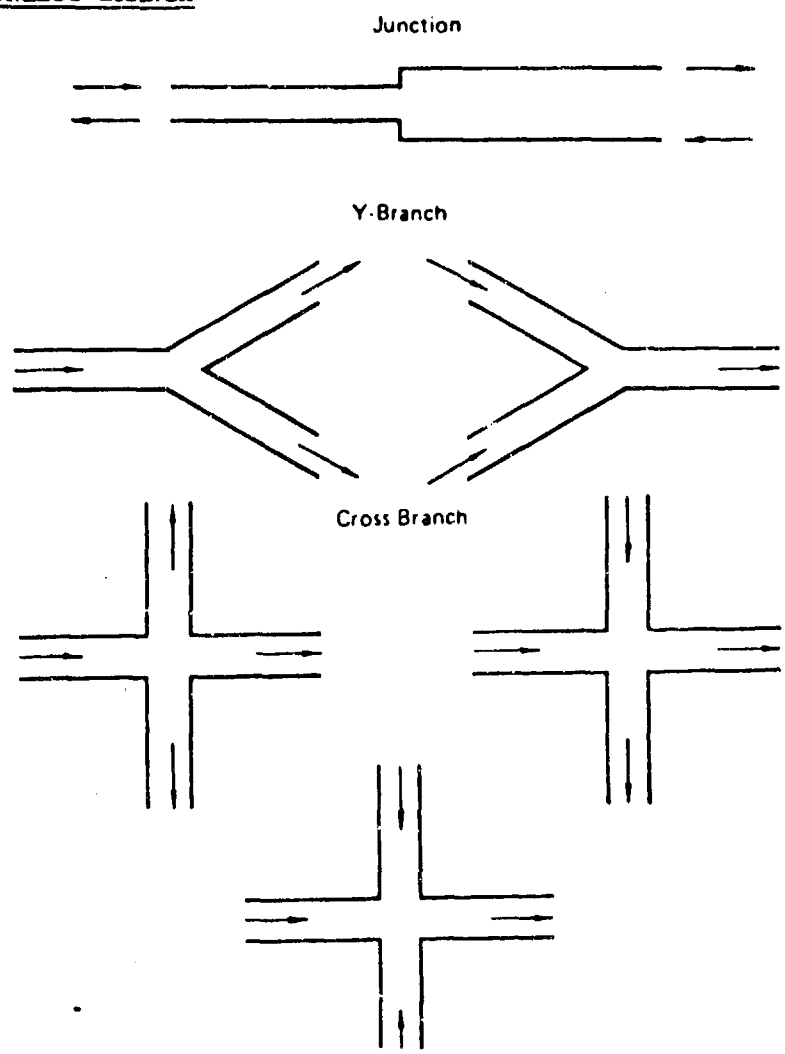


FIGURE 6.11-1

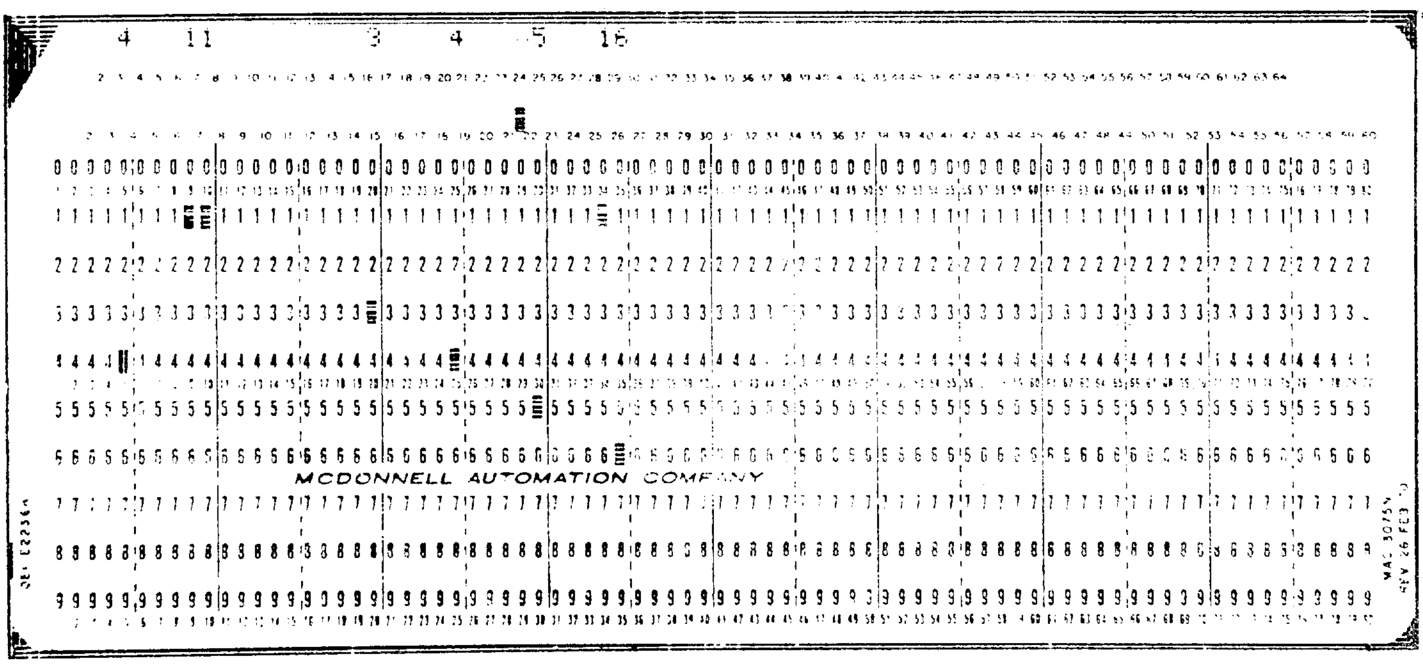
Type No. 11 Frictionless Branch

Type 11 is a frictionless branch with one through four connections. With one connecting line, the line is blanked off. With two connecting lines, it acts as a line junction between two lines. With three or four connections the branch acts as a "Y" or "cross", respectively.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 11
11-15	I5	Number of Real Data Cards = 0
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	Line Number (with sign) attached to Connection 4
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

EXAMPLE CARD



6.20 CONTROL VALVES

Control valves, either shutoff or modulating types, can be simulated by inputting the valve opening characteristics versus time. The following types are currently included in the program:

Type #21 Two-Way Control Valve (VALV 21)

Type #22 Four-Way or Three-Way Valve (VALV22)

6.21 TYPE #21 TWO-WAY CONTROL VALVE

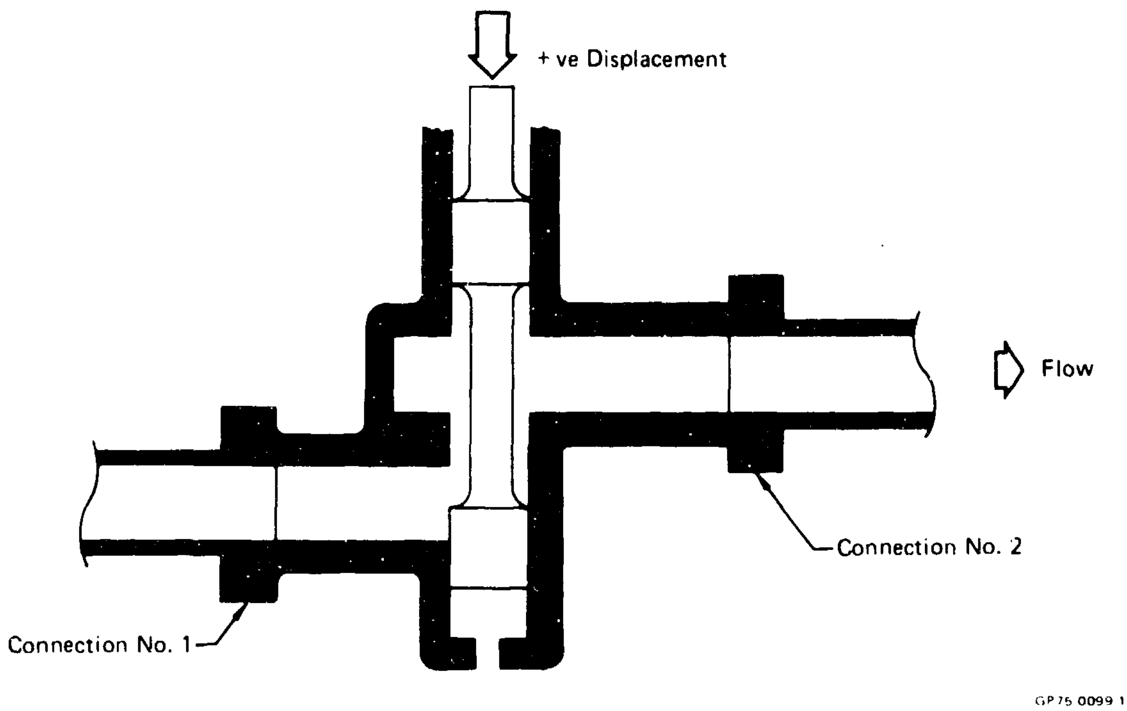


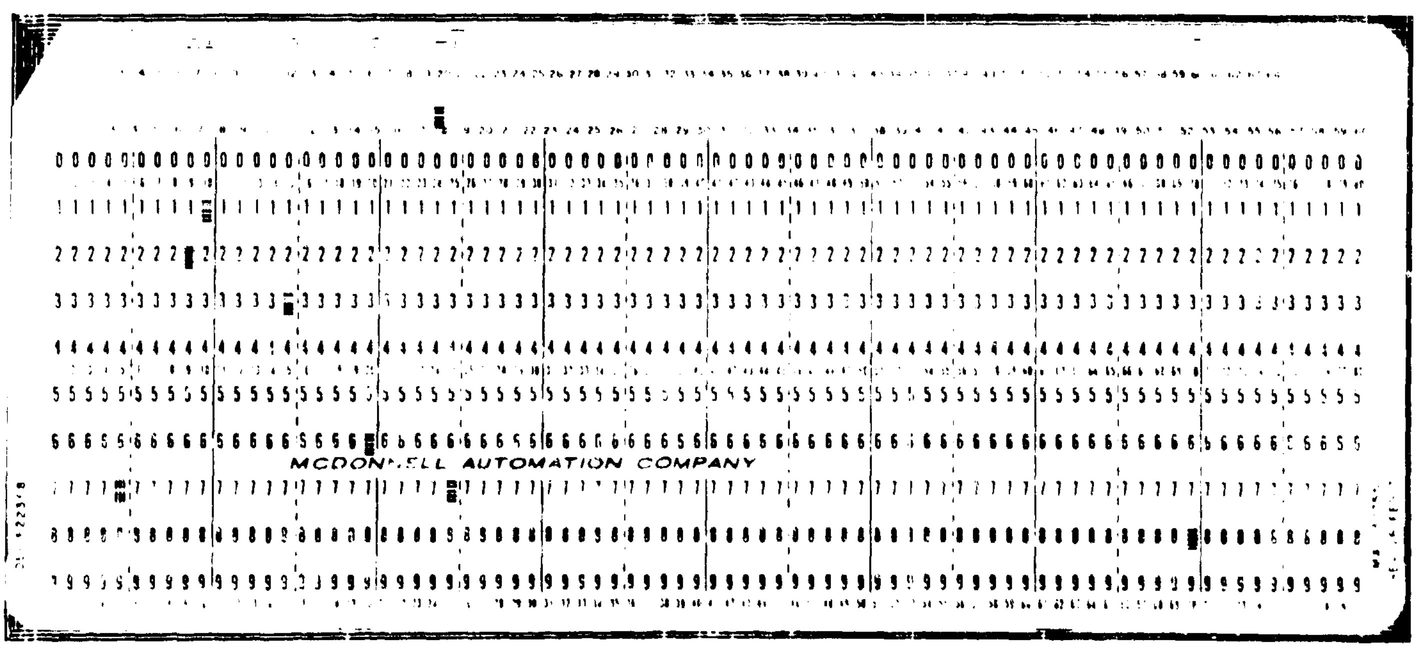
FIGURE 6.21-1
TYPE NO. 21 TWO-WAY VALVE

Type #21 valve uses an externally controlled time history input. The valve opening versus time is derived from the tabulated data input on the third and fourth cards. The total number input on both the time and displacement tables must be equal to the number input on column 70 of the first card.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 21
11-15	I5	Number of Real Data Cards = 3 or more
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	Number of data points in table.
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

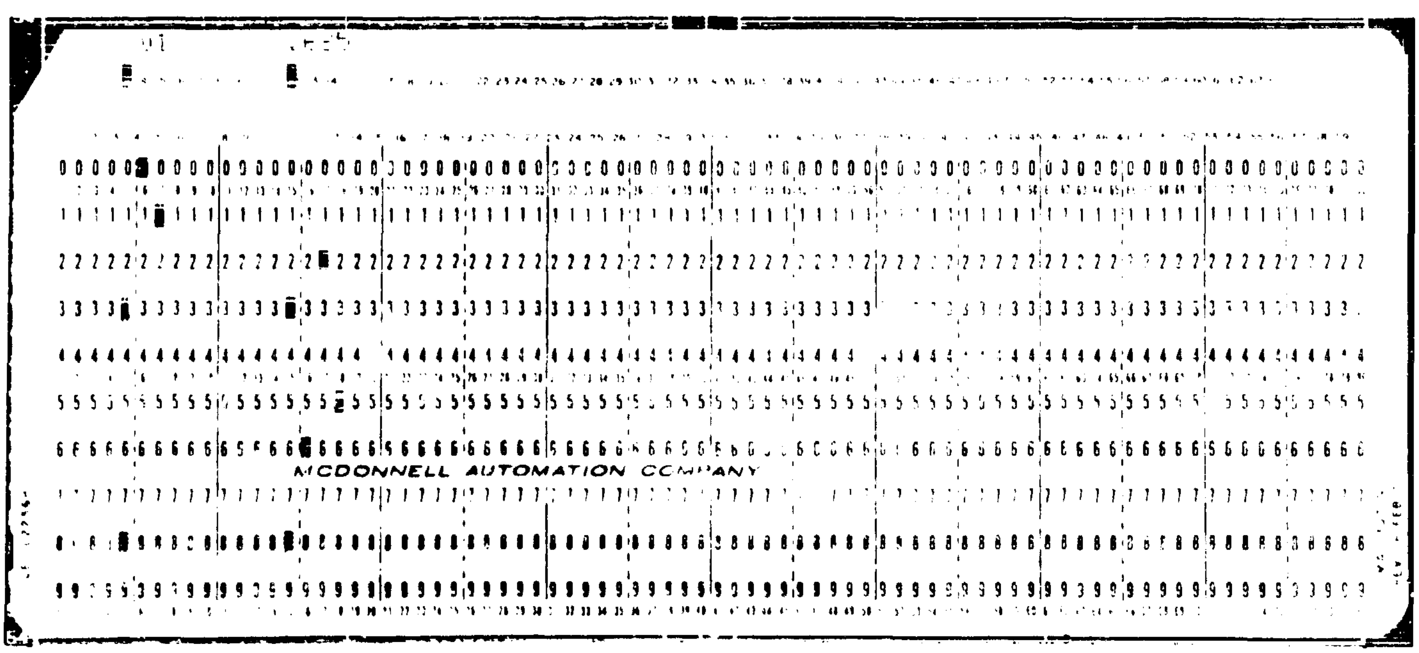
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Valve Slot Width	in
11-20	E10.0	Valve Discharge Coefficient	-
21-30	E10.0		
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

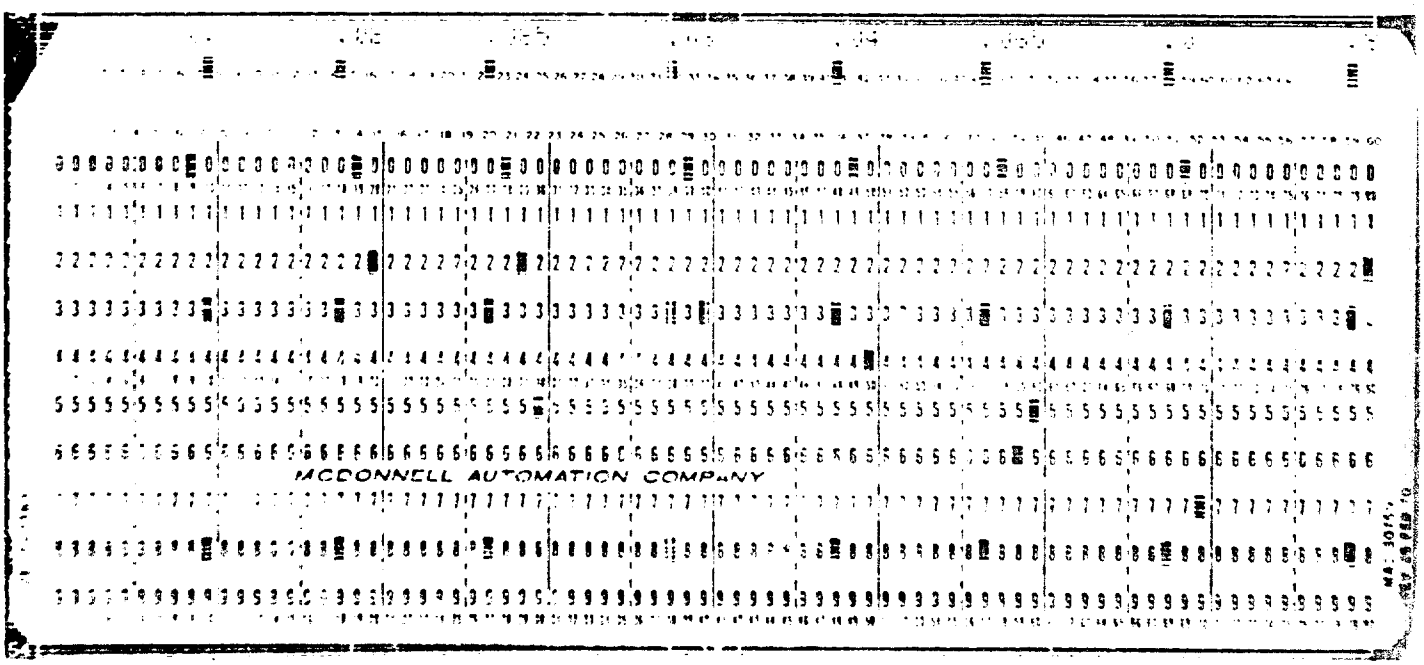
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Value - Should be 0.0	sec
11-20	E10.0	(Enter as many time	sec
21-30	E10.0	values as required using	
31-40	E10.0	as many columns and cards	
41-50	E10.0	as necessary - Final	
51-60	E10.0	time should be Final	
61-70	E10.0	Calculation Time).	
71-80	E10.0		

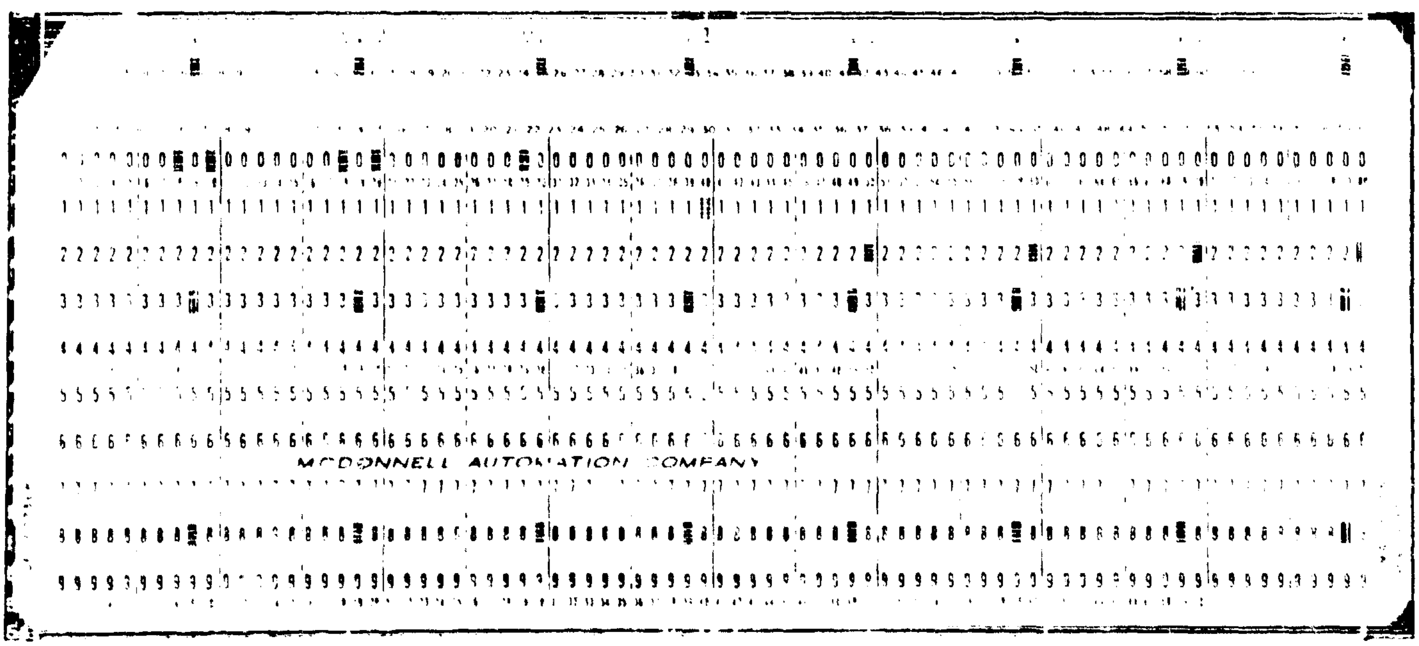
EXAMPLE CARD



CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Valve Position @ T = 0.0	in
11-20	E10.0	(Enter as many valve	
21-30	E10.0	positions as time values.)	
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.22 TYPE #22 FOUR-WAY/THREE-WAY CONTROL VALVE

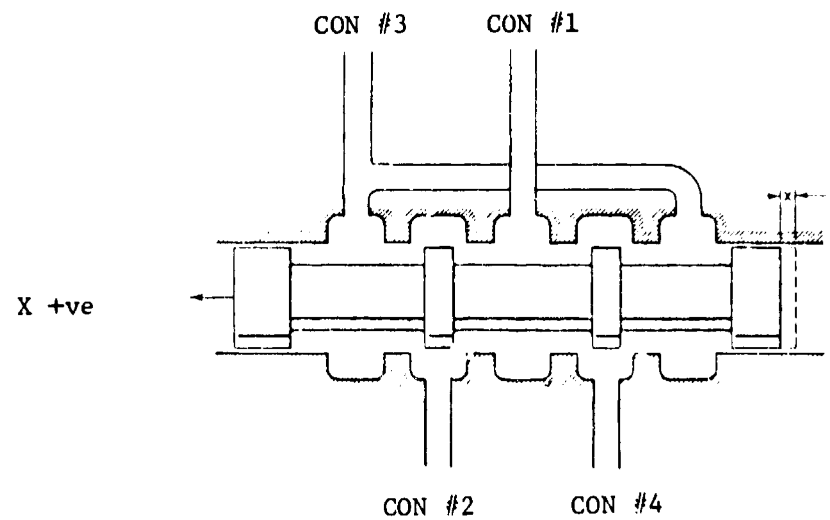


FIGURE 6.22-1 FOUR-WAY CONTROL VALVE

The Type #22 valve can be used either as a four-way or three-way control valve with an externally controlled time history input. The valve opening versus time is derived from the tabulated input data.

The valve model can handle any or all ports flowing simultaneously and if necessary, all or any group may open in the same direction. The center position of the valve is just a reference point. To input the data for the valve it is necessary to know the approximate characteristics to be simulated such as valve overlap; open center underlap, etc.

The valve opening versus position characteristics are described separately for each port. The description is the same for each one and if all inputs were identical the valve areas of each port would be equal versus valve position.

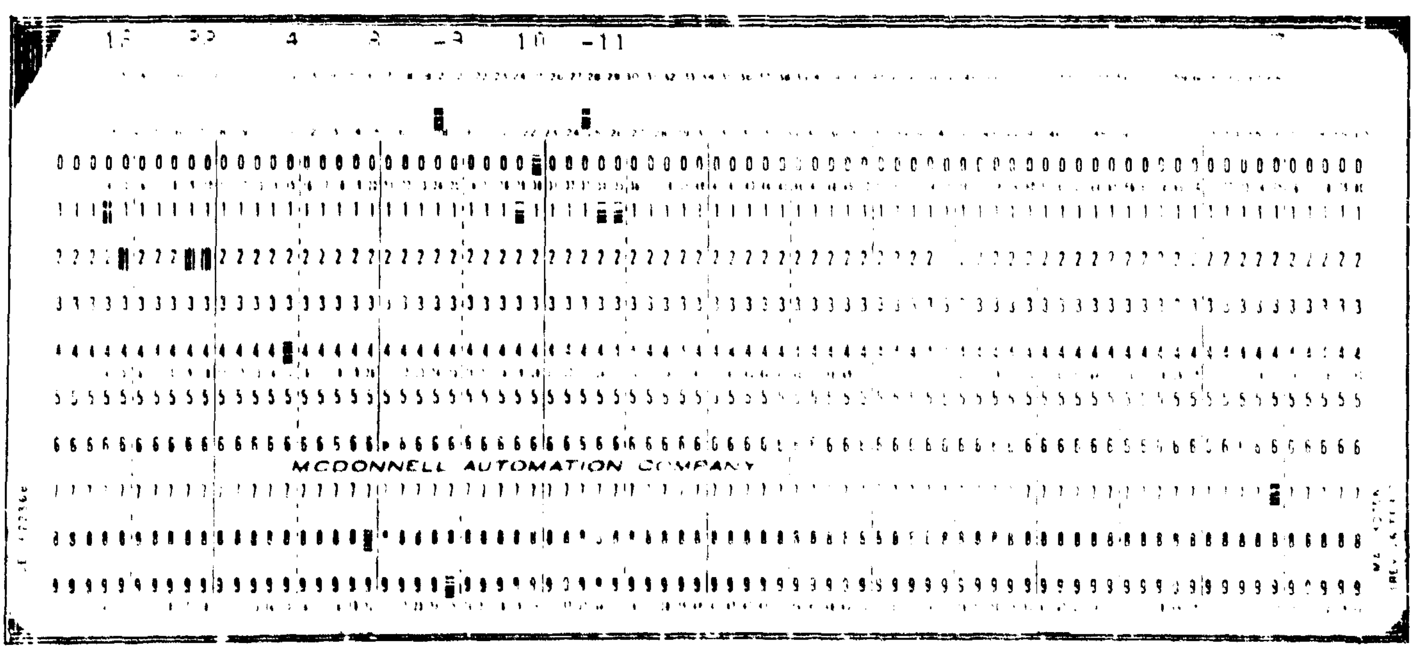
The user should choose from the family of curves in Figures 6.22-2 the valve area versus position characteristic best suited to his valve. The next task is to determine the projected cutoff and the max opening position which will give the required area slope. It should be noted that either of these two values may be beyond the input position range. Additional non-linearity can be simulated by the use of non-linear position versus time input.

Typical plots of valve area versus position, for the input card data are given in Figure 6.22-3.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 22
11-15	I5	Number of Real Data Cards = 4 or more
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	Line Number (with sign) attached to Connection 4
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	Number of Data Points on the Time Data Table
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

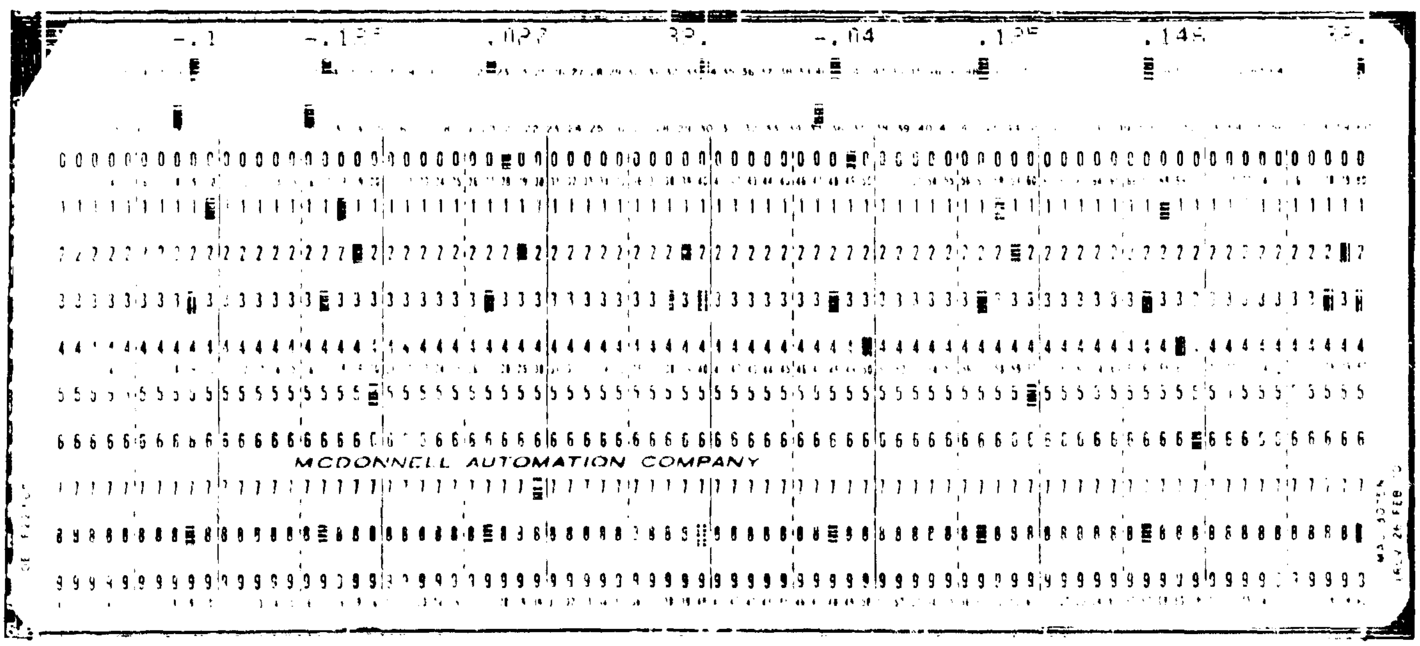
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Con #1-2 Projected Cutoff Position	in
11-20	E10.0	Con #1-2 Projected Max Opening Position	in
21-30	E10.0	Con #1-2 Max Effective Valve Area	in^2
31-40	E10.0	Con #1-2 Characteristic Curvature Coeff.	-
41-50	E10.0	Con #2-3 Projected Cutoff Position	in
51-60	E10.0	Con #2-3 Projected Max Opening Position	in
61-70	E10.0	Con #2-3 Max Effective Valve Area	in^2
71-80	E10.0	Con #2-3 Characteristic Curvature Coeff.	-

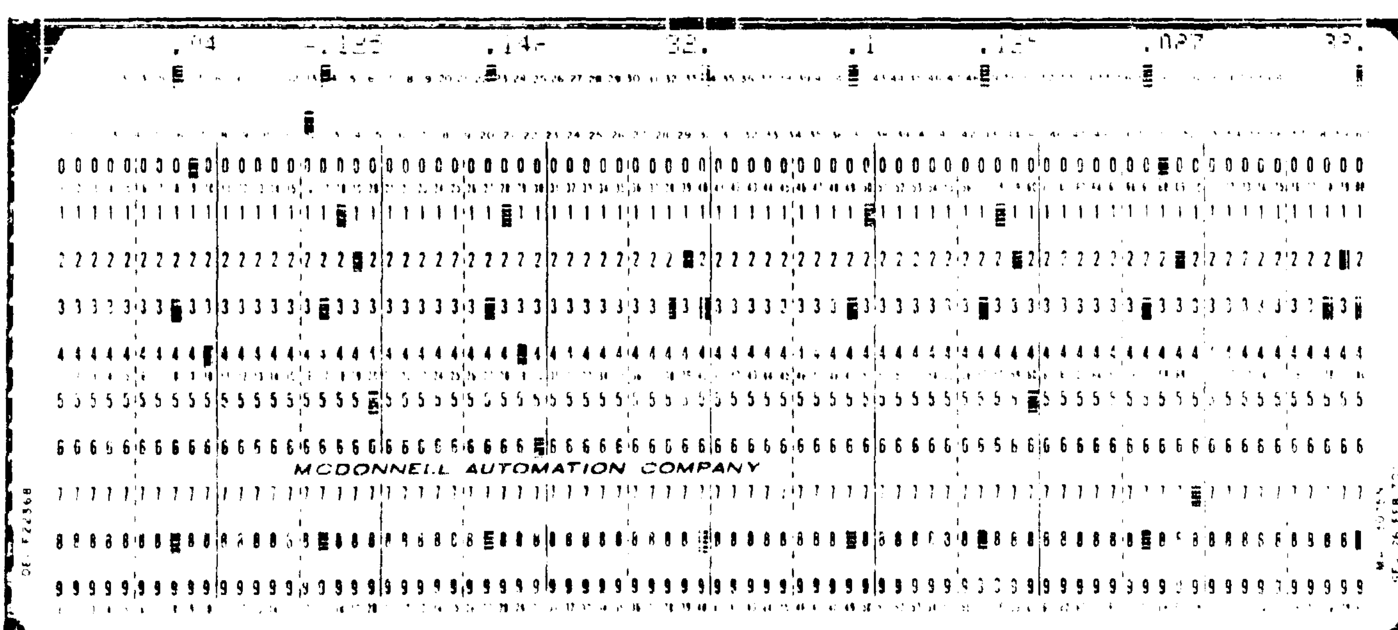
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Con #3-4 Projected Cutoff Position	in
11-20	E10.0	Con #3-4 Projected Max Opening Position	in
21-30	E10.0	Con #3-4 Max Effective Valve Area	in^2
31-40	E10.0	Con #3-4 Characteristic Curvature Coeff.	
41-50	E10.0	Con #4-1 Projected Cutoff Position	in
51-60	E10.0	Con #4-1 Projected Max Opening Position	in
61-70	E10.0	Con #4-1 Max. Effective Valve Area	in^2
71-80	E10.0	Con #4-1 Characteristic Curvature Coeff.	

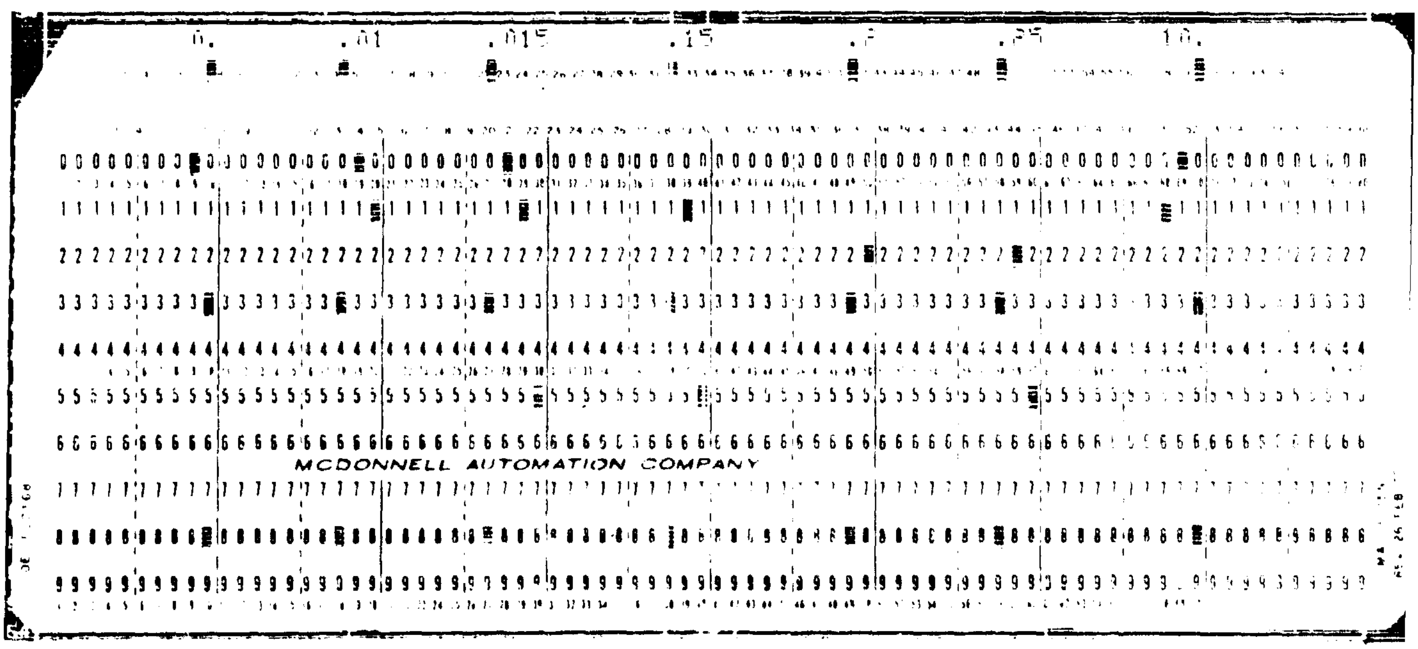
EXAMPLE CARD



CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Value - Should Be 0	sec
11-20	E10.0	(Enter as many time values	
21-30	E10.0	as Required using as many	
31-40	E10.0	columns and cards as	
41-50	E10.0	necessary - Final time	
51-60	E10.0	should be Final calculation	
61-70	E10.0	Time).	
71-80	E10.0		

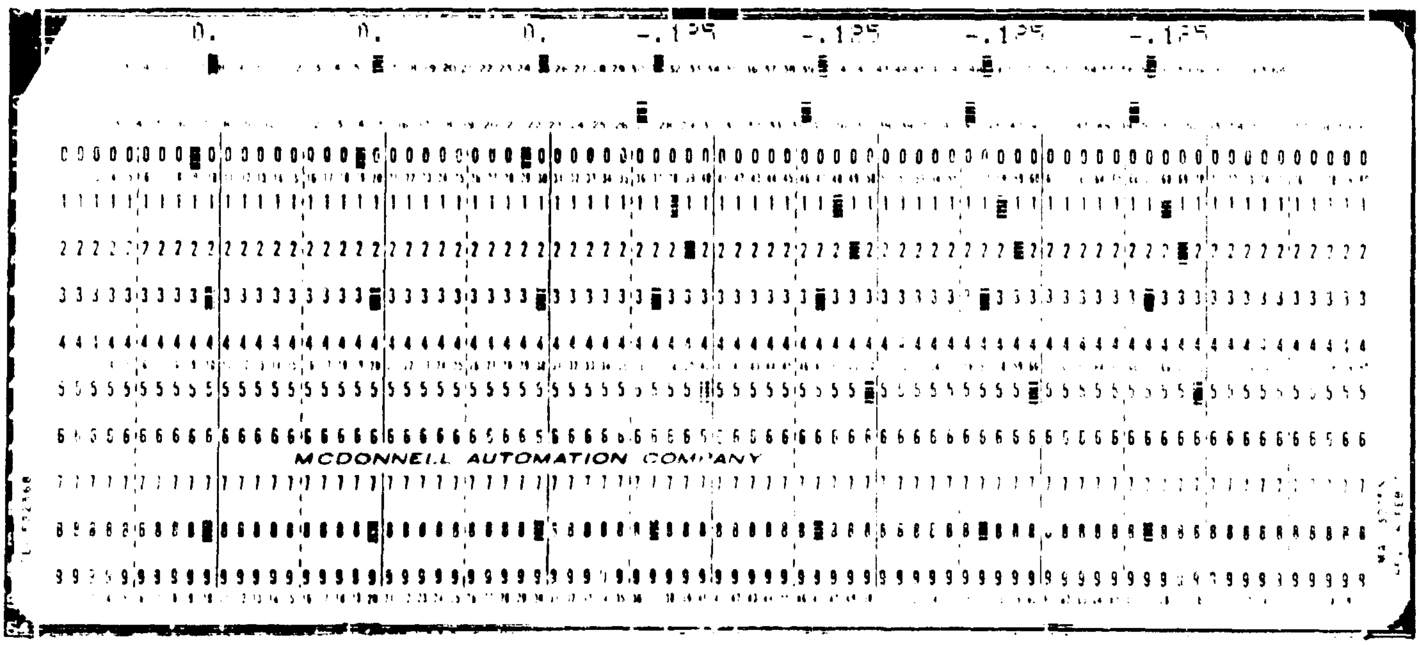
EXAMPLE CARD



CARD NUMBER 5

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Valve Position @ T = 0	in
11-20	E10.0	(Enter as many valve positions	
21-30	E10.0	as Time values)	
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



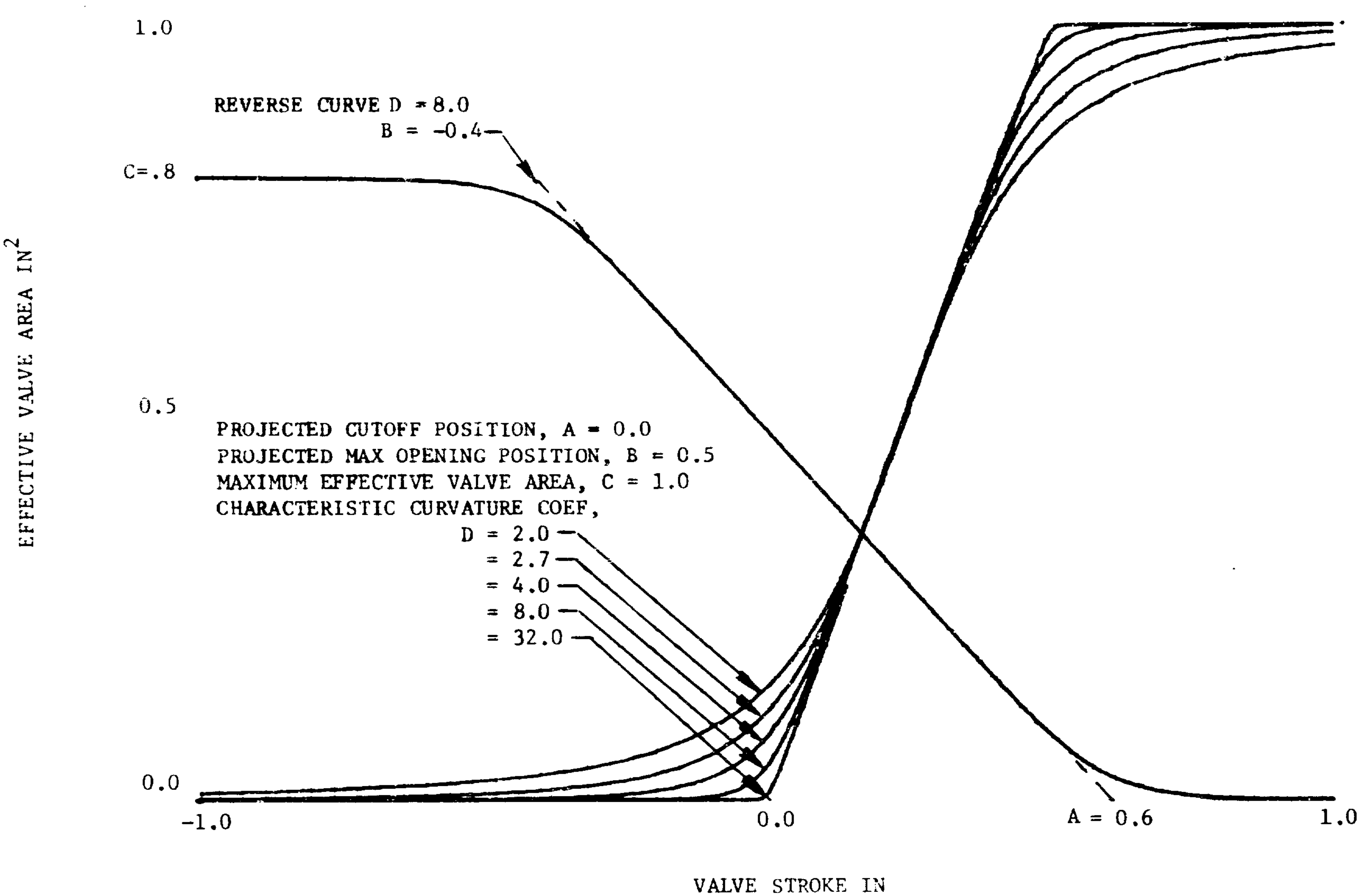


FIGURE 6.22-2
EFFECTIVE VALVE AREA CHARACTERISTICS

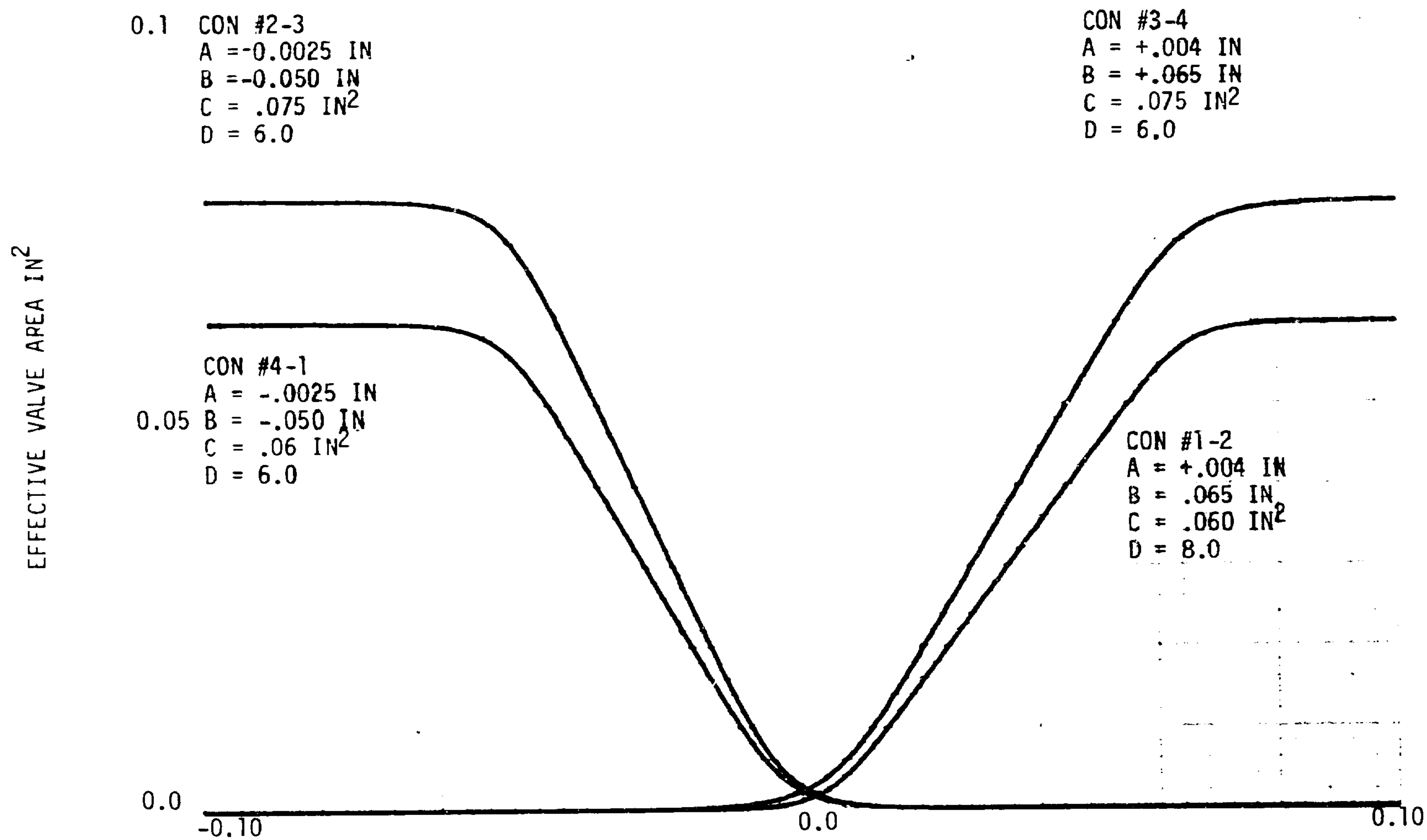


FIGURE 6.22-3
EFFECTIVE VALVE AREA VERSUS POSITION
FOR EXAMPLE DATA

6.30 CHECK VALVES

Check valves can be considered to fall into three general categories. The first includes those that remain fully open during system operation and hence do not need simulation of the poppet dynamics. The second category is for those which need dynamic simulation of the poppet when it is located between the fully open and closed positions. The third category is for special valves with damping and displacement characteristics. The following type is currently included in the program:

Type #31 Undamped Check Valve (CVAL31)

Type #32 Priority Valve (CREL32)

Type #33 One-Way Restrictor (CVAL33)

Type #34 Two-Stage Relief Valve (CVAL34)

6.31 TYPE #31 UNDAMPED CHECK VALVE

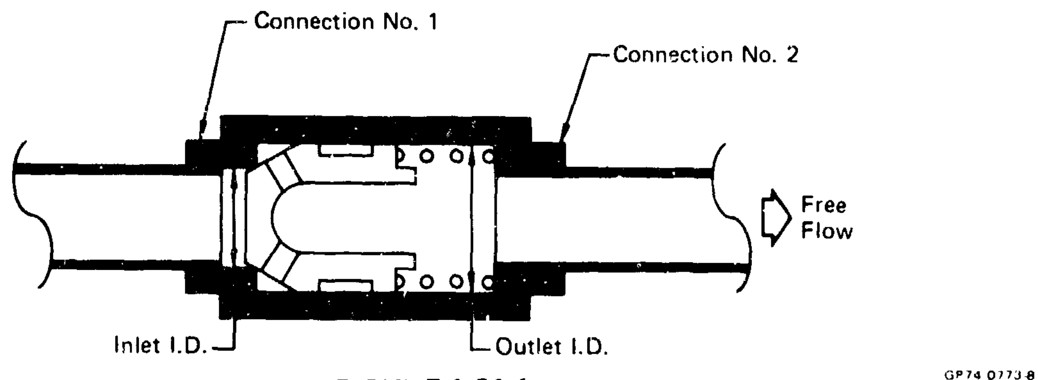


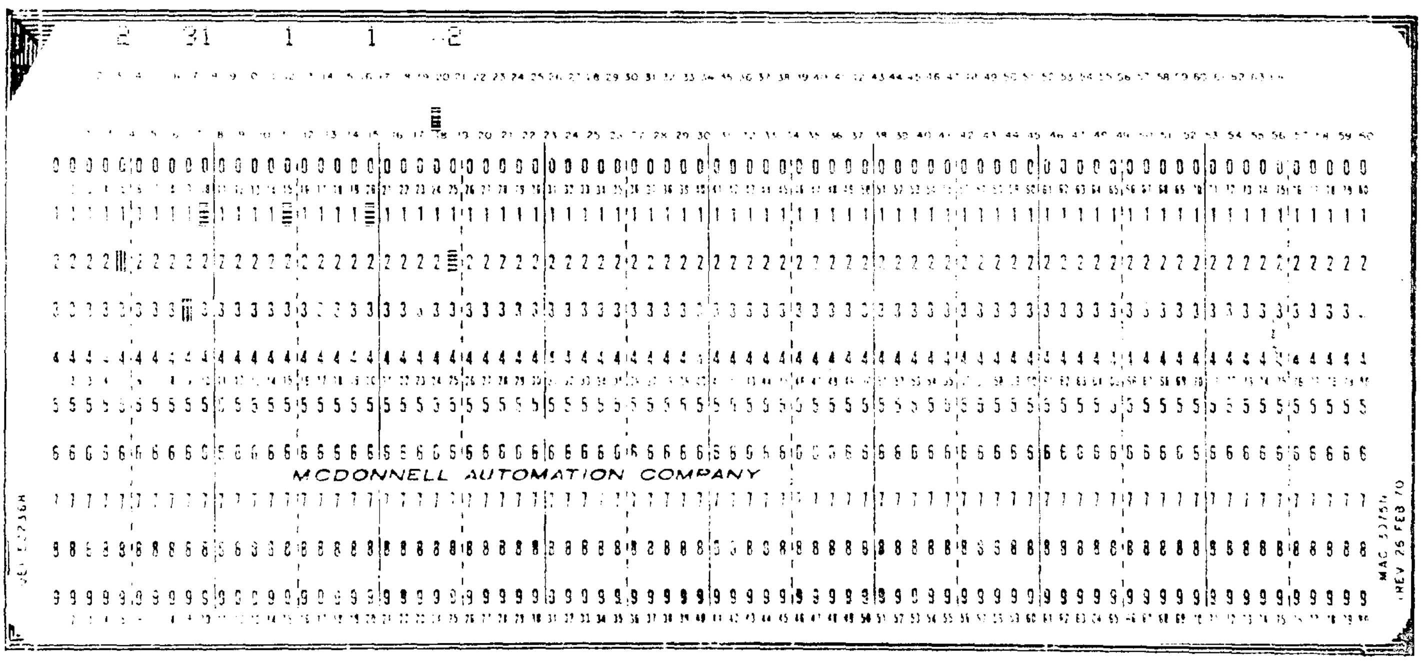
FIGURE 6.31-1
TYPE NO. 31 CHECK VALVE

A check valve that can open and close during operation without damping and displacement characteristics is defined as a Type #31. These type check valves are used repeatedly throughout the F-15 hydraulic system.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 31
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Connection Order 0 - Conventional 1 - Backwards
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

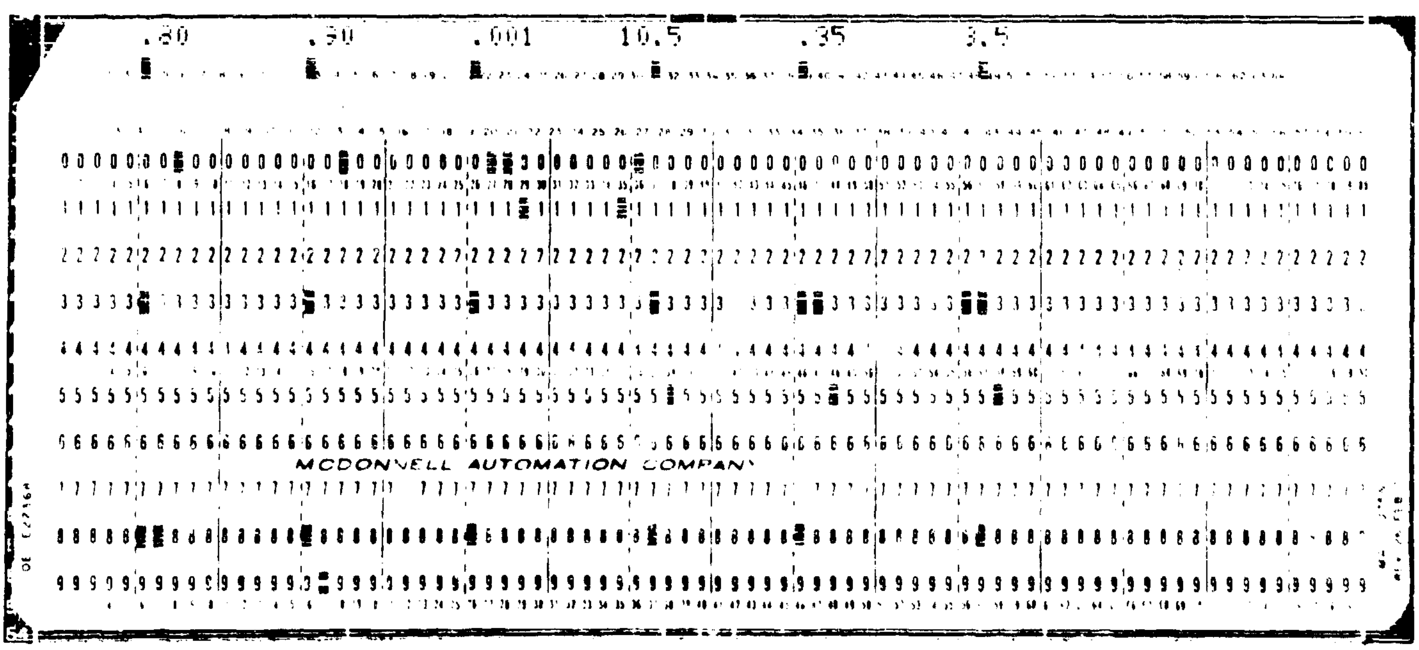
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet I.D.	in
11-20	E10.0	Outlet I.D.	in
21-30	E10.0	Poppet Mass	$lb\text{-}sec^2/in$
31-40	E10.0	Spring Constant	lb/in
41-50	E10.0	Max Poppet Stroke	in
51-60	E10.0	Spring Preload	lb
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.32 TYPE #32 PRIORITY VALVE

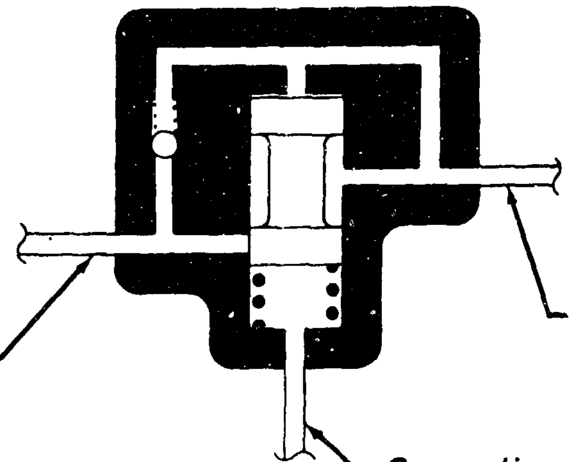


FIGURE 6-32-1
TYPE NO. 32 PRIORITY VALVE

The type #32 Priority Valve, Figure 6.32-1, is modeled as a combination of a check valve and relief valve in parallel between connections #1 and #2. The relief valve cracking pressure is referenced between connections #2 and #3.

If the pressure difference between connections #2 and #3 is less than the relief valve cracking pressure, flow is allowed in only one direction through the check valve from connection #1 to connection #2.

If the pressure difference between connections #2 and #3 is greater than the relief valve cracking pressure flow is allowed in either direction between connections #1 and #2.

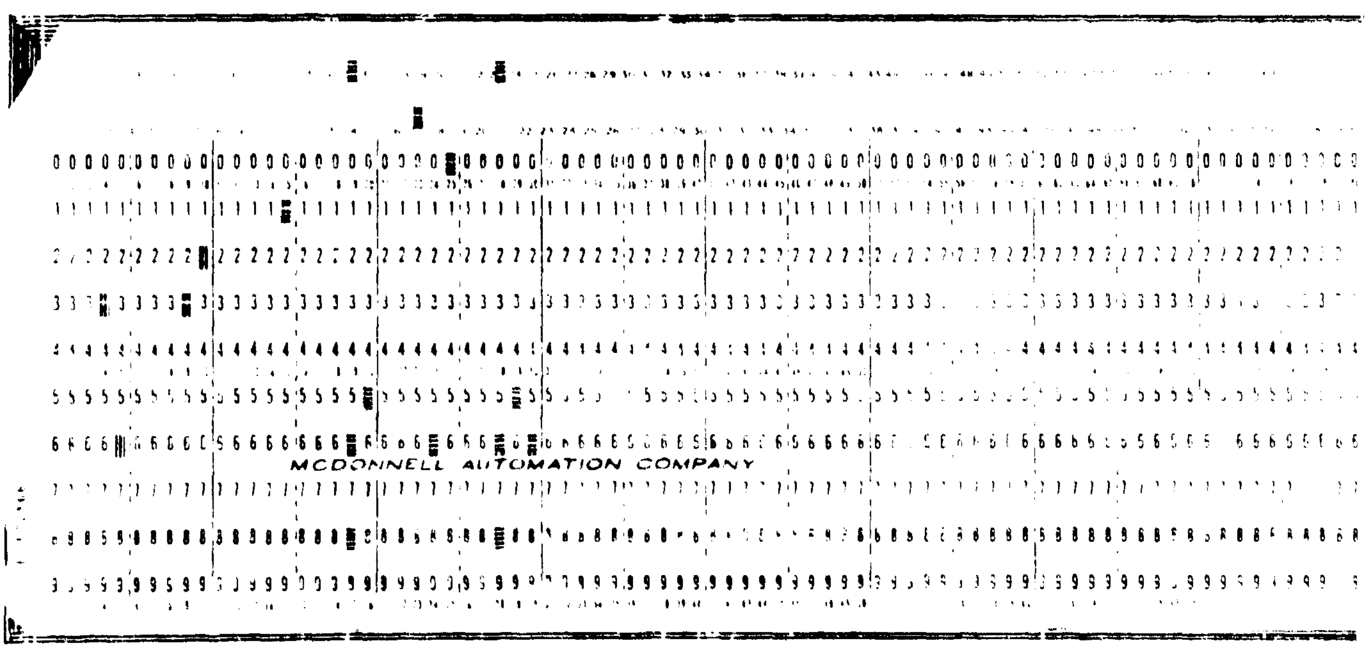
Connection #3 is used for reference only, there is no flow between connection #3 and the other connections to the valve. Since the program treats the line ending in connection #3 as a closed end line it is considered a node of the system.

During steady state calculations the program assumes the priority valve is open allowing flow in both directions in the leg when the system is pressurized, and closed when the system is depressurized.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 32
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	System Number
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

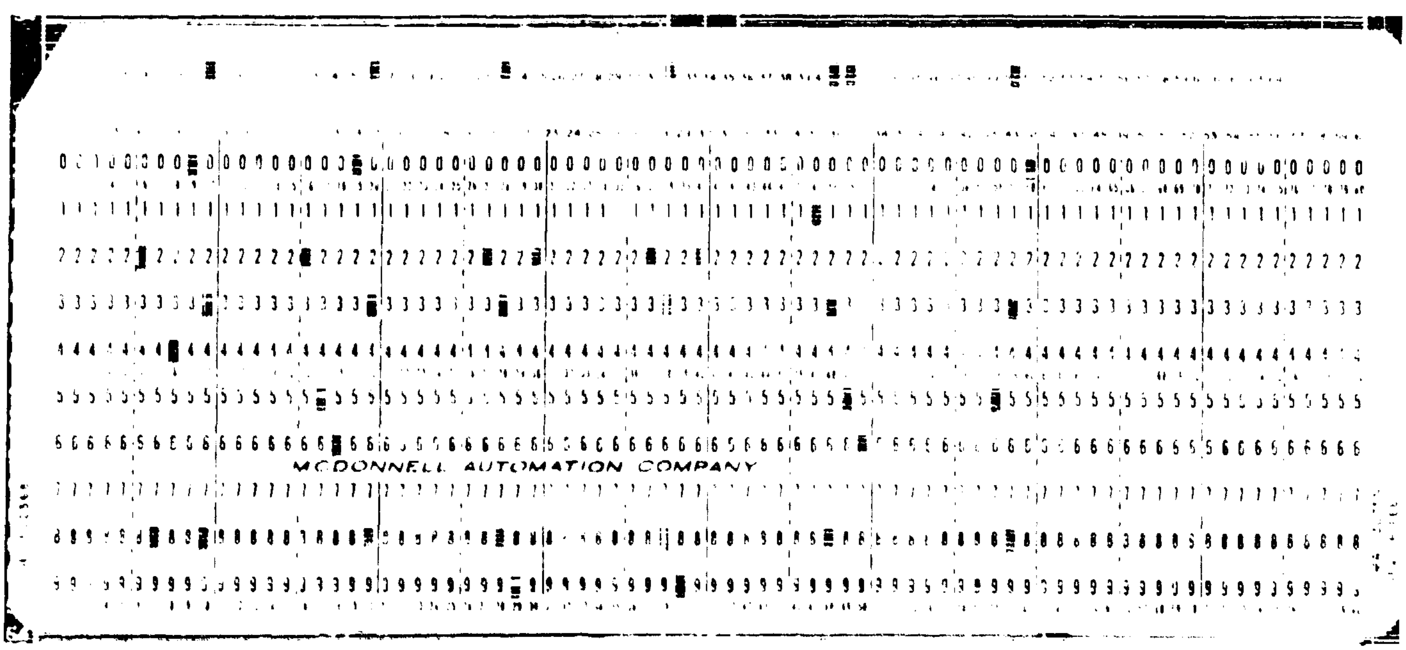
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Relief Valve Cracking Pressure	PSI
11-20	E10.0	Relief Valve Reseat Pressure	PSI
21-30	E10.0	Slope of Relief Characteristic	PSI/CIS
31-40	E10.0	Slope of Check Characteristic	PSI/CIS
41-50	E10.0	Leakage Impedance	PSI/CIS
51-60	E10.0	Check Valve Cracking Pressure	PSI
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.33 ONE-WAY RESTRICTOR

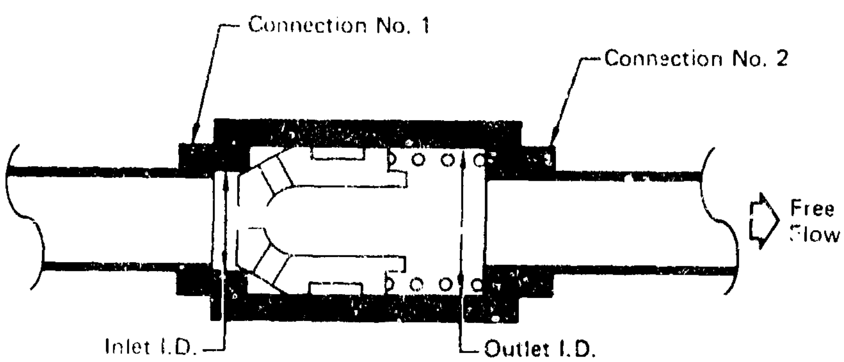


FIGURE 6.33-1

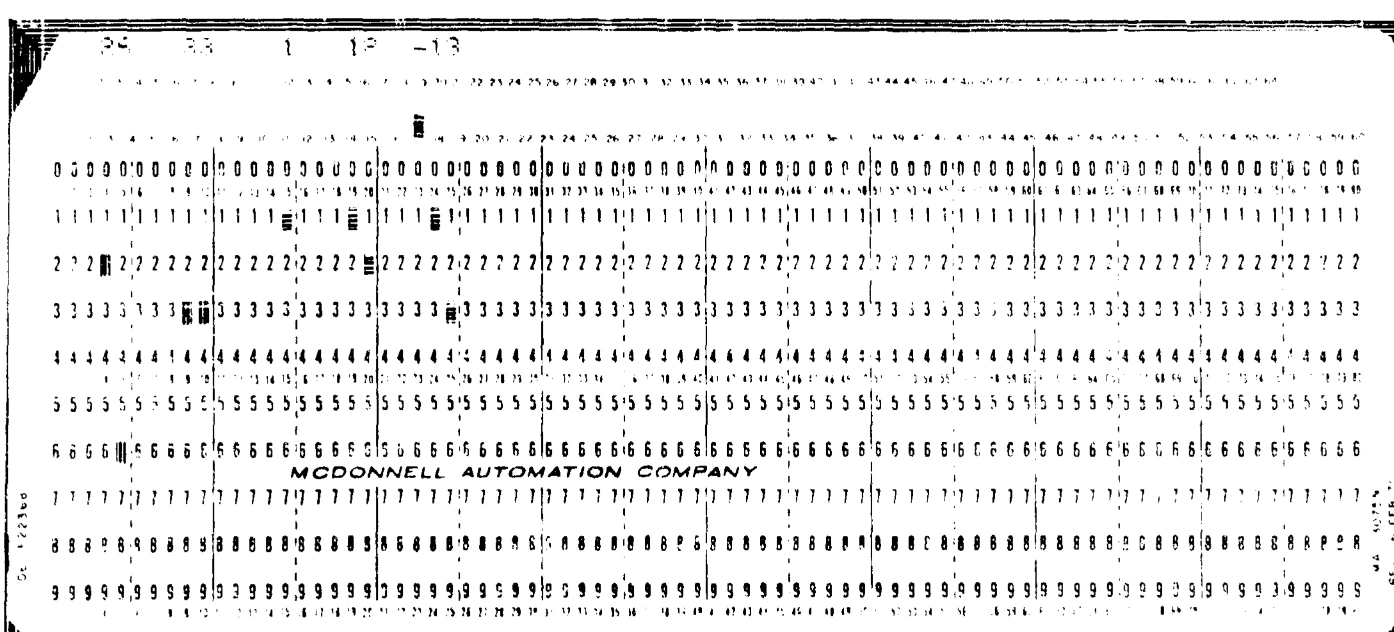
TYPE NO. 33 ONE-WAY RESTRICTOR

A simple undamped one-way restrictor is defined as a type #33. Although the actual mechanical configurations vary greatly the basic method of operation stays about the same. Figure 6.33-1 is typical of the many one-way restrictors in use on aircraft and in industry.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 33
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Connection Order 0 - Conventional 1 - Backwards
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

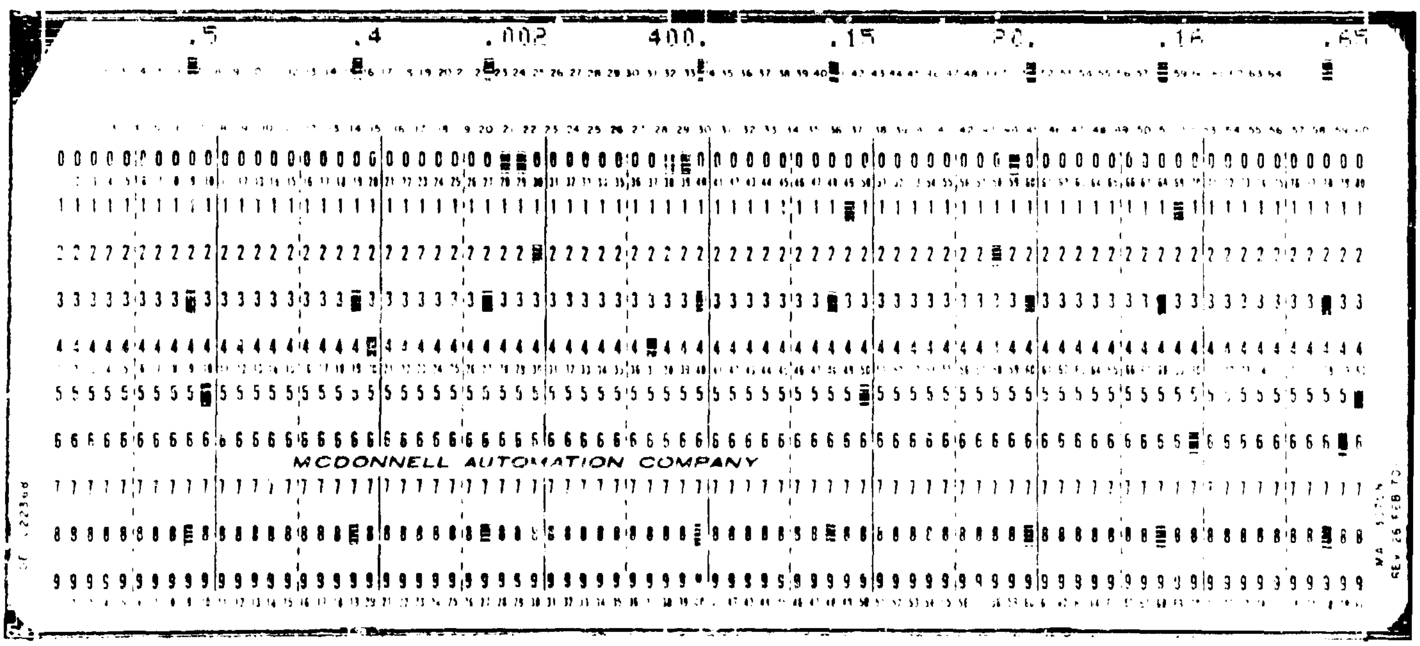
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet I. D.	IN
11-20	E10.0	Outlet I. D.	IN
21-30	E10.0	Poppet Mass	$\frac{\text{LB-SEC}^2}{\text{IN}}$
31-40	E10.0	Spring Constant	LB/IN
41-50	E10.0	Max Poppet Stroke	IN
51-60	E10.0	Spring Preload	LB
61-70	E10.0	Orifice Diameter	IN
71-80	E10.0	Discharge Coefficient	-

EXAMPLE CARD



6.34 TYPE #34 TWO STAGE RELIEF VALVE

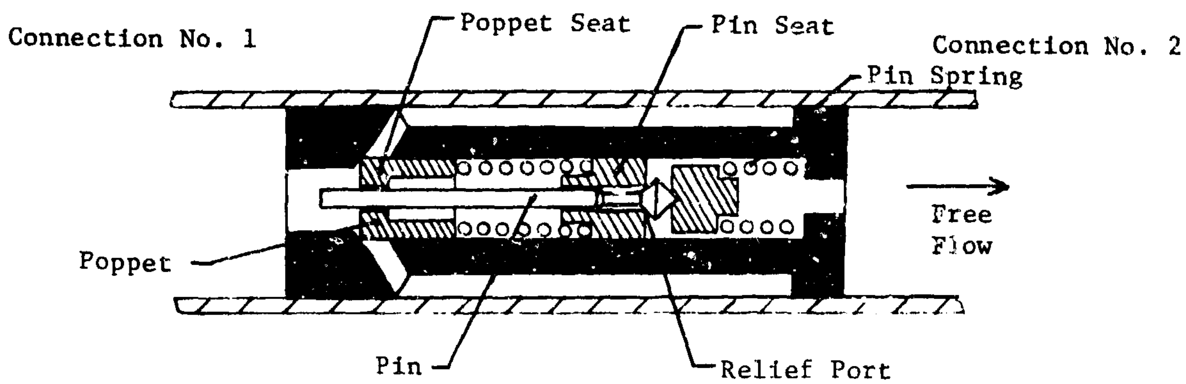


FIGURE 6.34-1

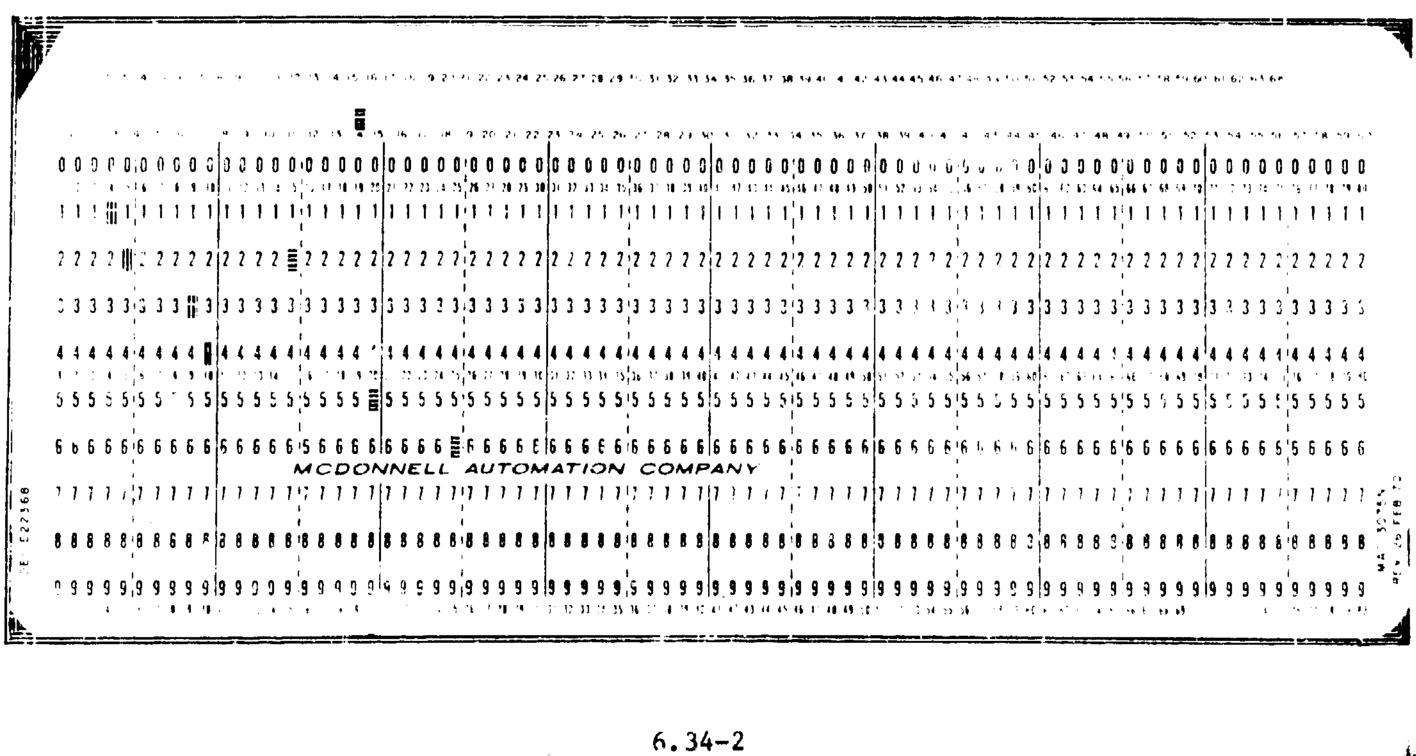
TYPE NO. 34 RELIEF VALVE

The two stage relief valve is a high response device used to limit pressure surges and to compensate for slow pump pressure controls. These type valves are used in the F-4 and F-15 hydraulic systems and are manufactured by the James Pond & Clark Division of the Circle Seal Corporation.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 34
11-15	I5	Number of Real Data Cards = 2
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

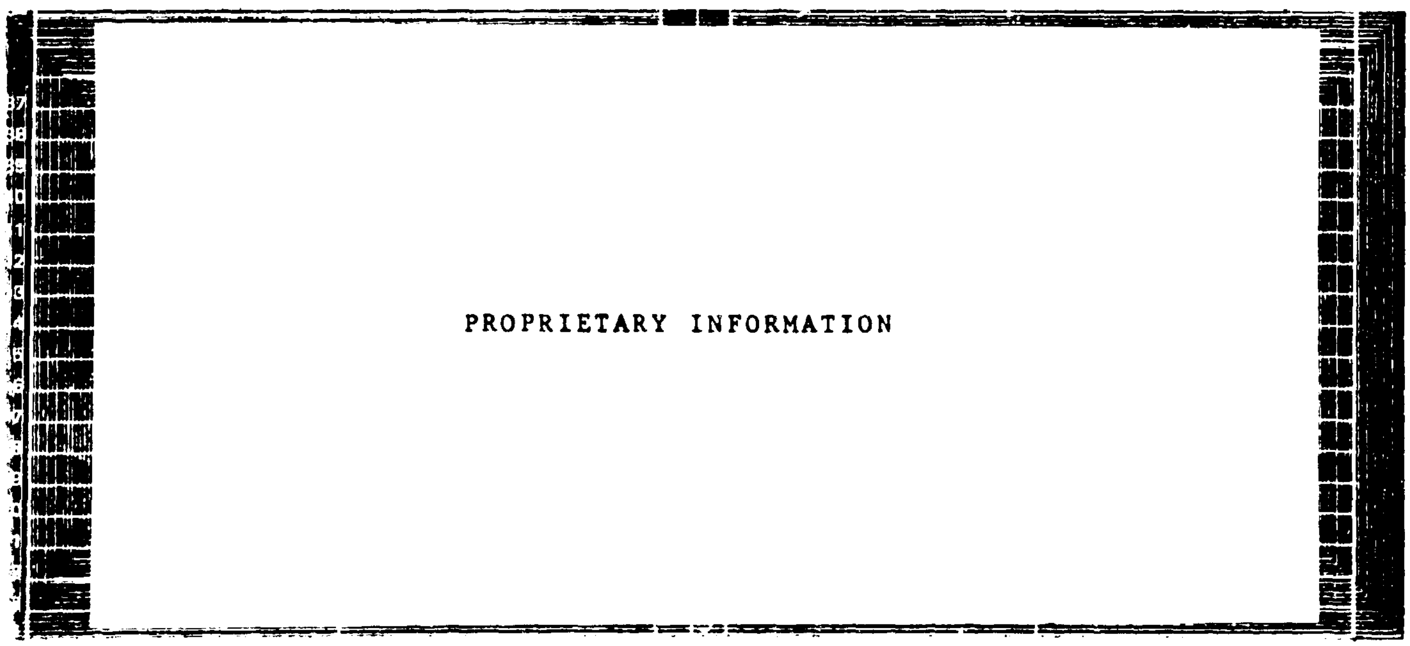
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Poppet Diameter	IN
11-20	E10.0	Maximum Poppet Displacement	IN
21-30	E10.0	Poppet Spring Constant	$\frac{LB}{IN}$
31-40	E10.0	Poppet Spring Preload	LB
41-50	E10.0	Relief Pressure	PSI
51-60	E10.0	Pin Leakage Coefficient at Poppet (Anular Passage Between Poppet and Pin)	$\frac{PSI}{CIS}$
61-70	E10.0	Pin Leakage Coefficient at Seat (Annular Passage Between Pin and Pin Seat)	$\frac{PSI}{CIS}$
71-80	E10.0	Diameter of Seat Relief Port	IN

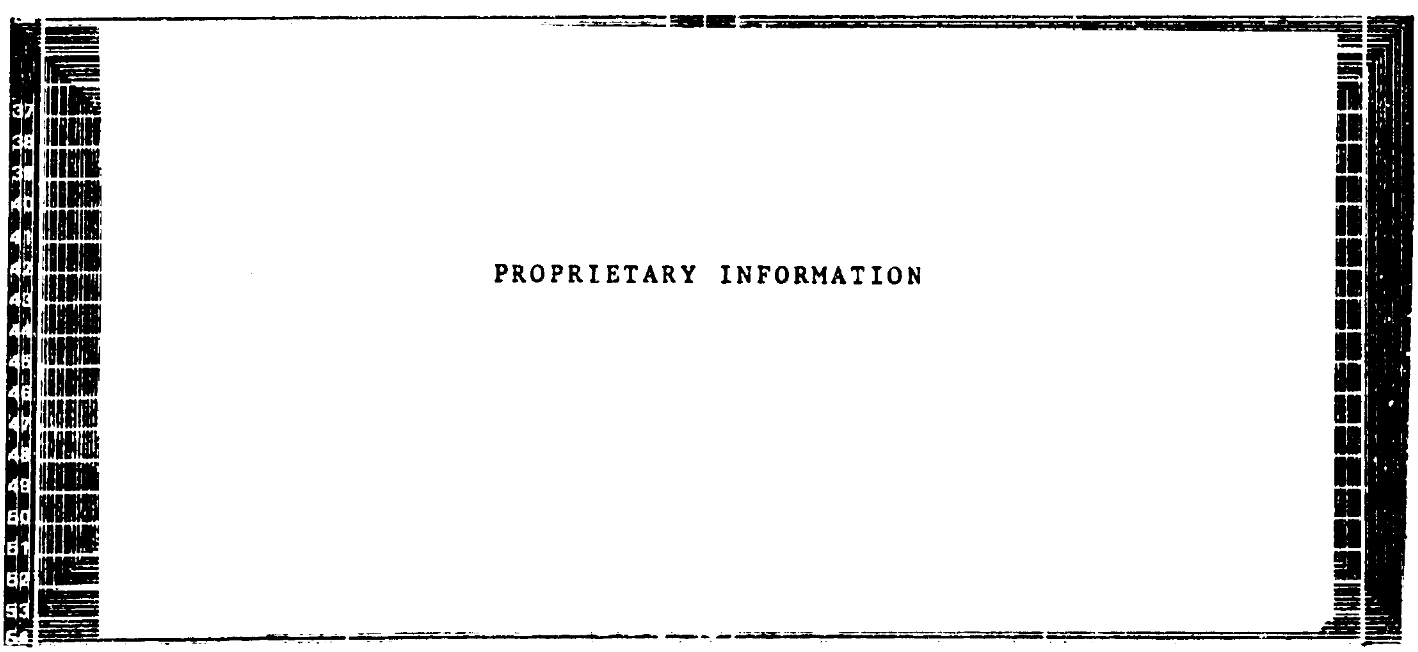
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Pin Rod Diameter	IN
11-20	E10.0	Pin Spring Constant	$\frac{LB}{IN}$
21-30	E10.0	Poppet Damping Factor	LB/IN/SEC
31-40	E10.0	Angle of Relief Flow	DEG
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.40 RESTRICTORS

There are several varieties of restrictors, including the simple orifice, Lee Jet and two-way. The following type is currently included in the program.

Type #41 Orifice Restrictor (REST41)

6.41 TYPE #41 ORIFICE RESTRICTORS

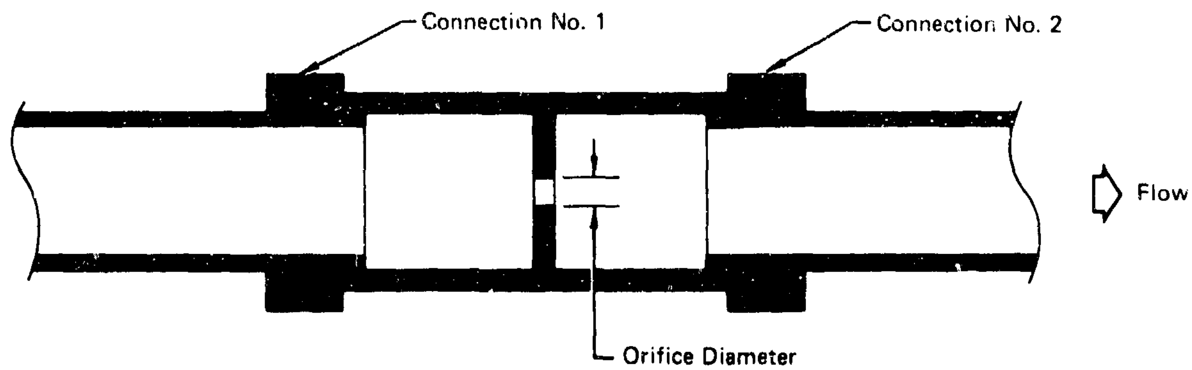


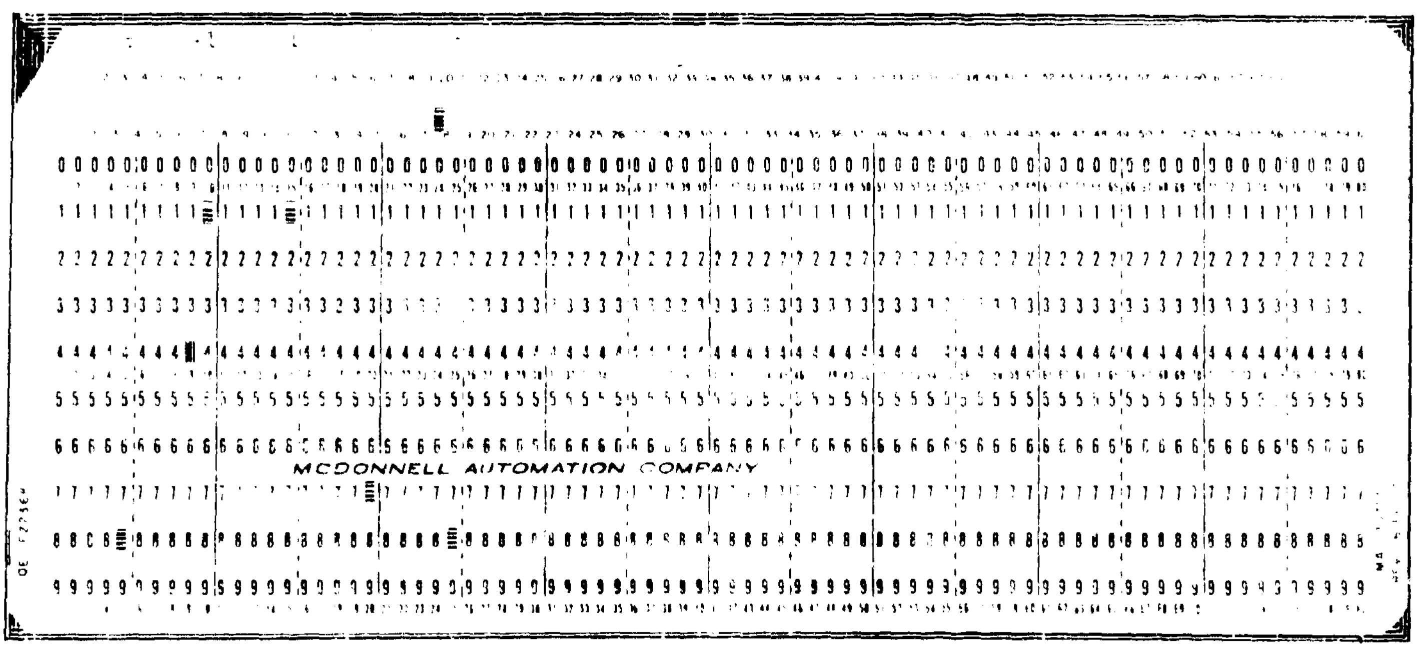
FIGURE 6.41-1
TYPE NO. 41 ORIFICE RESTRICTOR

Type #41 orifice restrictors need only the line connections and orifice dimensions as input data. Connection #1 can be assigned to either end since the discharge coefficient is assumed the same for flow in either direction.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 41
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

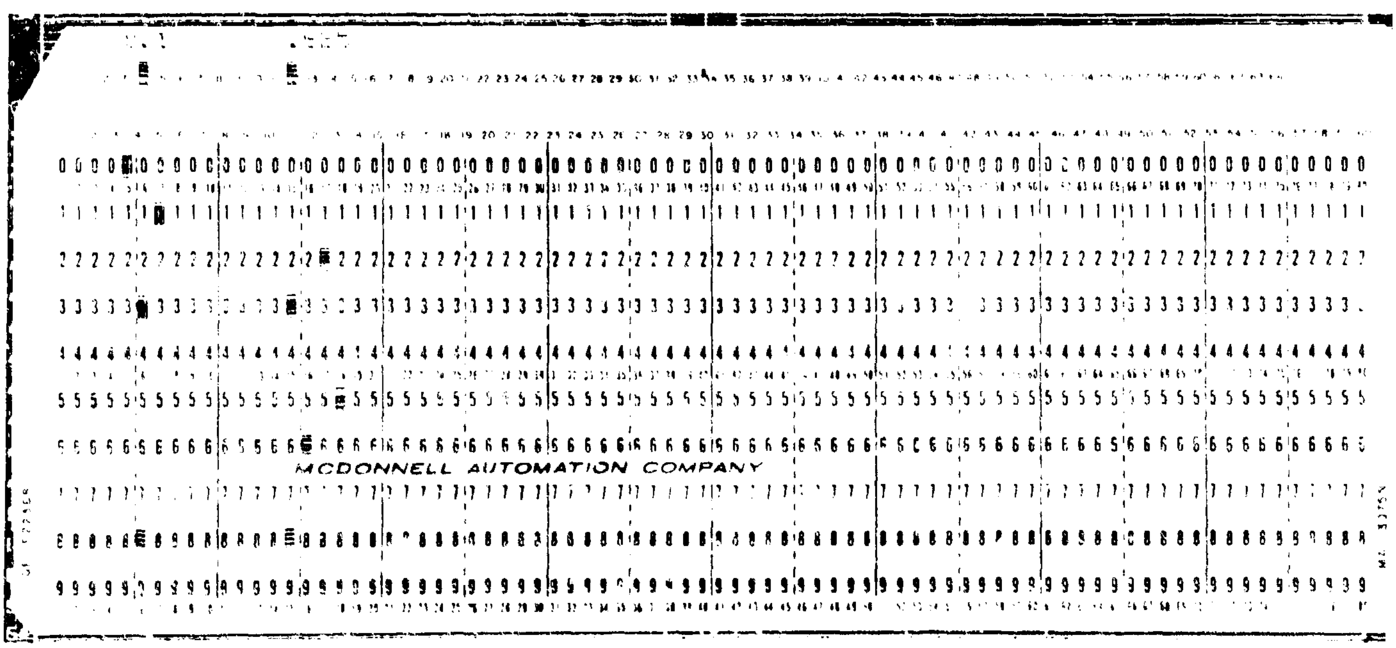
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Orifice Diameter	in
11-20	E10.0	Orifice Discharge Coeff.	-
21-30	E10.0		
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.50 PUMPS

The dynamic characteristics of pump require a comprehensive list of input data. With experience the programmer will be able to select some input parameters he would like to change from this input data, for varying the pump characteristics. The following pump types are currently included in the programs:

Type #51   F-15 Pump (PUMP51)

Type #54   Space Shuttle Pump (PUMP54)

6.51 TYPE #51 - F-15 PUMP

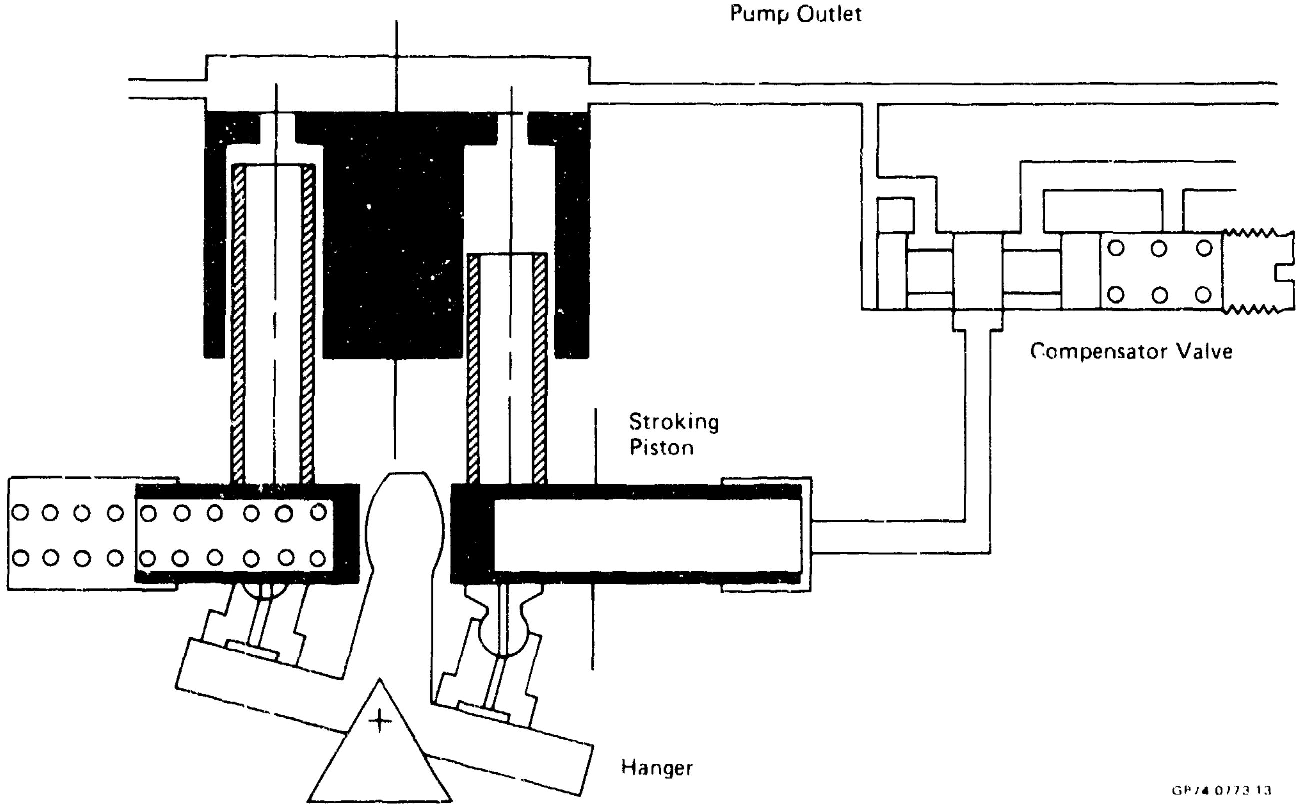


FIGURE 6.51-1
TYPE NO. 51 PRESSURE REGULATED VARIABLE DISPLACEMENT PUMP

The ABEX F-15 pump simulated by PUMP51 is perhaps the most complex of all the component subroutines and its dynamic characteristics are sufficiently complex, to warrant special treatment.

In modifying pump variables the user should be very careful. A pump is essentially a complex underdamped servo system which is prone to instability, and it is easy to make it worse.

In developing the model it has been necessary to assume certain damping characteristics and estimate others. Some of these characteristics do not fall within the classical concepts of damping, so the result is a best guess. Subsequent verification testing will show if this guess was correct. For details of the damping factor derivation see Vol. II.

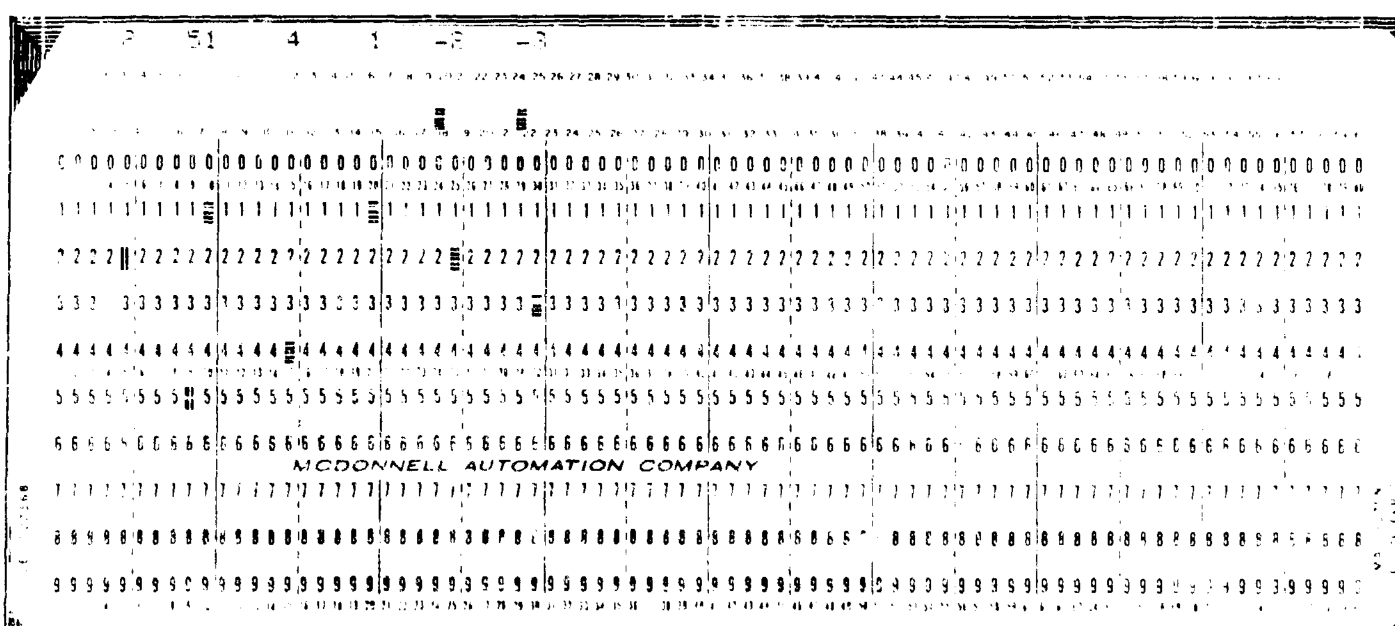
The ABEX F-15 pump has a fast response going from 10% to 90% stroke in approximately 15 milliseconds, so the user should take care in designing the system, to avoid cavitation problems, caused by rapidly changing flow demands in the suction lines.

The input data for the F-15 pump is specific to that pump and cannot be used for other pumps.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 51
11-15	I5	Number of Real Data Cards = 4
16-20	I5	Line Number (with sign) attached to Connection 1 (Inlet)
21-25	I5	Line Number (with sign) attached to Connection 2 (Outlet)
26-30	I5	Line Number (with sign) attached to Connection 3 (Case Drain)
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

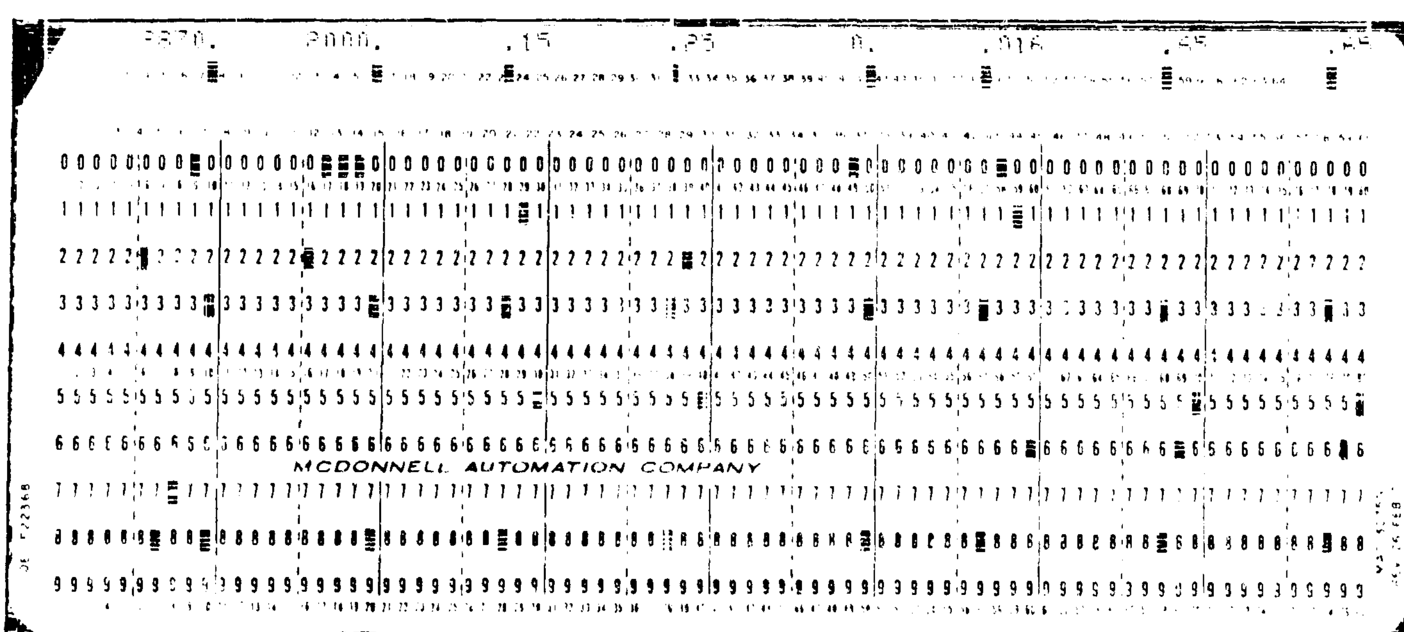
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Pressure at which valve begins to open from outlet to actuator	PSI
11-20	E10.0	Valve spring rate	LBS/IN
21-30	E10.0	Compensator Valve Area	IN**2
31-40	E10.0	Slot width	IN
41-50	E10.0	Flow force on spool	LB
51-60	E10.0	Valve overlap	IN
61-70	E10.0	Discharge Coefficient - Outlet to Actuator	--
71-80	E10.0	Discharge Coefficient - Actuator to Case	--

EXAMPLE CARD



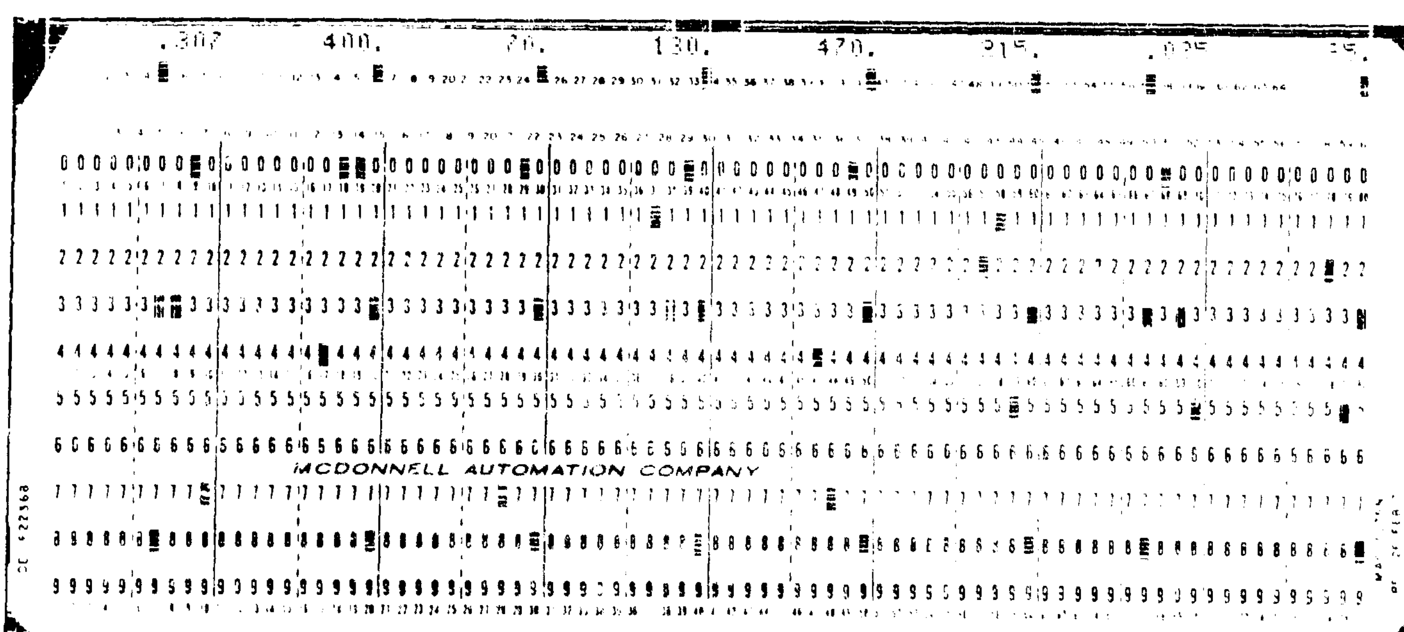
CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Actuator Area	IN**2
11-20	E10.0	Actuator Pressure Due to Spring Force at Zero Pump Displacement	PSI
21-30	E10.0	Actuator Pressure due to Spring Force at Maximum Pump Displacement	PSI
31-40	E10.0	Actuator Pressure Due to Piston Acceleration @ 3600 RPM	IN**2/SEC
41-50	E10.0	Actuator Pressure Inputed at 3600 RPM and Zero Pump Displacement +	PSI
51-60	E10.0	Actuator Pressure at 3600 RPM and Maximum Pump Displacement +	PSI
61-70	E10.0	Slope of Pressure vs RPM Curve +	PSI/RPM
71-80	E10.0	Hanger Damping*	PSI/IN/SEC

* = Referenced to Actuator Pressure

+ = Excluding the effects of pressure due to the spring and pumping piston acceleration.

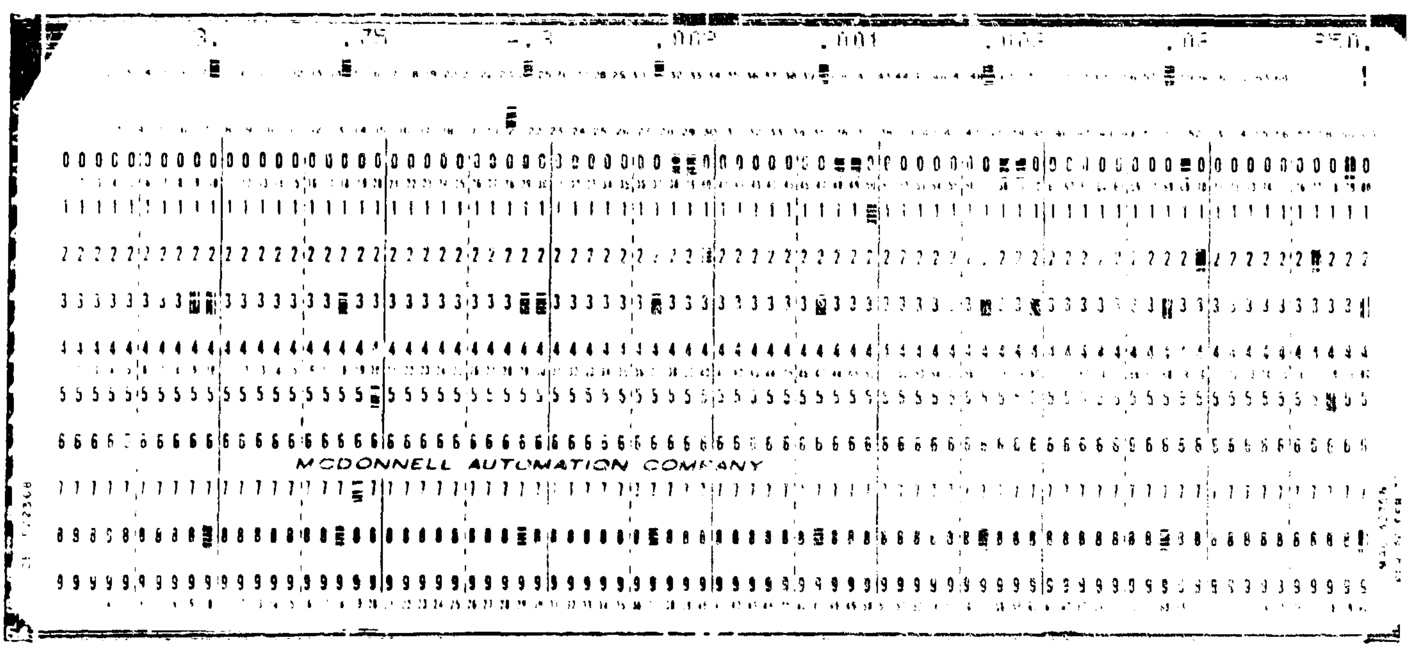
EXAMPLE CARD



CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Theoretical Maximum Pump Displacement	IN**3/REV
11-20	E10.0	Maximum Actuator Displacement @ Maximum Flow	IN
21-30	E10.0	Minimum Actuator Displacement @ Minimum Pump Flow (-ve)	IN
31-40	E10.0	Coefficient of Actuator Leakage at Zero Pump Displacement	CIS/PSI
41-50	E10.0	Coefficient of Actuator Leakage at Maximum Pump Displacement	CIS/PSI
51-60	E10.0	Coefficient of Pump Leakage	CIS/PSI
61-70	E10.0	Coefficient of Leakage from Case to Inlet	CIS/PSI
71-80	E10.0	Case Volume	IN**3

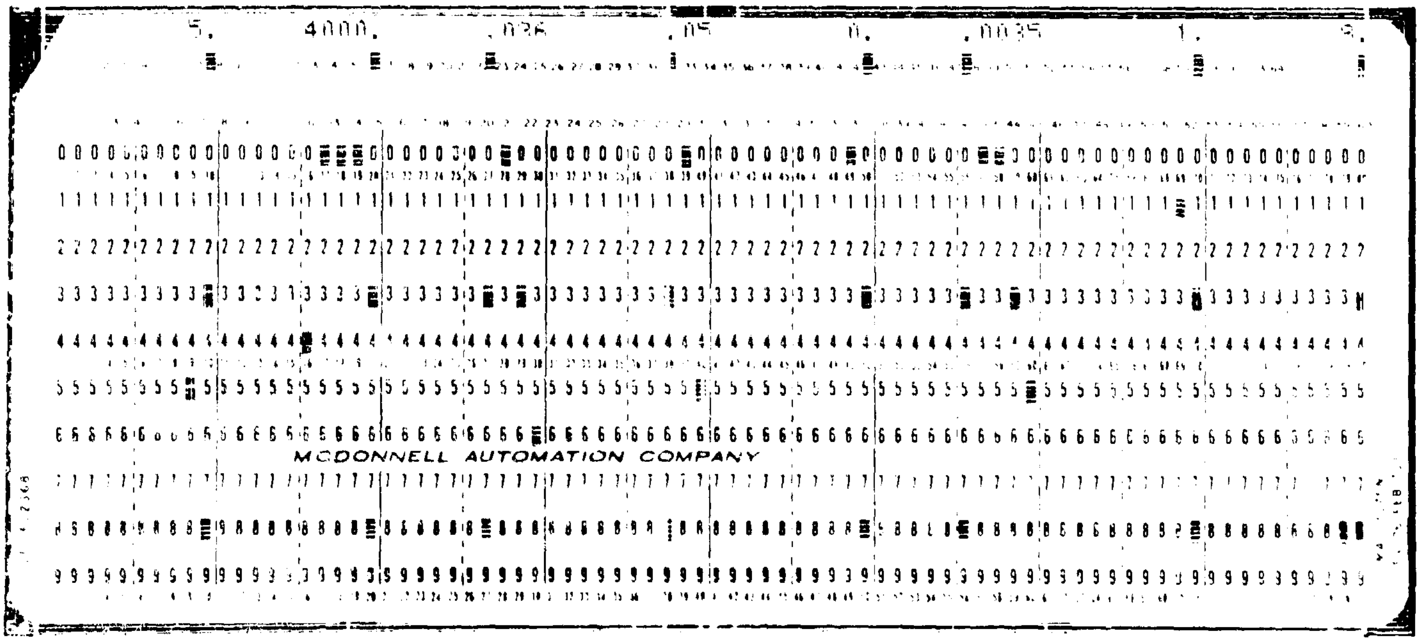
EXAMPLE CARD



CARD NUMBER 5

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Minimum Inlet Pressure	PSI
11-20	E10.0	Pump Operating Speed	RPM
21-30	E10.0	Coefficient of Outlet Flow Due to Actuator Motion	CIS/(IN/SEC)
31-40	E10.0	Maximum Valve Displacement	IN
41-50	E10.0	Pressure at which valve is open from outlet to actuator	PSI
51-60	E10.0	Hanger Inertia Referred to the Actuator	LBS-SEC**2/IN
61-70	E10.0	Actuator Volume	IN**3
71-80	E10.0	Outlet Volume	IN**3

EXAMPLE CARD



6.54 TYPE #54 SPACE SHUTTLE PUMP (F-14 PUMP)

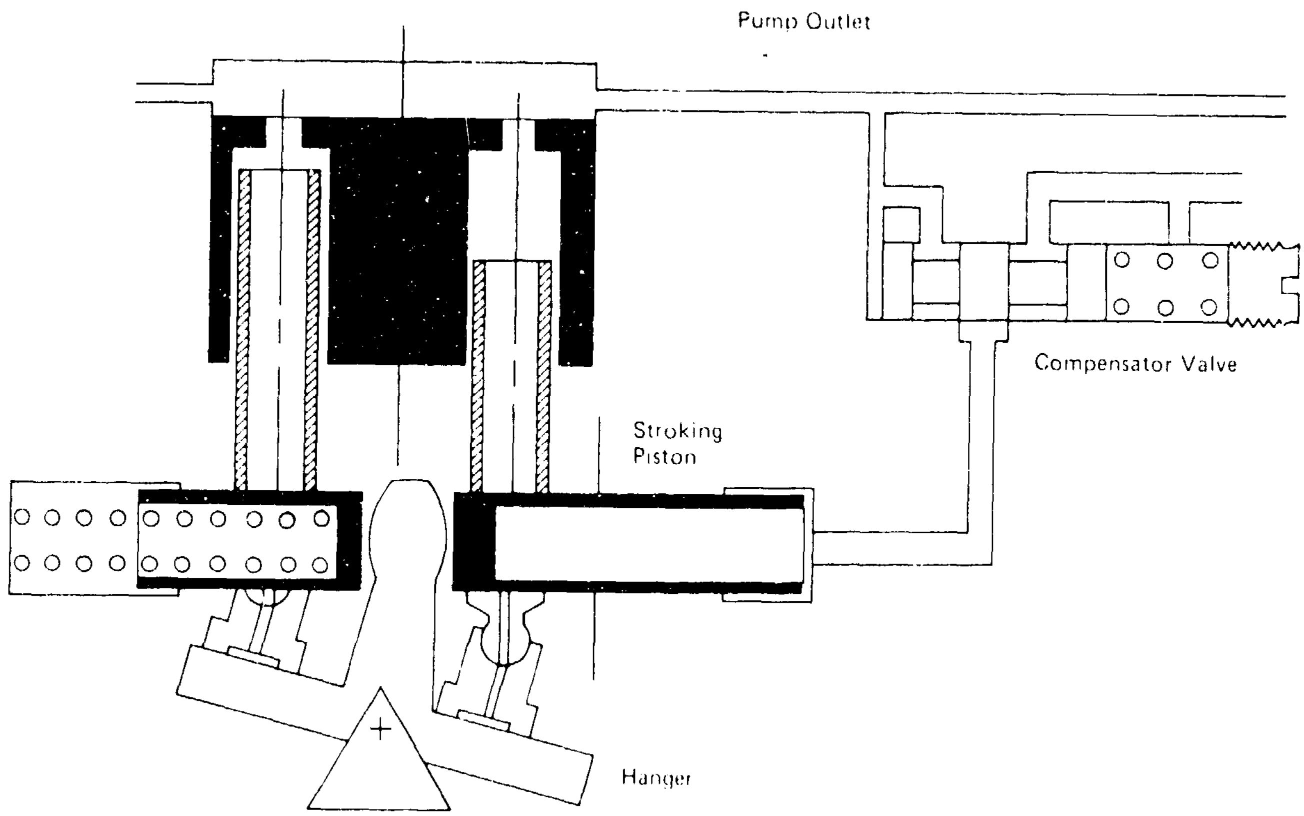


FIGURE 6.54-1

TYPE NO. 54 PRESSURE REGULATED VARIABLE

DISPLACEMENT PUMP - SCHEMATIC DIAGRAM

Type #54 pump is a simulation of the ABEX F-14 pump. In developing the model it has been necessary to assume certain damping and leakage characteristics and estimate others. See Volume II for an explanation of these characteristics. The pump is essentially a complex underdamped servo system which is prone to instability. The user should be careful in modifying pump variables to avoid meaningless output.

The input data for the F-14 pump is specific to that pump and cannot be used for other pumps.

When using the PUMP 54 model, the selected system or systems can initially be depressurized using a coded system number in columns 71-75 of the first data card.

Card Column 31-35		
0	=	All systems are normal.
+N	=	System #N is normal, all others are depressurized
-N	=	System #N is depressurized, all others are normal

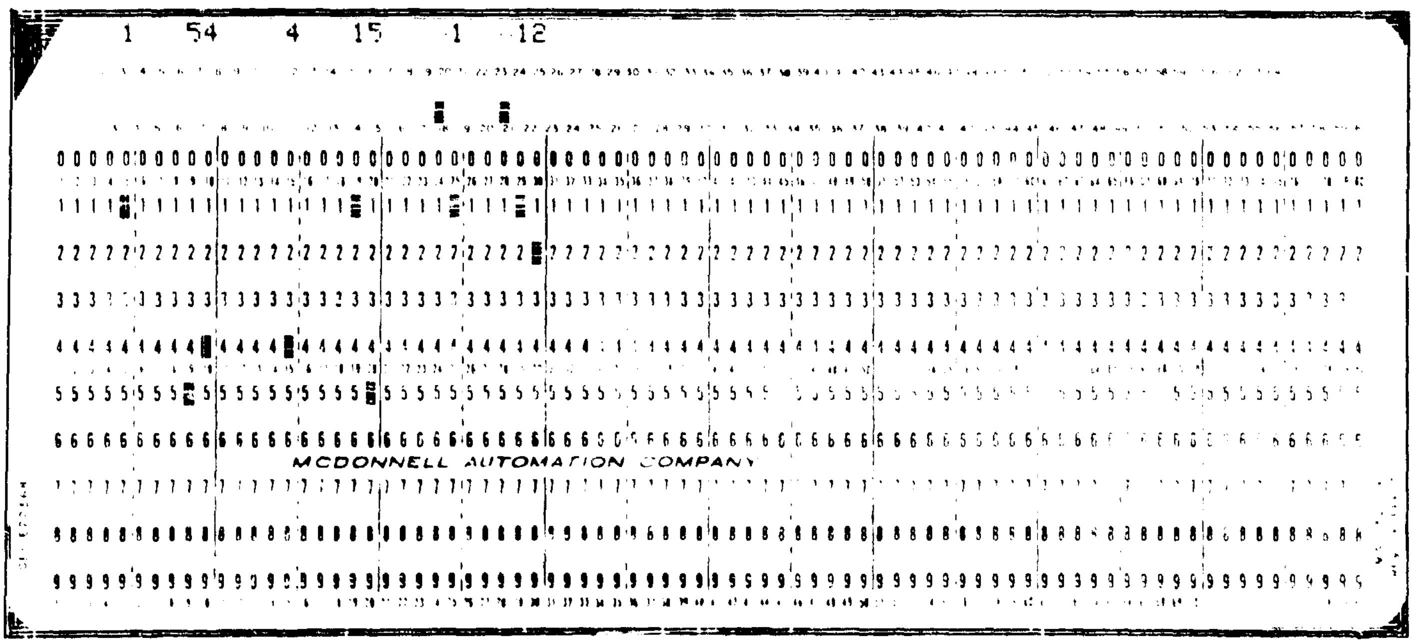
This indicator is used by the Elevon, TVC and Rudder speedbrake subroutines to determine the initial positions of their switching valves and the system which is supplying the secondary actuator leakage.

Depressurization or repressurization during the transient simulation can be initiated by inputting a time value in columns 41-50 of Card #5.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 54
11-15	I5	Number of Real Data Cards = 4
16-20	I5	Line Number (with sign) attached to Connection 1 (Inlet)
21-25	I5	Line Number (with sign) attached to Connection 2 (Outlet)
26-30	I5	Line Number (with sign) attached to Connection 3 (Case Drain)
31-35	I5	System Number
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

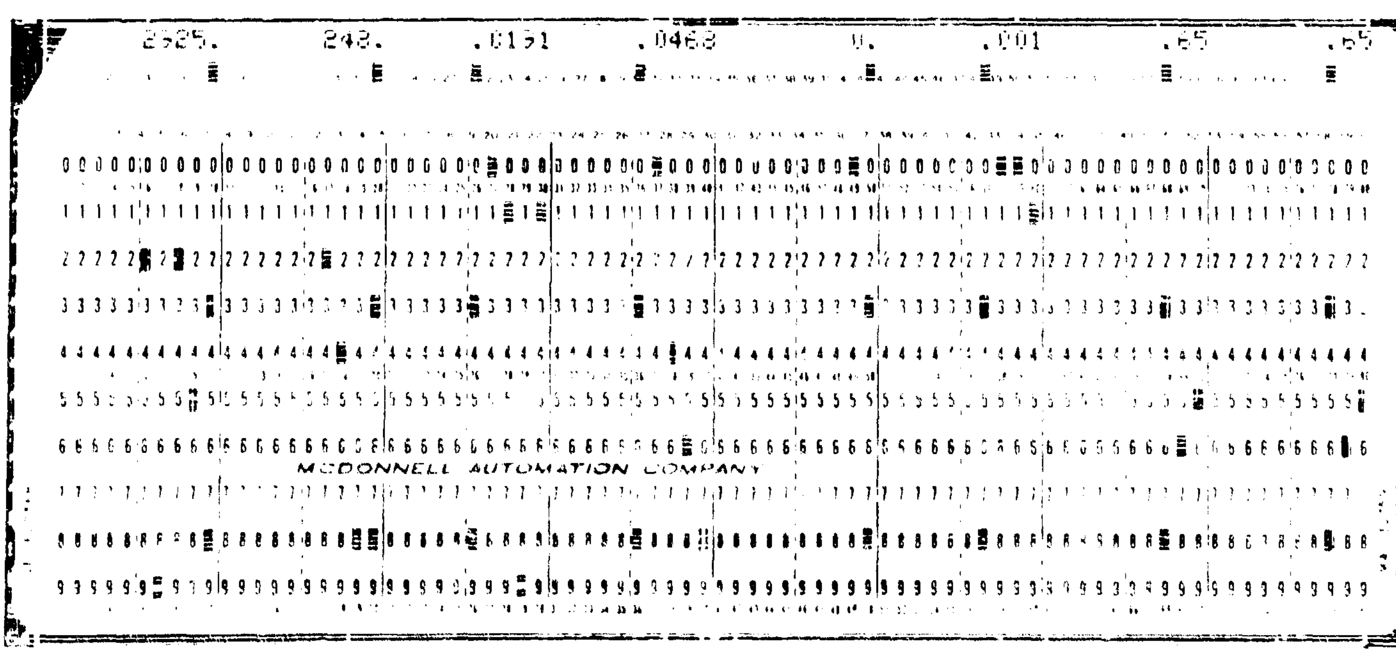
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Pressure at which valve begins to open from outlet to actuator	PSI
11-20	E10.0	Valve spring rate	LBS/IN
21-30	E10.0	Compensator valve area	IN**2
31-40	E10.0	Radius of valve port	IN
41-50	E10.0		
51-60	E10.0	Valve overlap	IN
61-70	E10.0	Discharge Coefficient - Outlet to Actuator	--
71-80	E10.0	Discharge Coefficient - Actuator to Case	--

EXAMPLE CARD



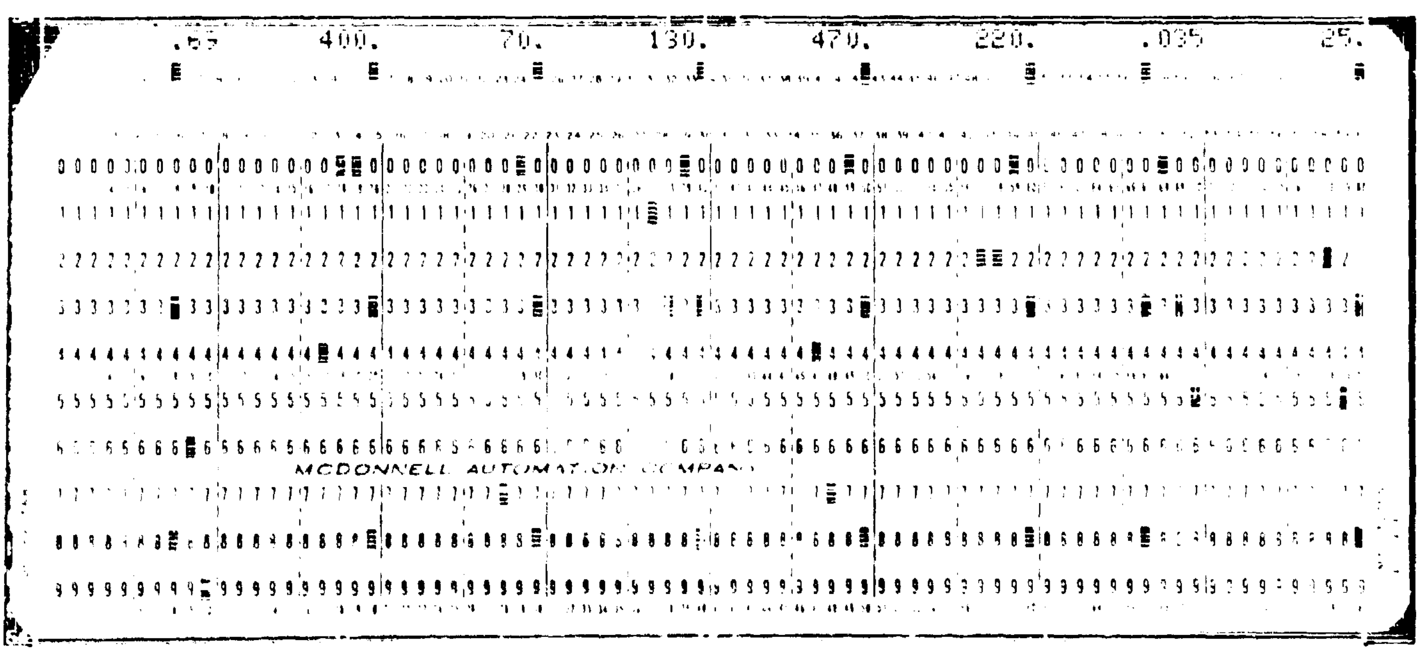
CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Actuator Area	IN**2
11-20	E10.0	Actuator Pressure Due to Spring Force at Zero Pump Displacement	PSI
21-30	E10.0	Actuator Pressure Due to Spring Force at Maximum Pump Displacement	PSI
31-40	E10.0	Actuator Pressure Due to Piston Acceleration at 3600 RPM and Maximum Pump Displacement	PSI
41-50	E10.0	Actuator Pressure Inputed at 3600 RPM and Zero Pump Displacement +	PSI
51-60	E10.0	Actuator Pressure at 3600 RPM and Maximum Pump Displacement +	PSI
61-70	E10.0	Slope of Pressure vs RPM Curve +	PSI/RPM
71-80	E10.0	Hanger Damping*	PSI/IN/SEC

* = Referenced to Actuator Pressure

\+ = Excluding the effects of piston acceleration and spring forces.

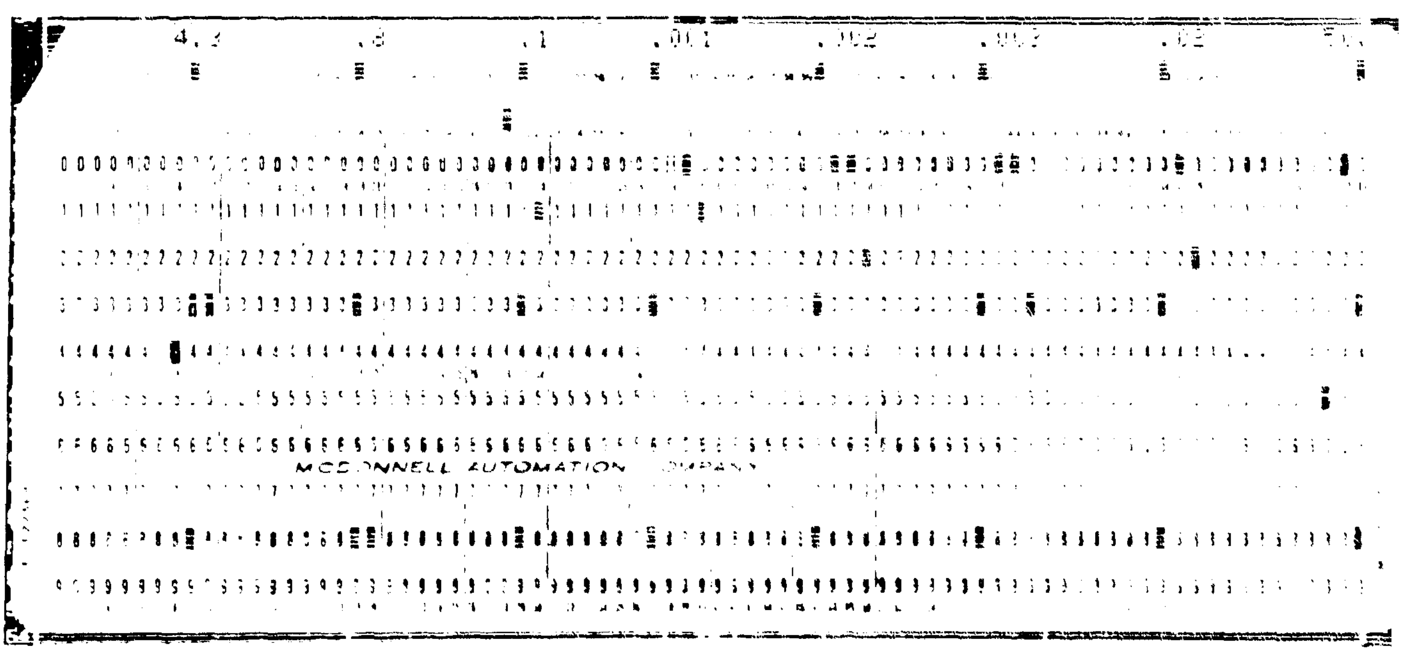
EXAMPLE CARD



CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Theoretical Maximum Pump Displacement	IN**3/REV
11-20	E10.0	Actuator Position at Maximum Pump Displacement	IN
21-30	E10.0	Actuator Position at Minimum Pump Displacement (-ve)	IN
31-40	E10.0	Coefficient of Actuator Leakage at Zero Pump Displacement	CIS/PSI
41-50	E10.0	Coefficient of Actuator Leakage at Maximum Pump Displacement	CIS/PSI
51-60	E10.0	Coefficient of Pump Leakage (outlet to case)	CIS/PSI
61-70	E10.0	Coefficient of Leakage from Case to Inlet	CIS/PSI
71-80	E10.0	Case Volume	IN**3

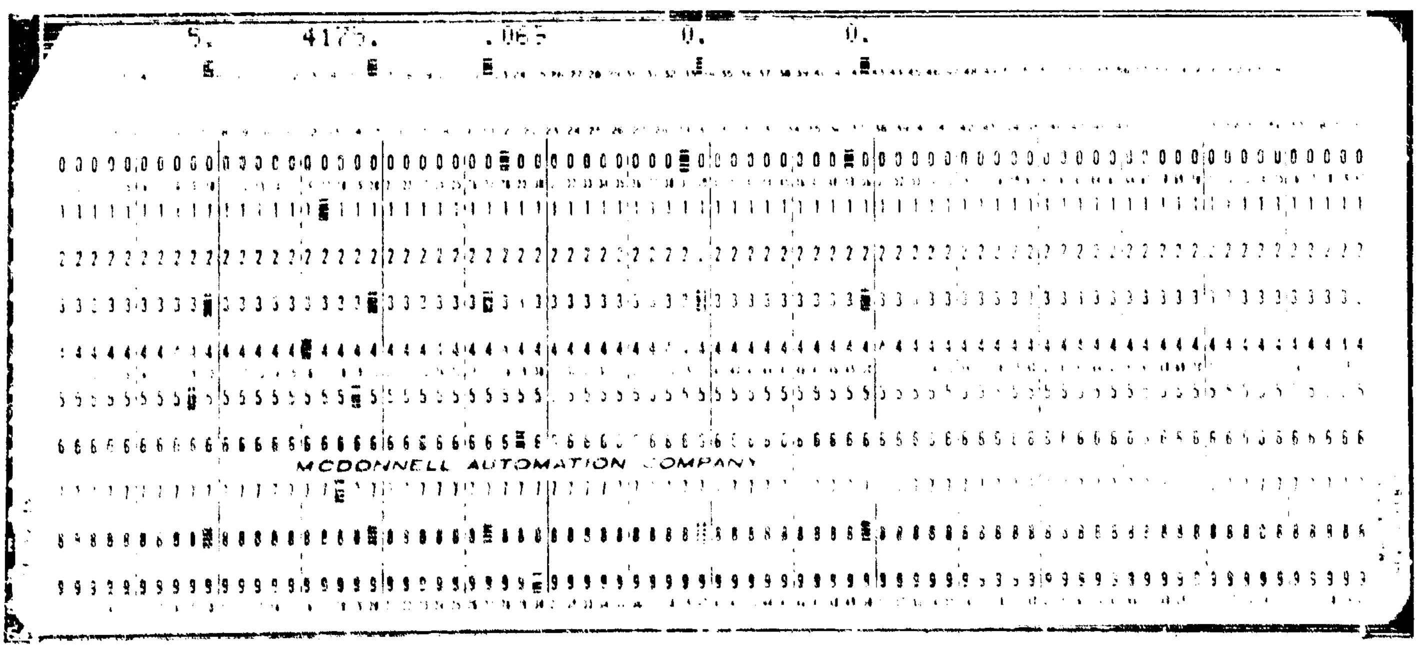
EXAMPLE CARD



CARD NUMBER 5

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Minimum Inlet Pressure	PSI
11-20	E10.0	Pump Operating Speed	RPM
21-30	E10.0	Coefficient of Outlet Flow Due to Actuator Motion	CIS/(IN/SEC)
31-40	E10.0		
41-50	E10.0	Pressurization/Depressurization Time	SEC
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.60 RESERVOIRS

There are a number of types of reservoirs which need different methods of analysis. Among these are, constant pressure reservoir, bootstrap reservoir, trapped bootstrap reservoir and reservoir with RLS and bootstrap. The following types are currently included in the program:

Type #61 Constant Pressure Reservoir (RSVR61)

Type #62 Bootstrap Reservoir (RSVR62)

6.61 TYPE #61 CONSTANT PRESSURE RESERVOIR

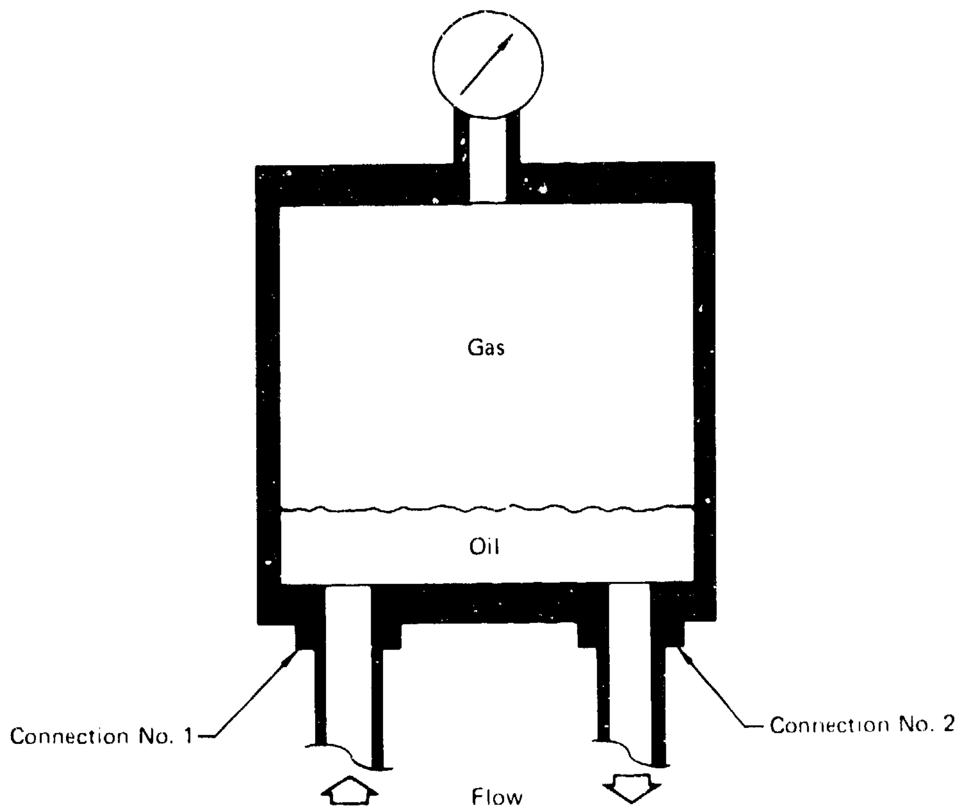


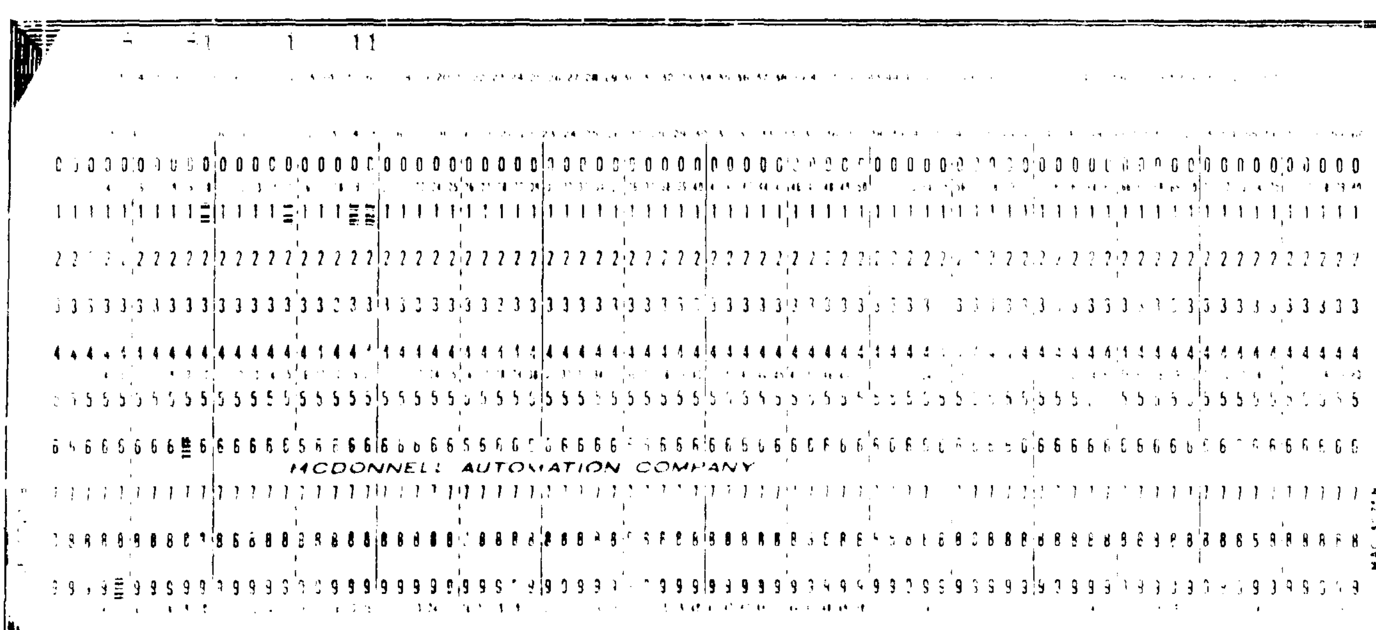
FIGURE 6.61-1
TYPE NO. 61 CONSTANT PRESSURE RESERVOIR

The Type #61 constant pressure reservoir which is used for test simulation purposes, requires only the connection information and the reservoir pressure. Any of the four connections not used are blanked off.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 61
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	Line Number (with sign) attached to Connection 4
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

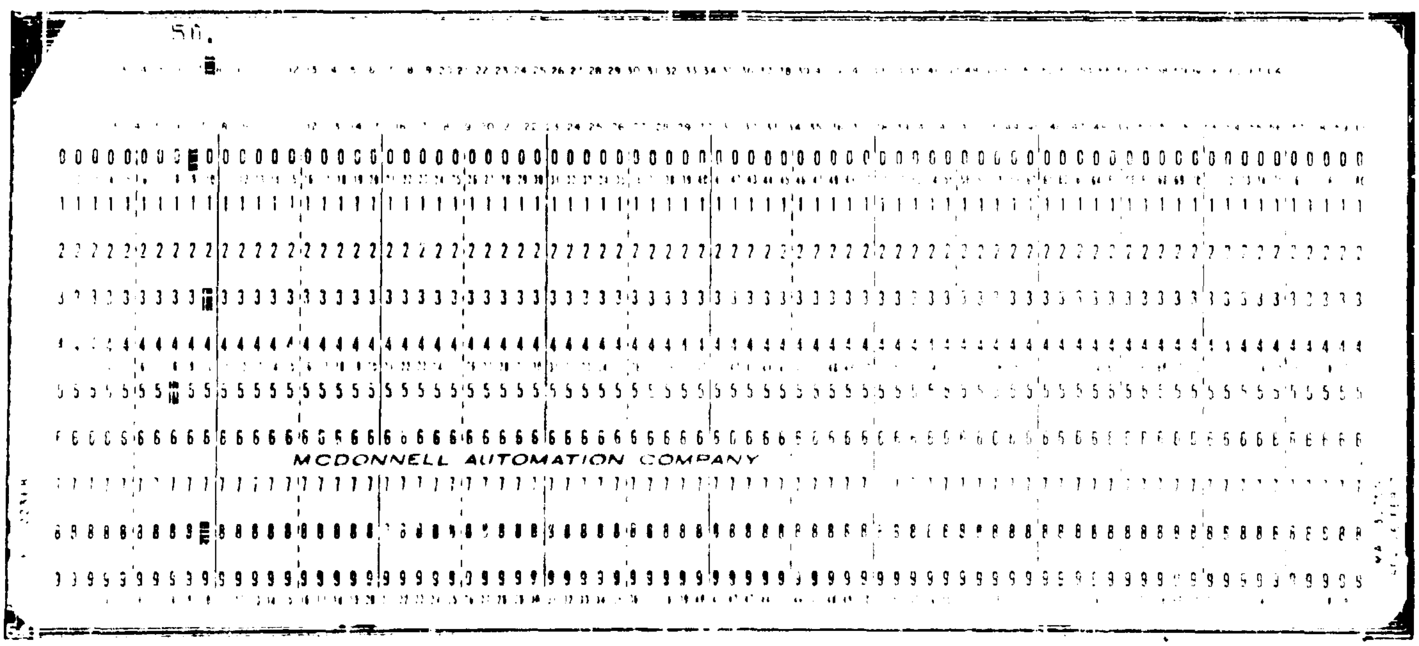
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Reservoir Pressure	psia
11-20	E10.0		
21-30	E10.0		
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.62 TYPE #62 BOOTSTRAP RESERVOIR

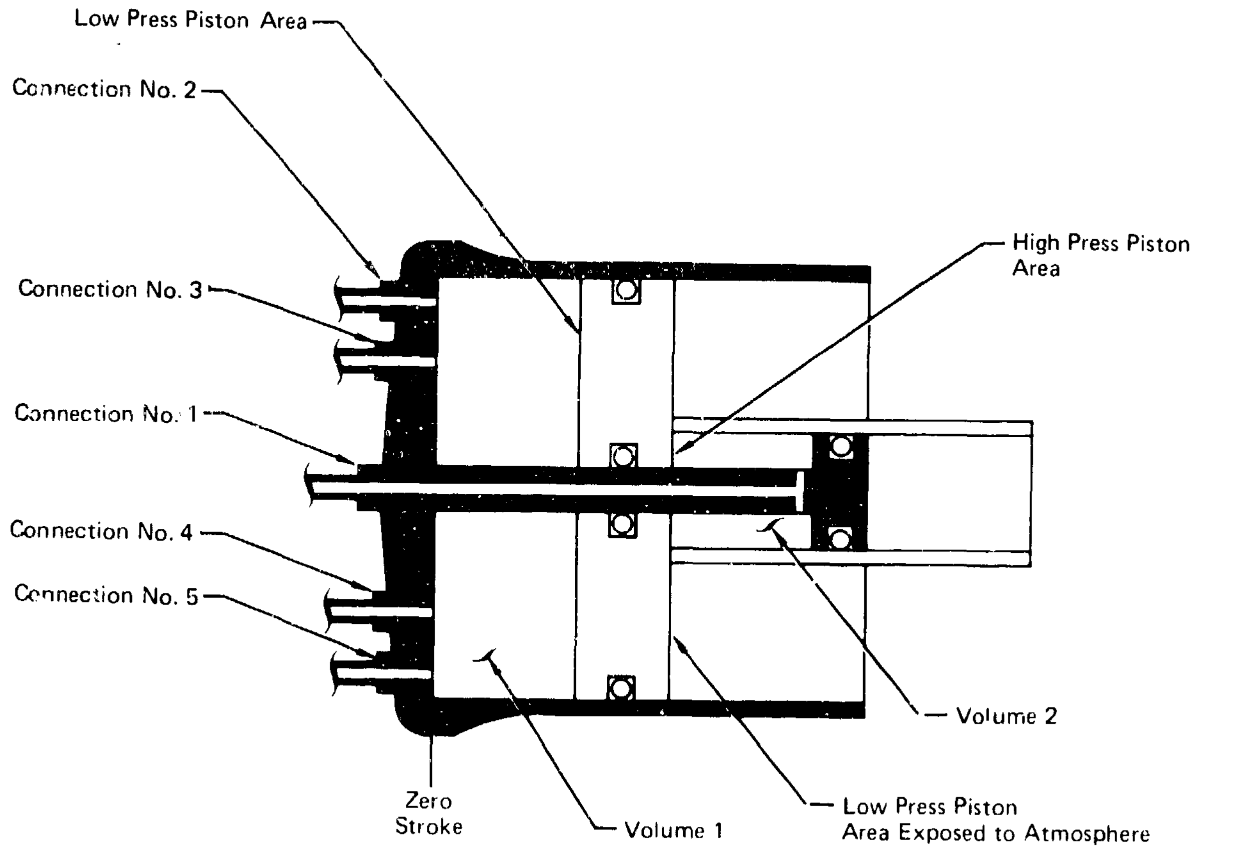


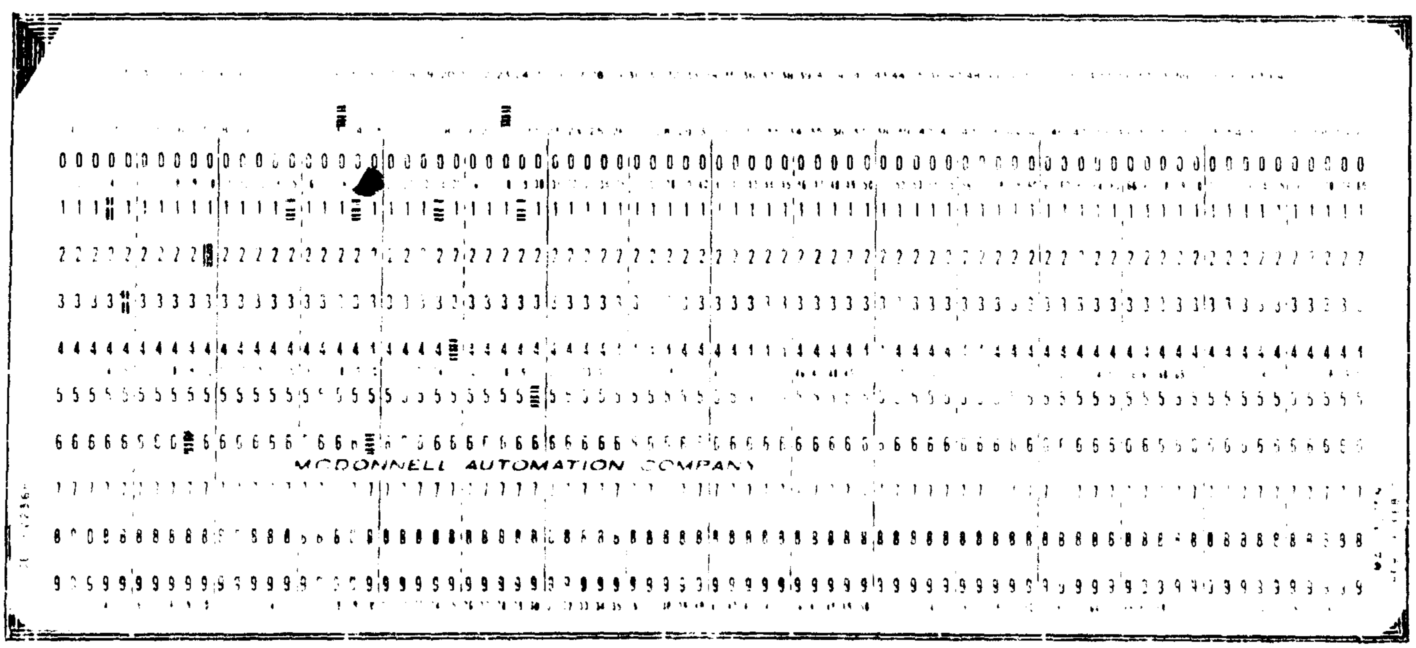
FIGURE 6.62-1 BOOTSTRAP RESERVOIR

The Type #62 bootstrap reservoir is the type used on the F-15 aircraft. As many as four low pressure connections can be used plus the high pressure connection. Any low pressure connection(s) not required is to be left blank.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 62
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1(High Press.)
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	Line Number (with sign) attached to Connection 4
36-40	I5	Line Number (with sign) attached to Connection 5
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

EXAMPLE CARD

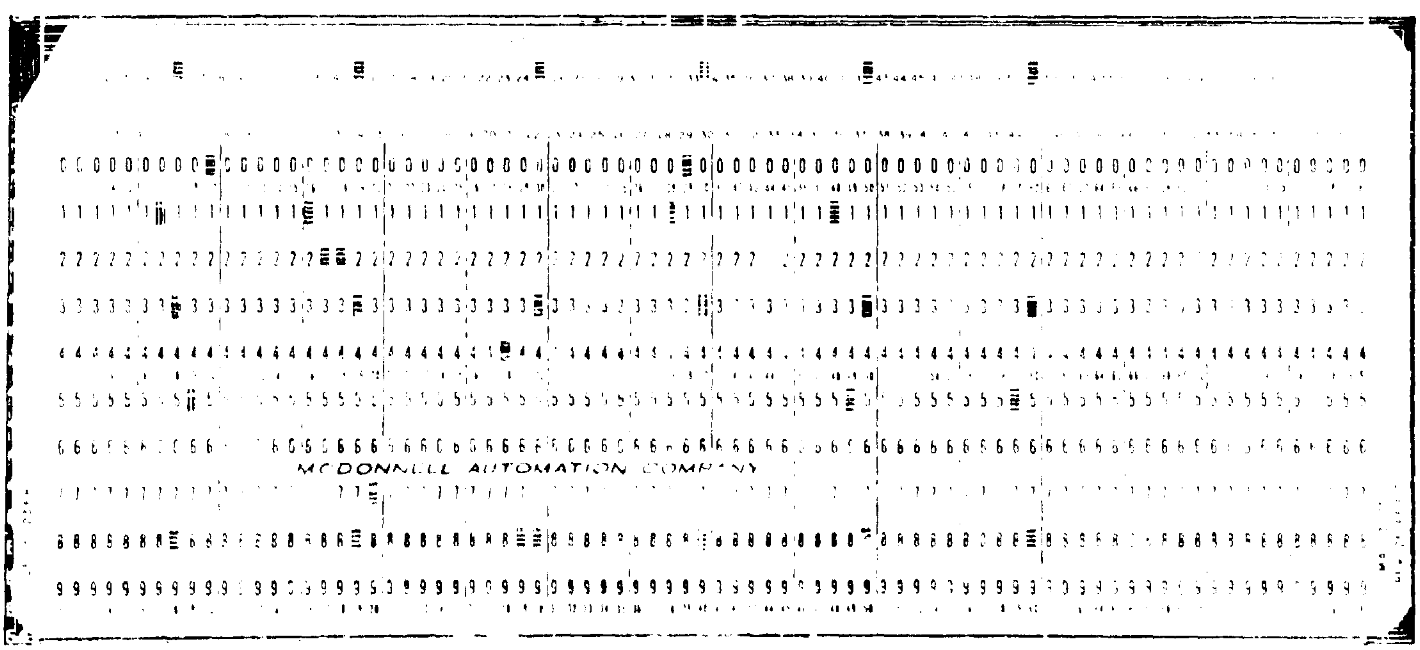


CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	High Press (Bootstrap) Piston Area	in^2
11-20	E10.0	Low Press (RSVR) Piston Area	in^2
21-30	E10.0	High Pressure Volume at Zero Stroke	in^3
31-40	E10.0	Low Pressure Volume at Zero Stroke	in^3
41-50	E10.0	Maximum Piston Stroke	in
51-60	E10.0	Initial Piston Position	in
61-70	E10.0		
71-80	E10.0		

NOTE: Zero Stroke is defined as the Piston Position with the Reservoir Empty.

EXAMPLE CARD



6.70 ACCUMULATORS

There are many varieties of accumulators. The three types that are in common usage are free piston accumulator, bladder accumulator and tandem piston accumulator (F-15 JFS accumulator). The following type is currently included in the program:

Type #71 Free Piston Accumulator (ACUM71)

The accumulator subroutine is setup based on using dry nitrogen gas.

6.71 TYPE #71 FREE PISTON ACCUMULATOR

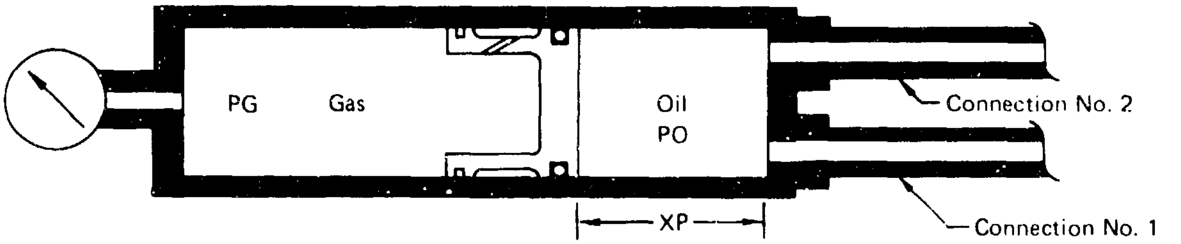


FIGURE 6.71-1
TYPE NO. 71 FREE PISTON ACCUMULATOR

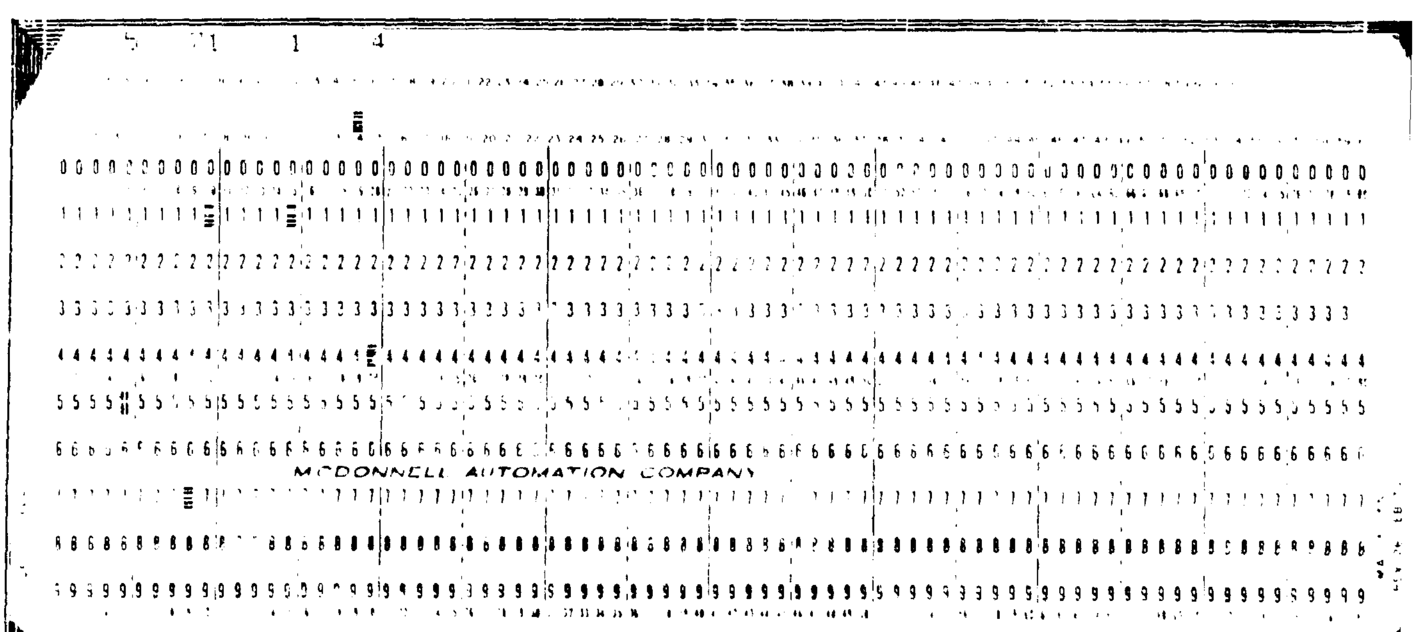
GP74 0773 1

The input data for the Type #71 accumulator are basically the minimum and maximum gas and oil volumes and the precharge pressure. The gas and oil piston areas are assumed to be equal.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 71
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

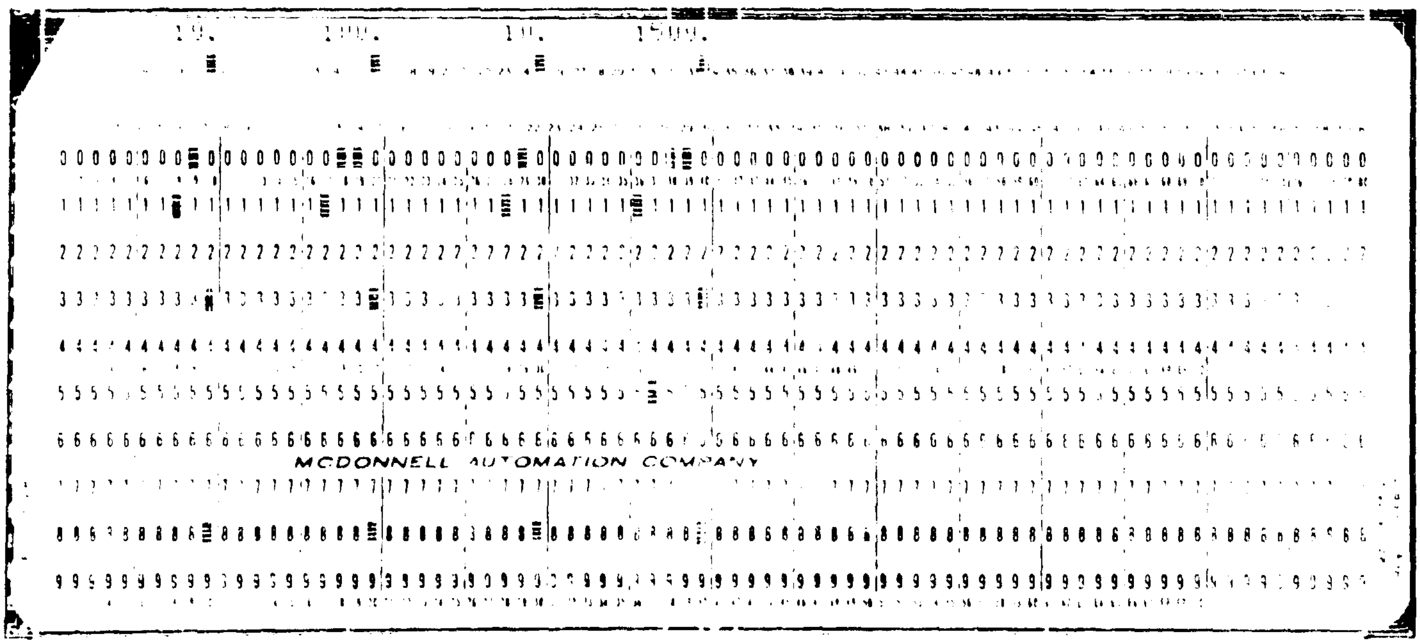
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Minimum Oil Volume	IN^3
11-20	E10.0	Maximum Oil Volume	IN^3
21-30	E10.0	Minimum Gas Volume	IN^3
31-40	E10.0	Precharge Pressure @ 60°F	PSI
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.80 FILTERS

There are numerous type filter elements and filter bodies to contain them. Often the bodies have multiple functions, such as the F-15 filter manifolds, which contain filter elements, relief valves and check valves, and have mnay external and internal connections. Hence only a few filters are sufficiently similar to allow the use of a common subroutine. The following type is currently included in the program:

Type #81	F-4 Type In-Line Filter	(FILT81)
Type #82	Filter Manifold (FILT82)	
Type #83	Inline, Bypass Filter (FILT83)	

6.81 TYPE #81 F-4 TYPE IN-LINE FILTER

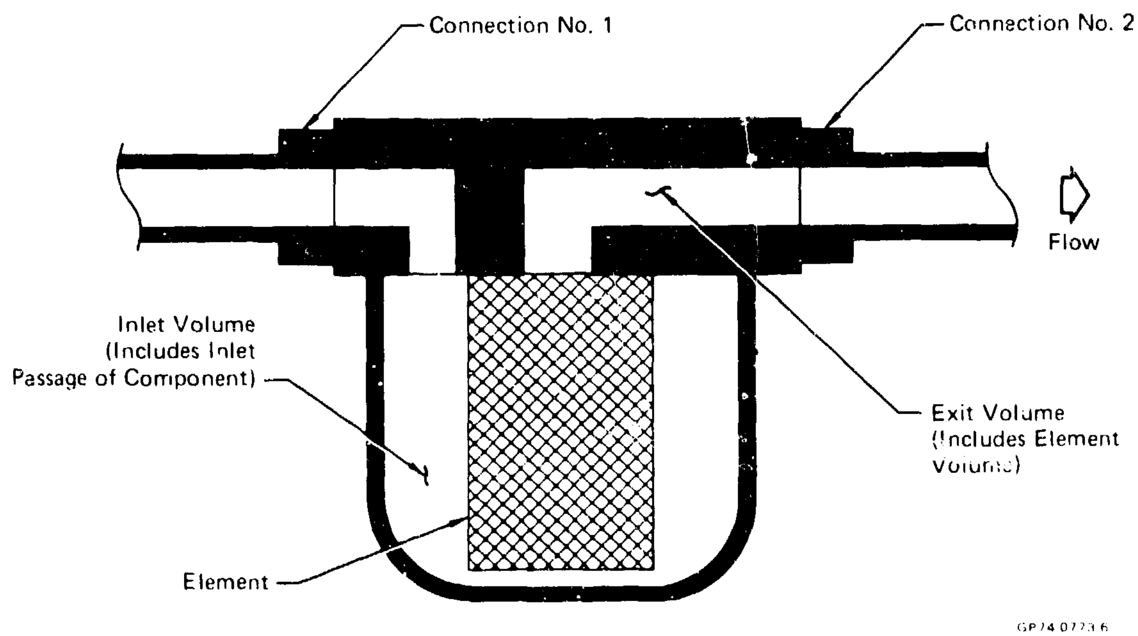


FIGURE 6.81-1
TYPE NO. 81 F-4 TYPE IN-LINE FILTER

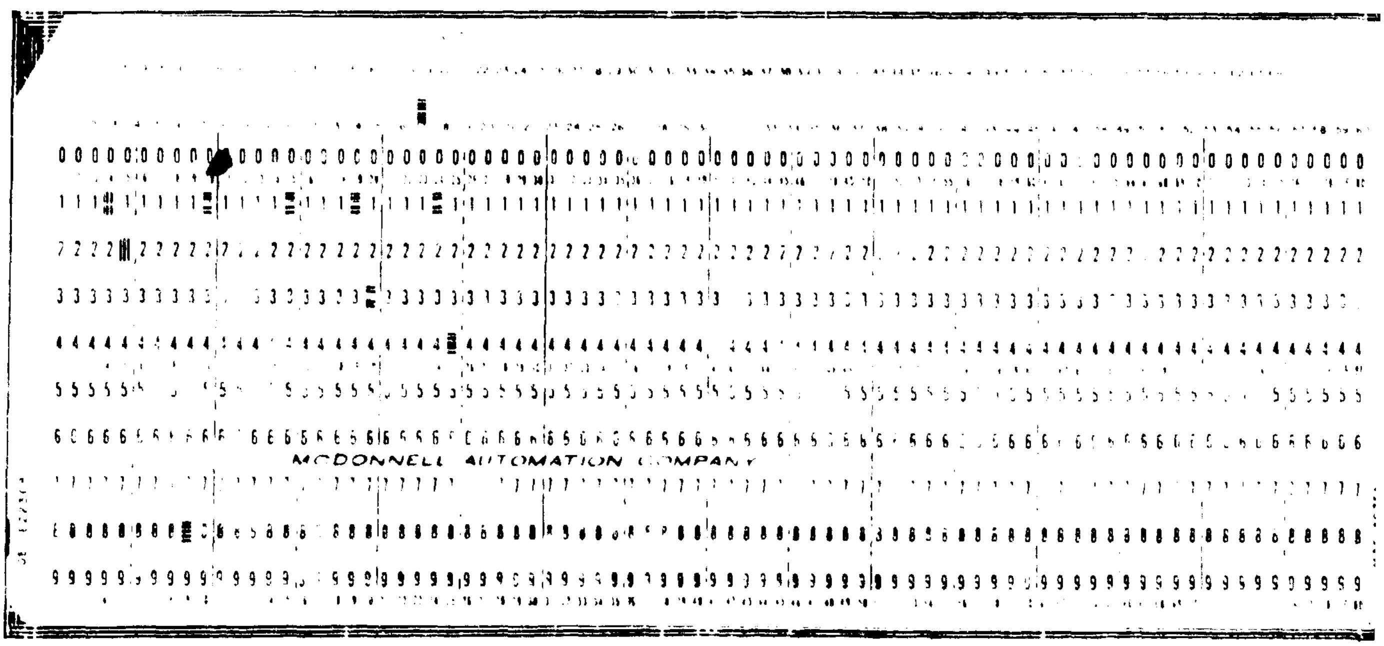
The Type #81 F-4 in-line filters are simple non-bypass units using standard cleanable elements.

This particular type will be used in simulation work because it is simple and has no ancillary components.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 81
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

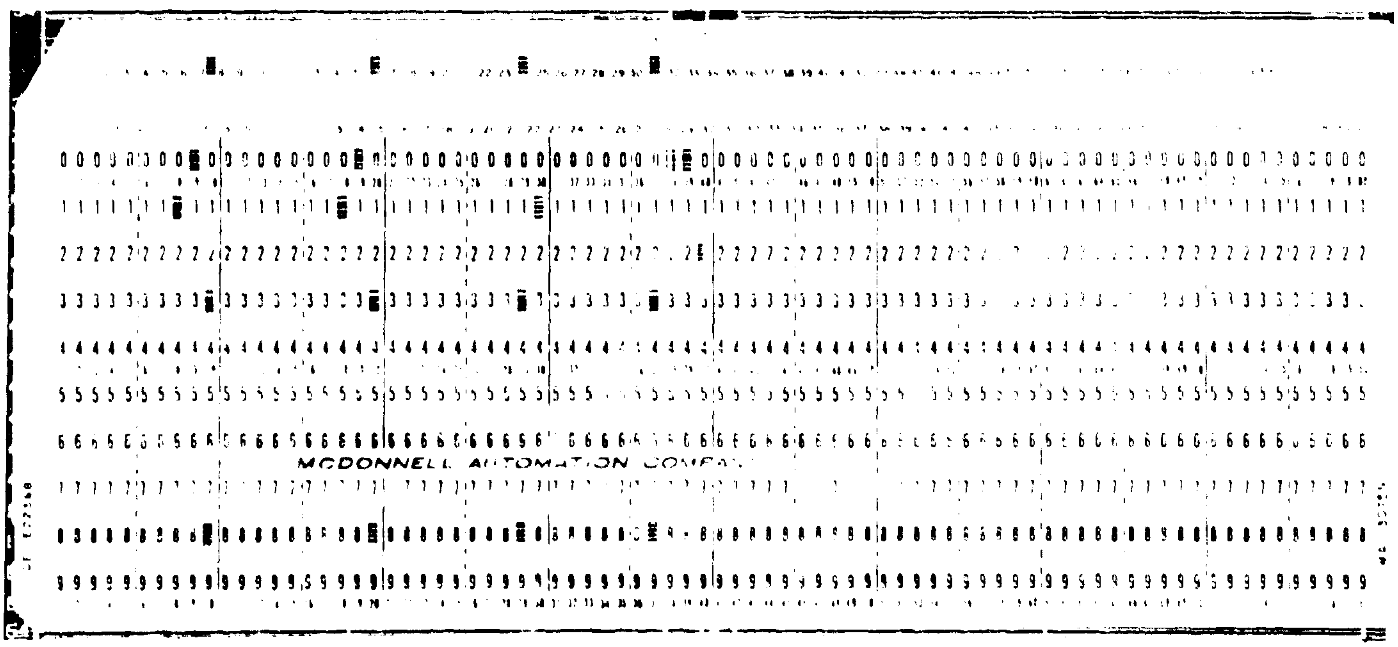
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet Volume	IN^3
11-20	E10.0	Exit Volume	IN^3
21-30	E10.0	Linear Element Flow Constant	See Note
31-40	E10.0	Non-Linear Element Flow Constant	See Note
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



Note: The values of the CONSEL and CONE2 are determined using the second order relationship

$$\Delta P = CONSEL*Q + CONE2*Q^2$$

The pressure drop relationship is to be determined using MIL-H-5606 hydraulic oil at 100°F.

6.82 Type #82 Filter Manifold

The Type #82 space shuttle filter manifold is a three element filter manifold incorporating a relief valve between the supply filter outlet and the return filter inlet. The first element filters the flow returning to the reservoir, the second element filters the pump case drain flow, and the third element filters the pump output flow.

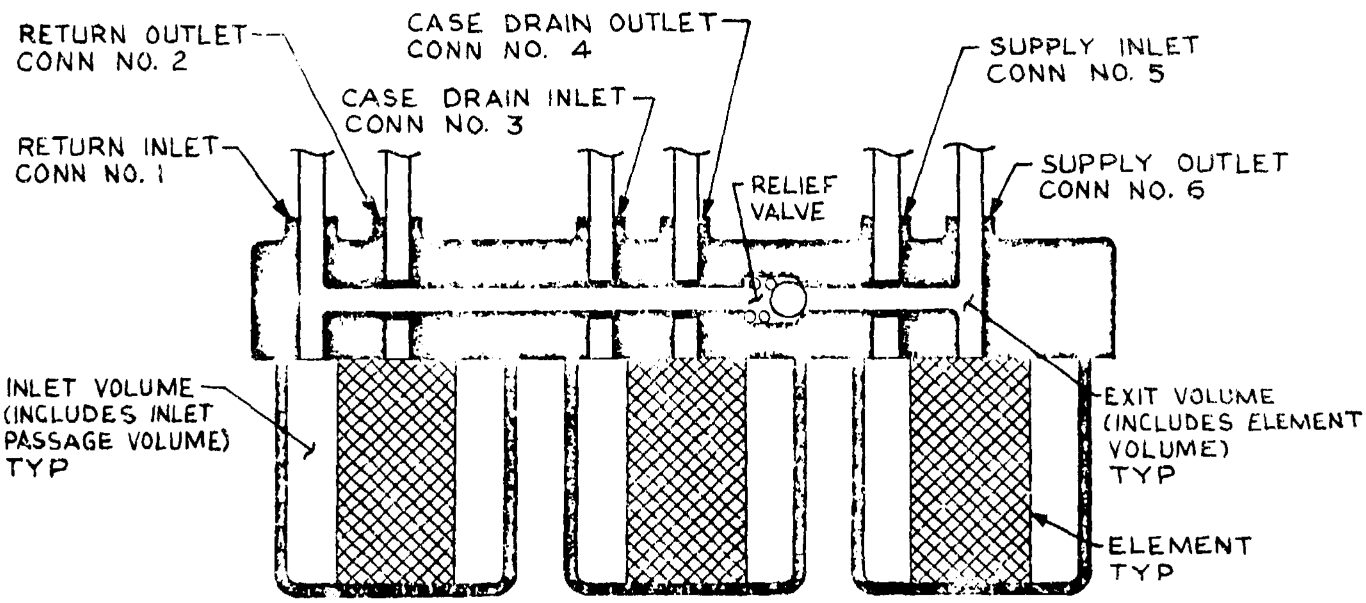


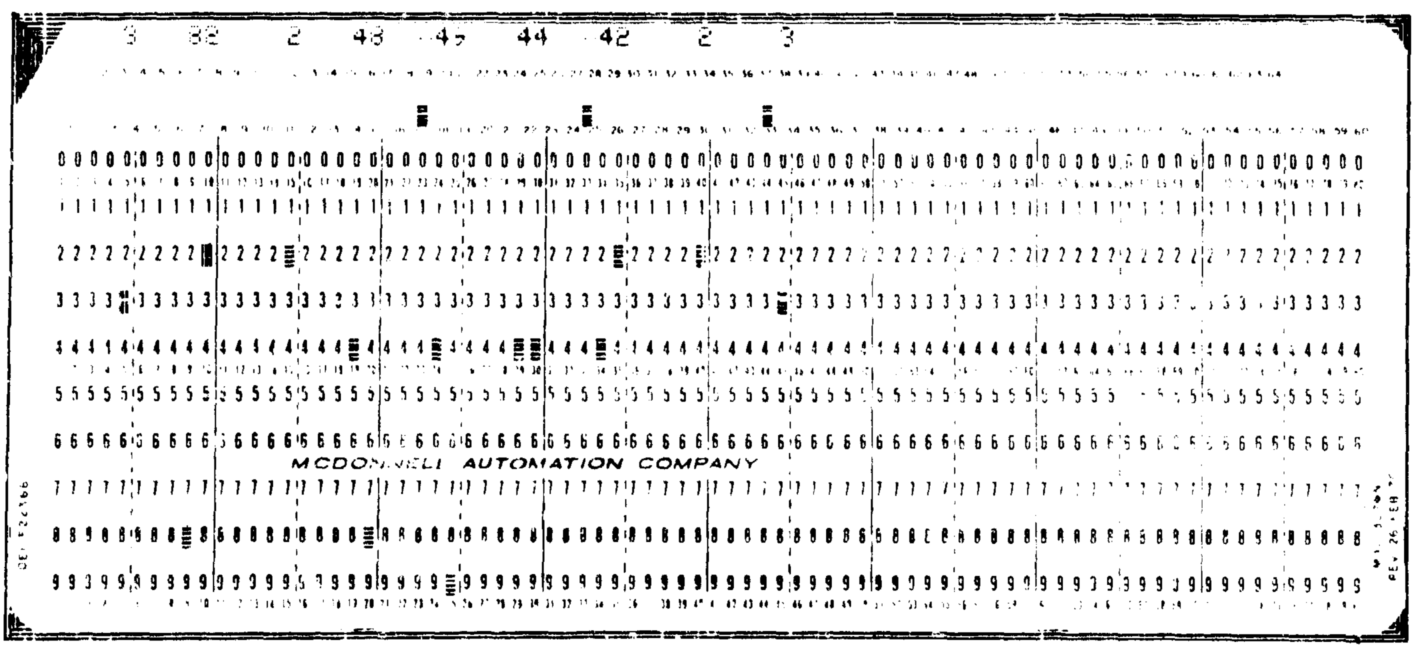
Figure 2.3-82

Type No. 82 Filter Manifold

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 82
11-15	I5	Number of Real Data Cards = 2
16-20	I5	Line Number (with sign) attached to Connection 1(ret. inlet)
21-25	I5	Line Number (with sign) attached to Connection 2(ret. outlet)
26-30	I5	Line Number (with sign) attached to Connection 3(case dr inlet)
31-35	I5	Line Number (with sign) attached to Connection 4(case dr outlet)
36-40	I5	Line Number (with sign) attached to Connection 5(sup. inlet)
41-45	I5	Line Number (with sign) attached to Connection 6(sup. outlet)
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

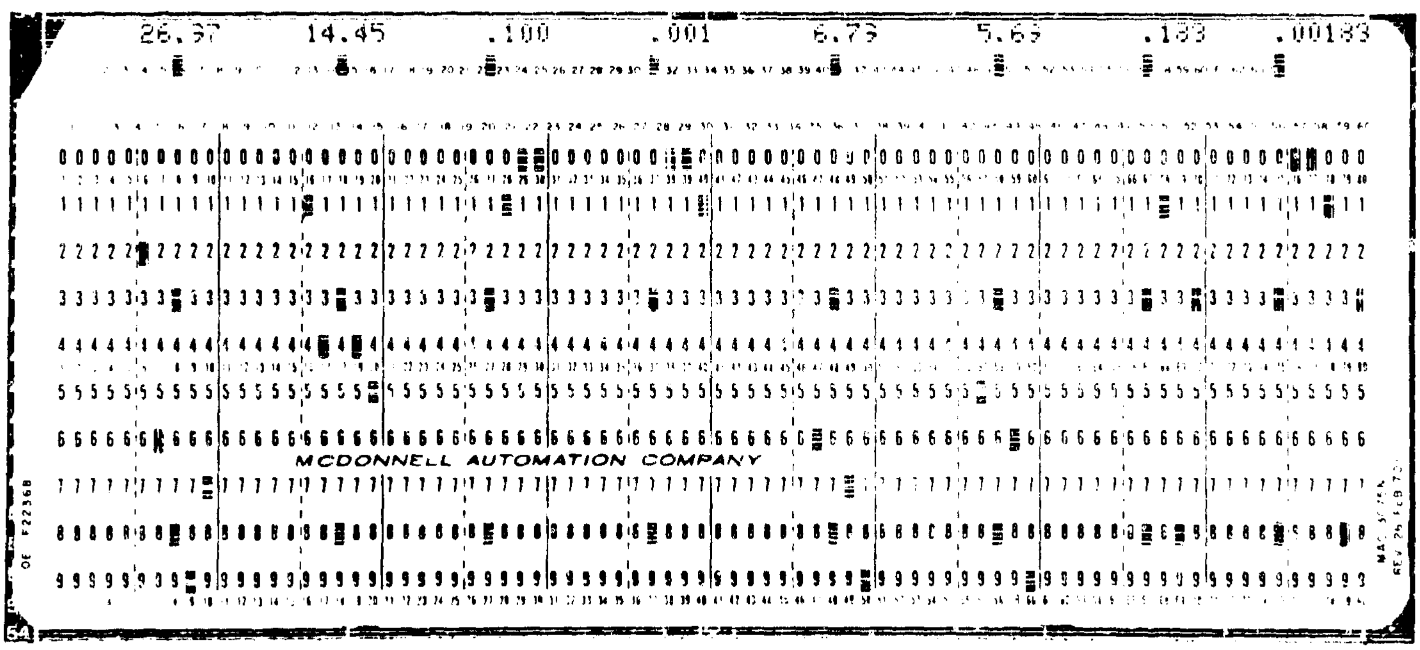
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet Volume (Return)	IN^3
11-20	E10.0	Exit Volume (Return)	IN^3
21-30	E10.0	Linear Element Flow Constant (Return)	See Note
31-40	E10.0	Non-Linear Element Flow Constant (Return)	"
41-50	E10.0	Inlet Volume (Case Drain)	IN^3
51-60	E10.0	Exit Volume (Case Drain)	IN^3
61-70	E10.0	Linear Element Flow Constant (Case Drain)	See Note
71-80	E10.0	Non-Linear Element Flow Constant (Case Drain)	"

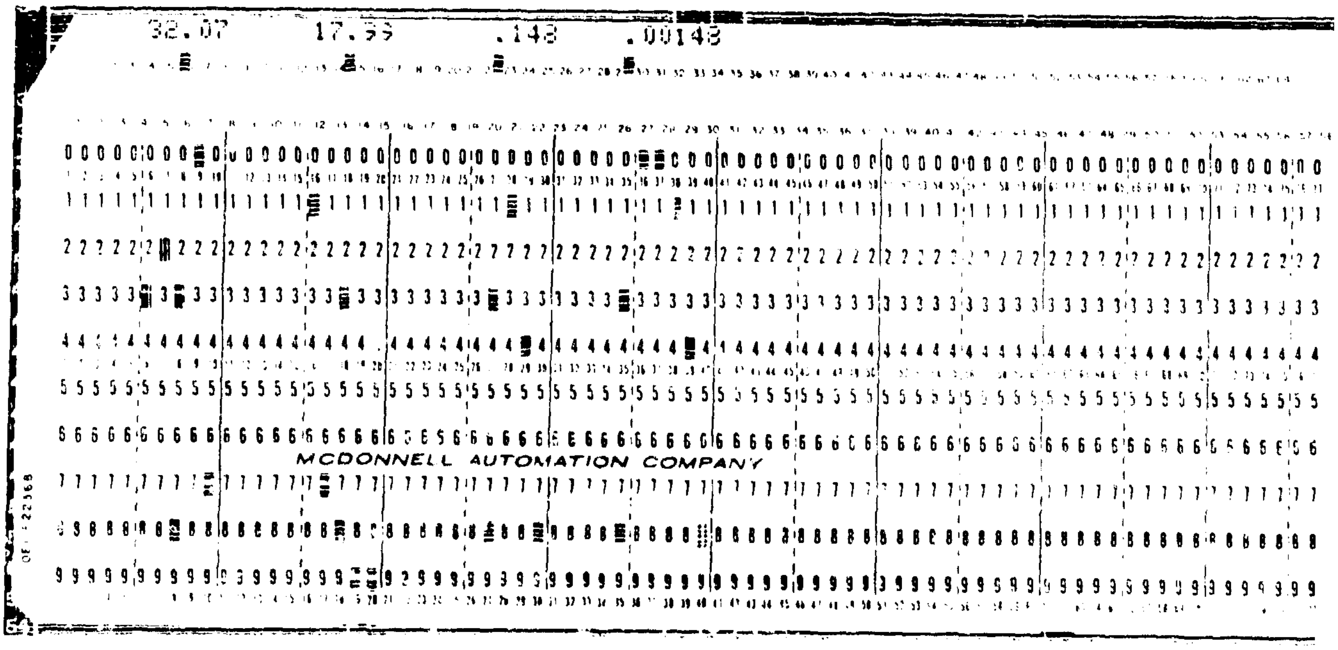
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet Volume (Supply)	IN^3
11-20	E10.0	Exit Volume (Supply)	IN^3
21-30	E10.0	Linear Element Flow Constant (Supply)	See Note
31-40	E10.0	Non-Linear Element Flow Constant (Supply)	"
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



Note: The values of the constants CONSEL and CONE2 are determined using the second order relationship

$$\Delta P = CONSEL*Q+CONE2*Q^2$$

The pressure drop relationship is to be determined using MIL-H-5606 hydraulic oil at 100°F.

6.83 TYPE #83 INLINE, BYPASS FILTER

FILT83 is a simulation of an inline, bypass type filter. One inlet and two outlet connections are used. Unused connections are considered to be blanked off.

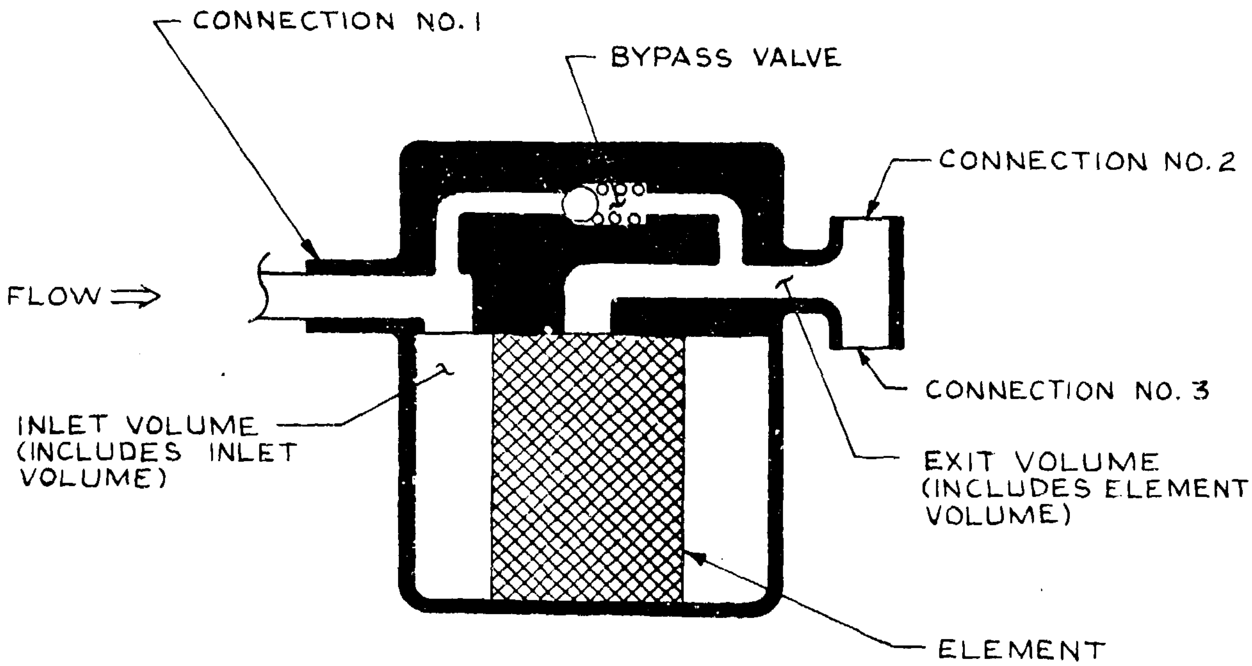


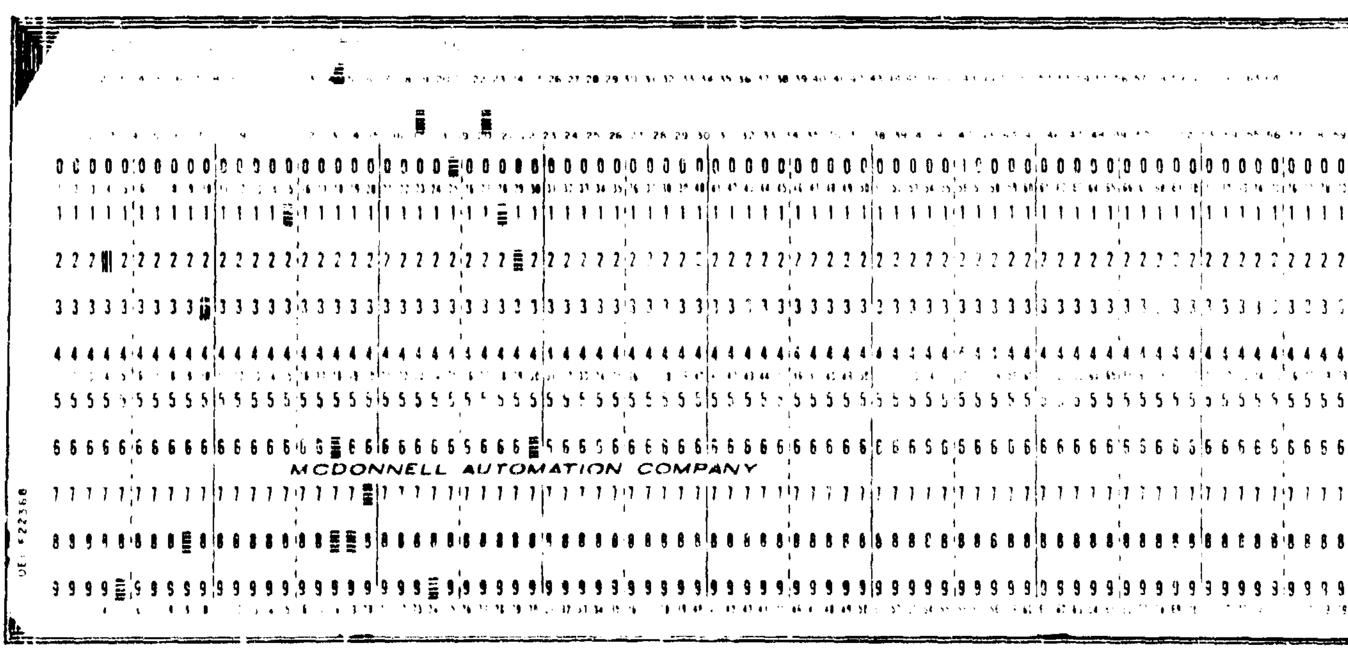
Figure 6.81-1

TYPE NO. 83 INLINE FILTER

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 83
11-15	I5	Number of Real Data Cards = 1
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

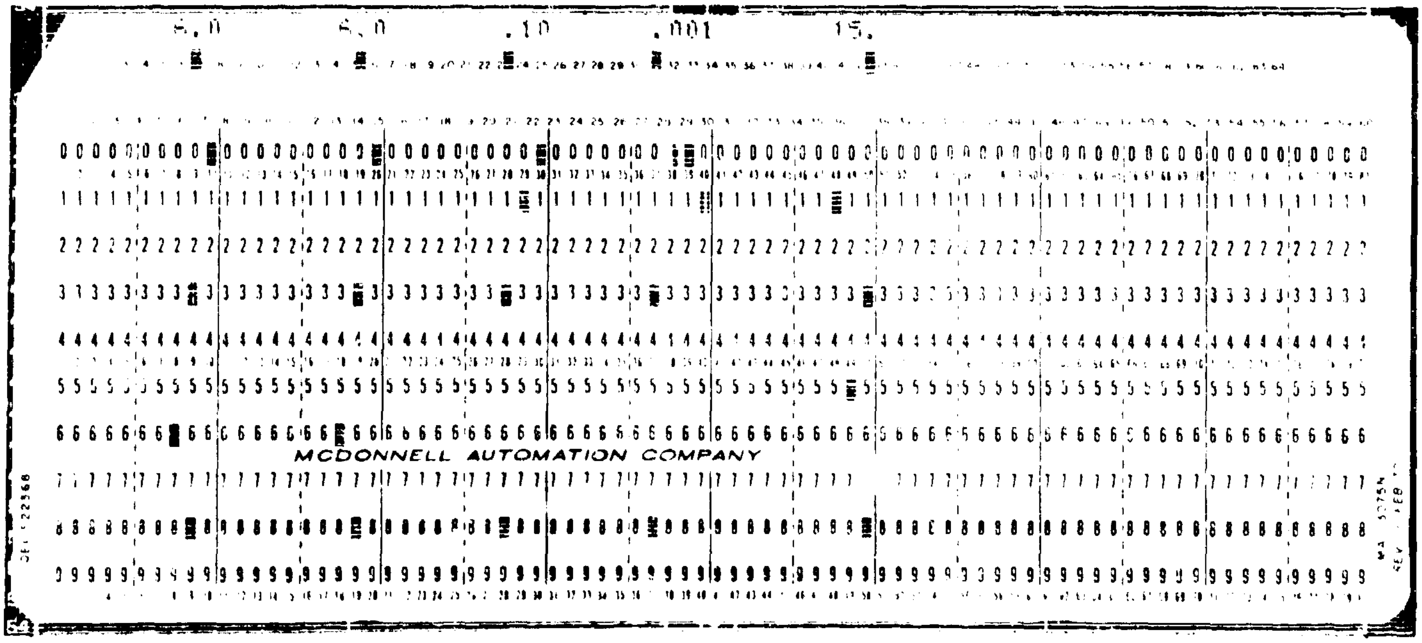
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Inlet Volume	IN^3
11-20	E10.0	Exit Volume	IN^3
21-30	E10.0	Element Flow Constant	See Note
31-40	E10.0	Relief Valve Constant	CIS/PSI
41-50	E10.0	Relief Valve Cracking Pressure	PSI
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



Note: The value of CONSEL is determined using the relationship

$$\Delta P = CONSEL*Q$$

The pressure drop relationship is to be determined using MIL-H-5606 hydraulic oil at 100°F.

6.92 CAD92 INPUT CONTROL DATA

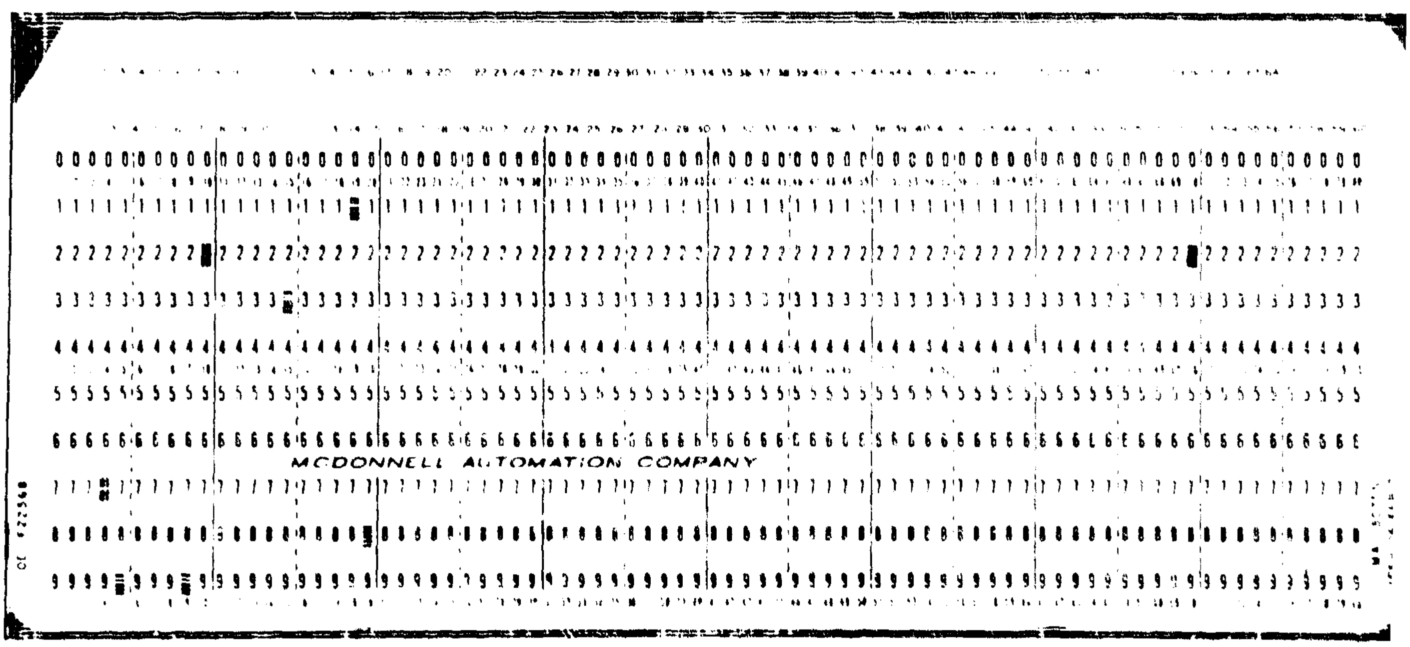
CAD92 is used as a dummy input subroutine for the elevon position commands and hinge moments, which are normally obtained from the guidance and control subroutine.

The input data is used as a time history of the elevon input position command, using a linear interpolation for times between the data points. The number of input time data points and position command data points should be both equal to the number of input on the first card columns 65-70.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 92
11-15	I5	Number of Real Data Cards = 3 or more
16-20	I5	Elevon Component Number
21-25	I5	
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	Number of Data Points in Time (& Input) Data Table
71-75	I5	
76-80	I5	

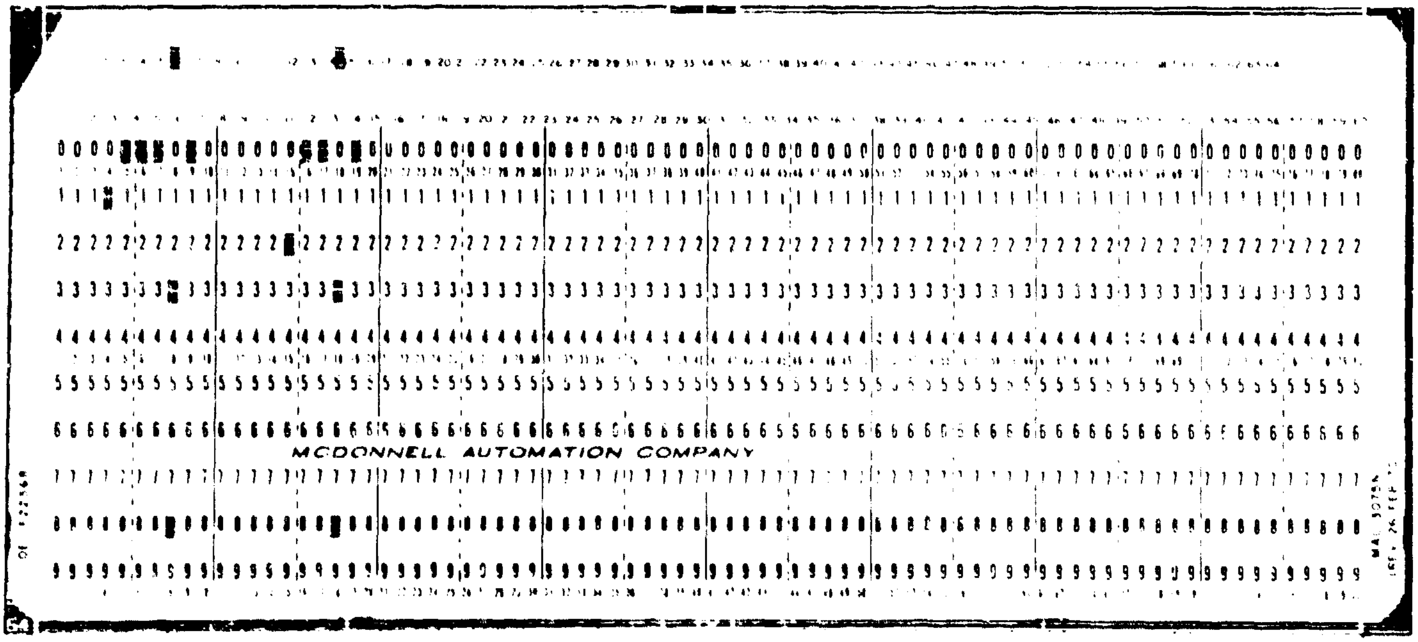
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Elevon Load a Zero Actuator Stroke	in lbs
11-20	E10.0	Elevon Load/Stroke Slope	in lbs/in
21-30	E10.0		
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



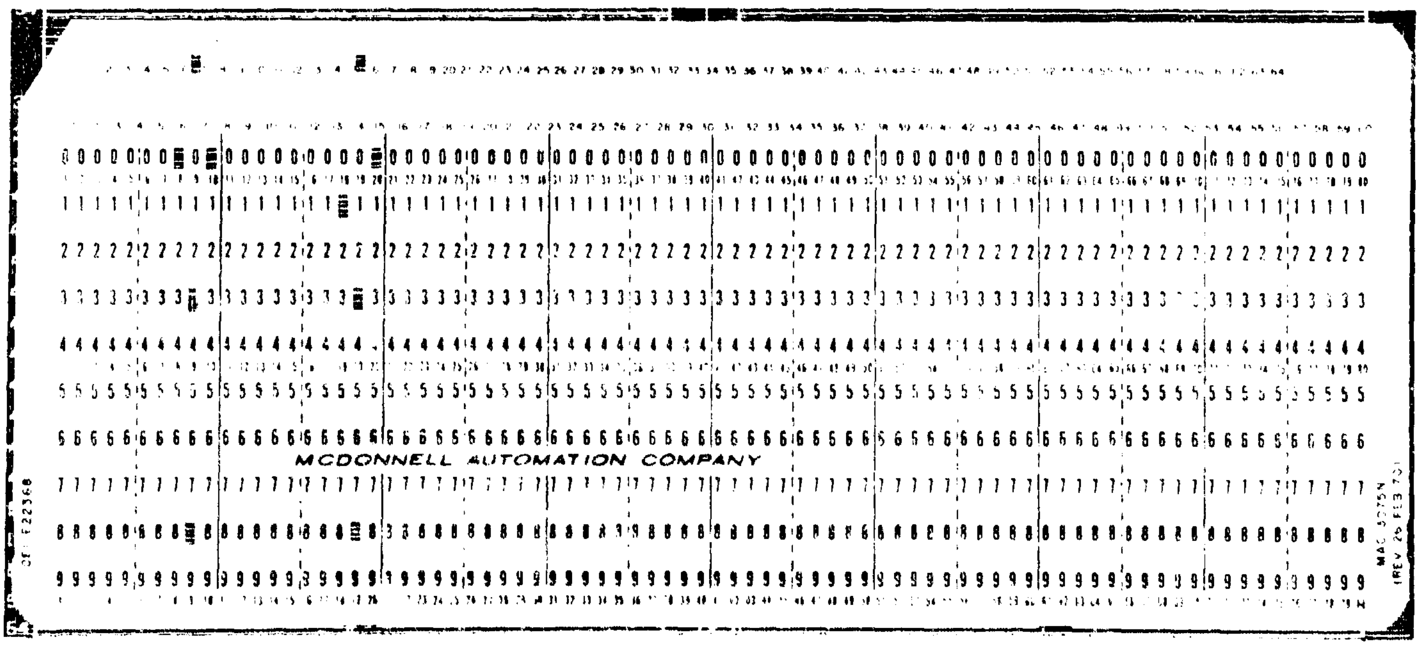
CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Value (Should be zero)	sec
11-20	E10.0	Second Time Value	sec
21-30	E10.0		
31-40	E10.0		

One or More Cards Can be Used

	E10.0	Final Time Value	sec
	E10.0		
	E10.0		

EXAMPLE CARD



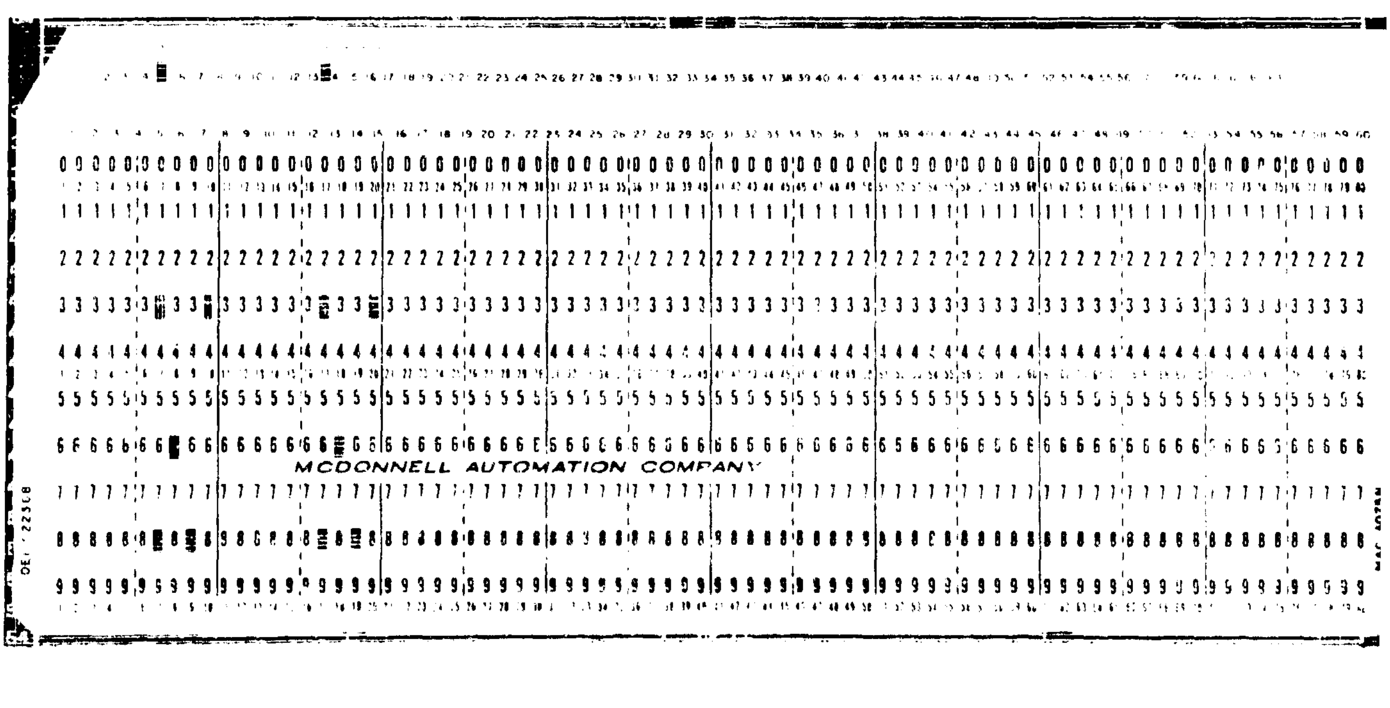
CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Input Position Command @ T = 0	in
11-20	E10.0	Subsequent Input Commands	in
21-30	E10.0		
31-40	E10.0		

One or More Cards can be Used

	E10.0	Final Input Command	
	E10.0		
	E10.0		

EXAMPLE CARD



6.93 CAD93 INPUT PUMP LOAD DATA

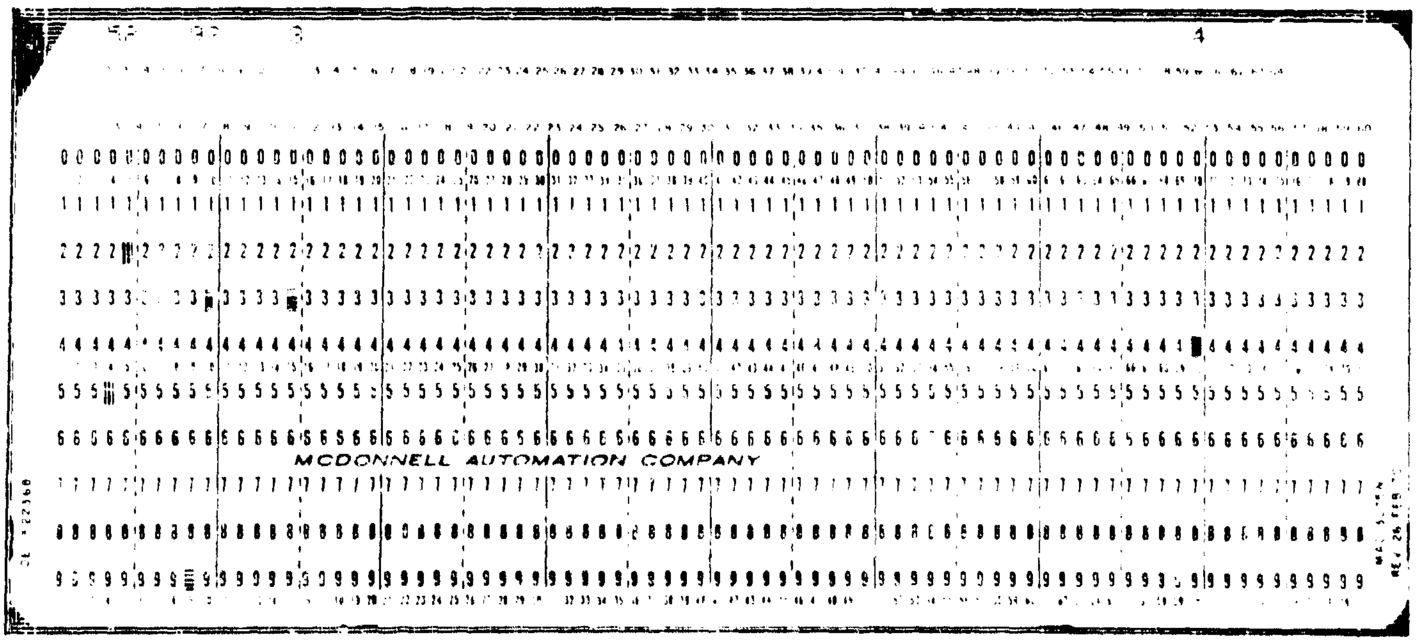
CAD93 is used as a dummy input subroutine to give the pump load torque which is normally obtained from the pump subroutine.

The input data is used as a time history of the pump torque using a linear interpolation for times between the data points. The number of input time data points and torque data points should be both equal to the number input on the first card columns 65-70.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 93
11-15	I5	Number of Real Data Cards = 3 or more
16-20	I5	
21-25	I5	
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	Number of Data Points in Time (& Input) Data Table
71-75	I5	
76-80	I5	

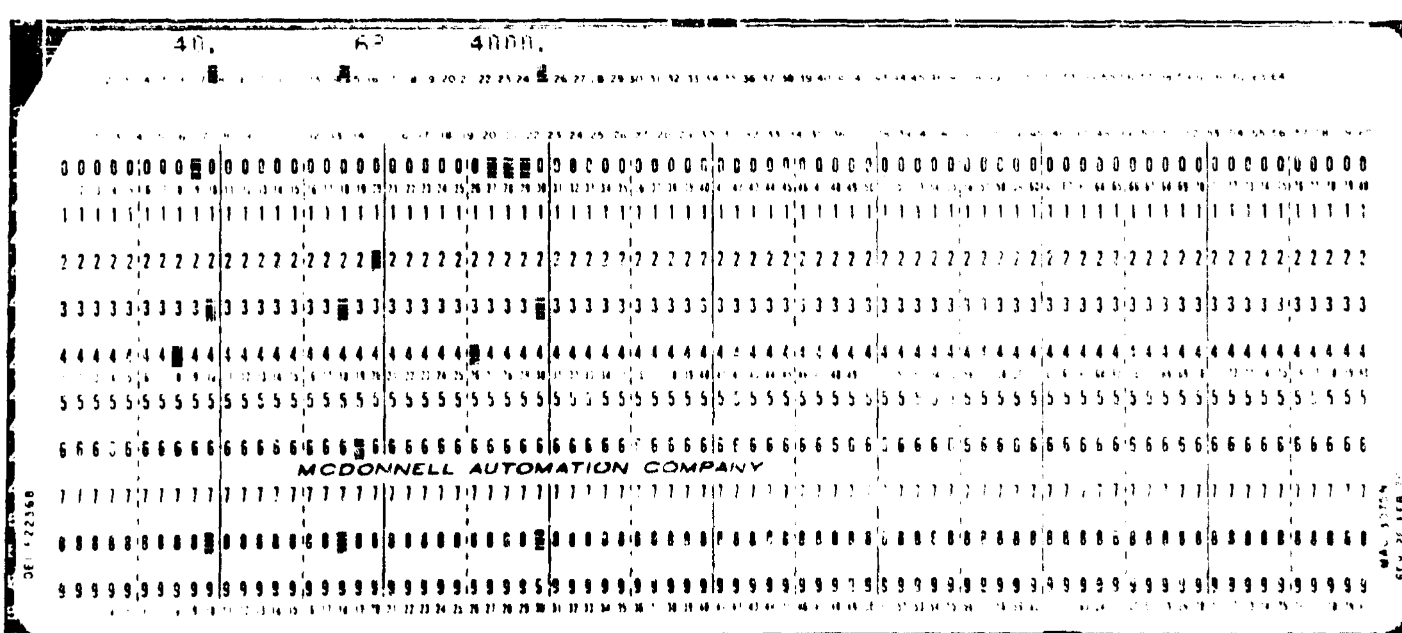
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Pump Load a Zero Pump Speed	in lbs
11-20	E10.0	Pump Load/Speed Slope	in lbs/rpm
21-30	E10.0	Inertial Pump RPM	rpm
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



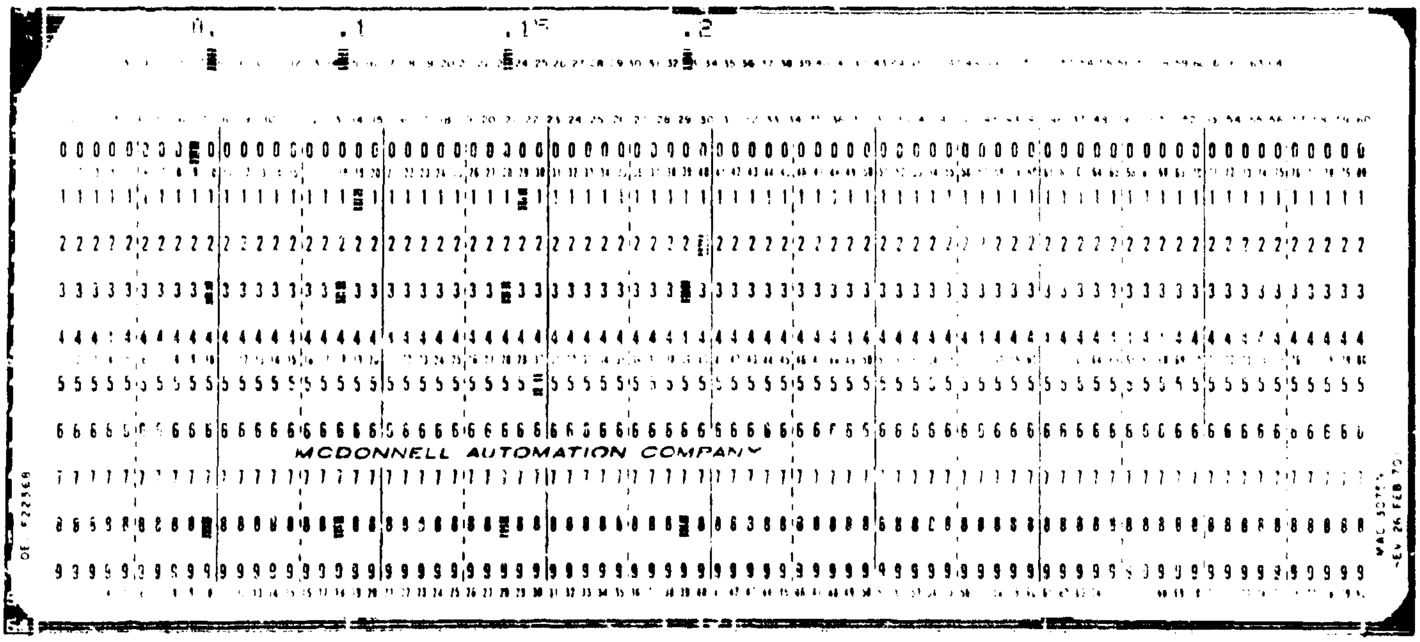
CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Values (Should be zero)	sec
11-20	E10.0	Second Time Value	sec
21-30	E10.0		
31-40	E10.0		

One or More Cards Can Be Used

	E10.0	Final Time Value	sec
	E10.0		
	E10.0		

EXAMPLE CARD



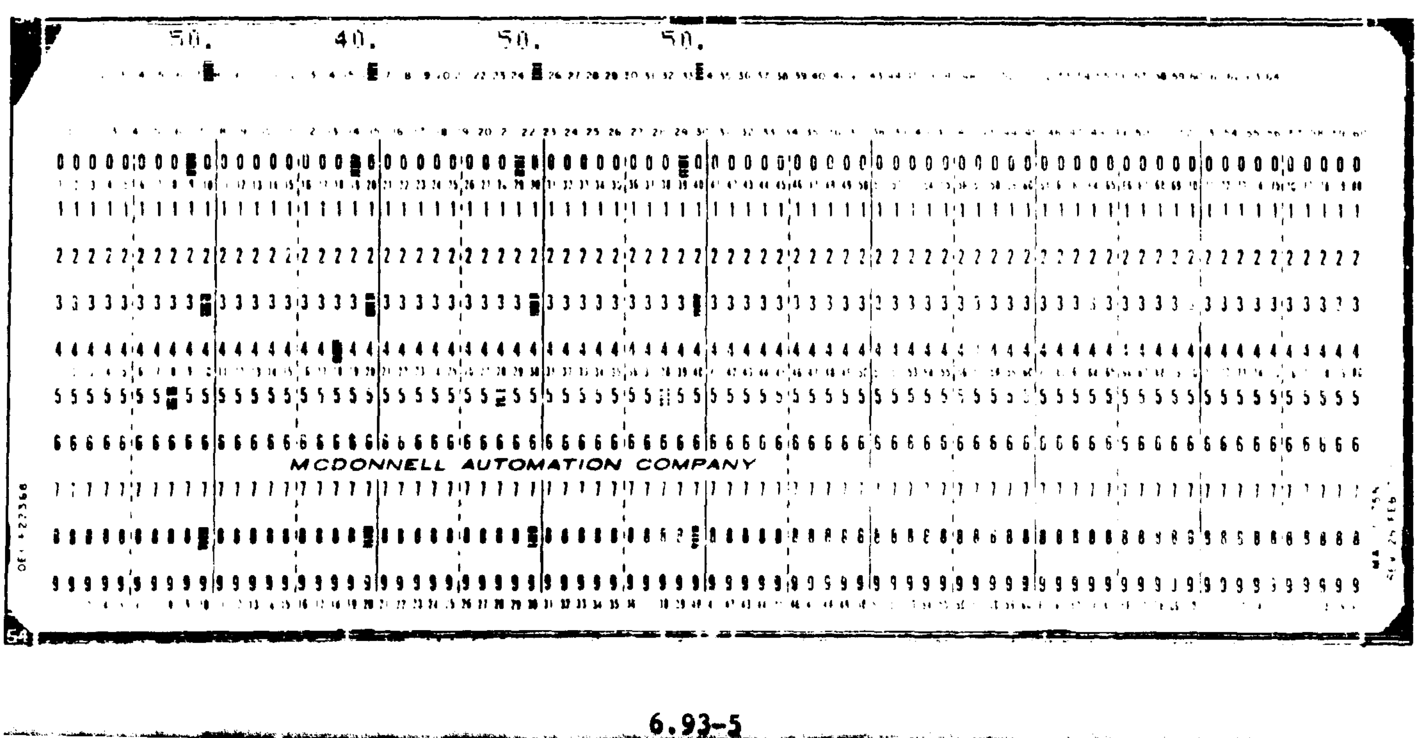
CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Load Torque @ T = 0	in lbs
11-20	E10.0	Subsequent Load Torques	in lbs
21-30	E10.0		
31-40	E10.0		

One or More Cards can be Used

	E10.0	Final Load Torques	in lbs
	E10.0		
	E10.0		

EXAMPLE CARD



6.95 TYPE #95 AUXILIARY POWER UNIT

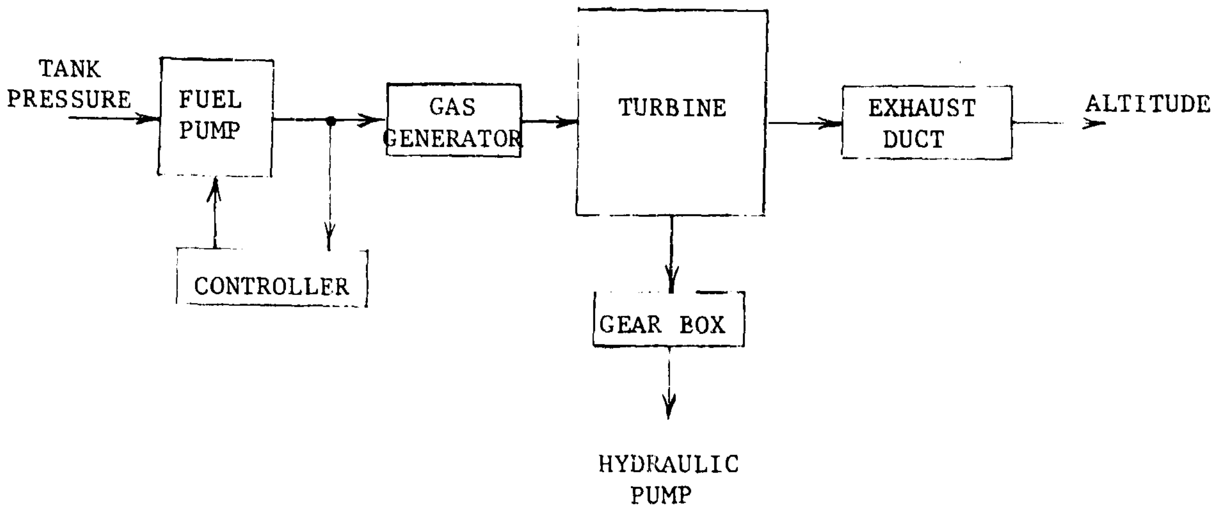


FIGURE 6.95-1

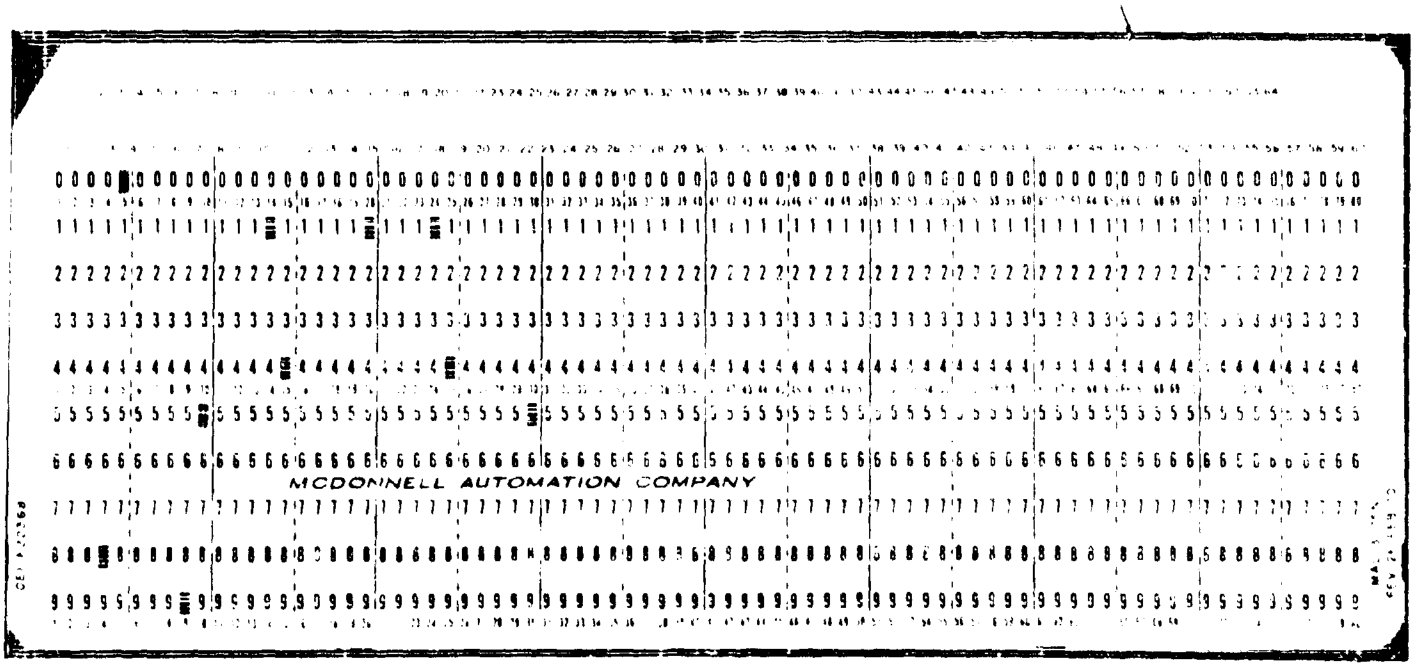
TYPE NO. 95 AUXILIARY POWER UNIT

The Type #95 auxiliary power unit is a simple turbine engine feed by a fuel pump. The turbine is used to power a hydraulic pump through a gear box connection.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 95
11-15	I5	Number of Real Data Cards =
16-20	I5	Component Number of Pump
21-25	I5	Number of APU Data Points for Each Pressure
26-30	I5	Number of APU Inlet Pressure

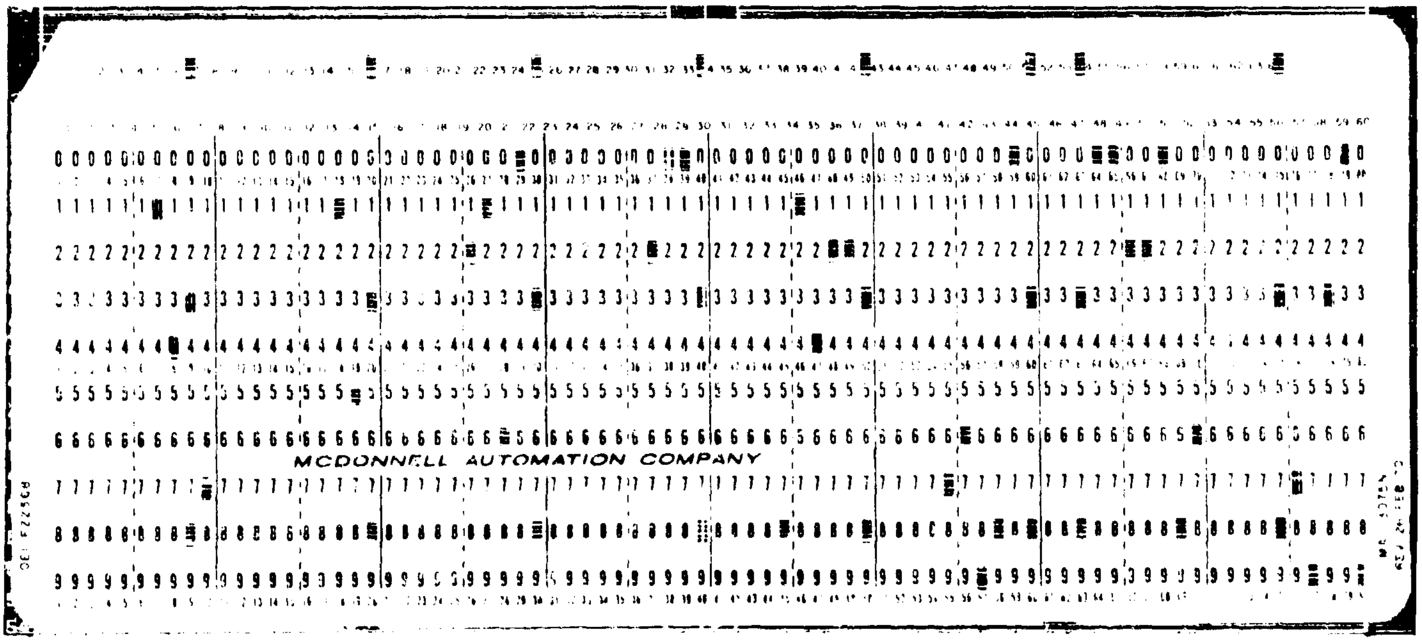
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Turbine Exhaust Pressure	PSI
11-20	E10.0	Gas Pressure	PSI
21-30	E10.0	Gas Temperature	^{o}R
31-40	E10.0	Fuel Tank Pressure	PSI
41-50	E10.0	High RPM	RPM
51-60	E10.0	Low RPM	RPM
61-70	E10.0	CED1	--
71-80	E10.0	CED2	--

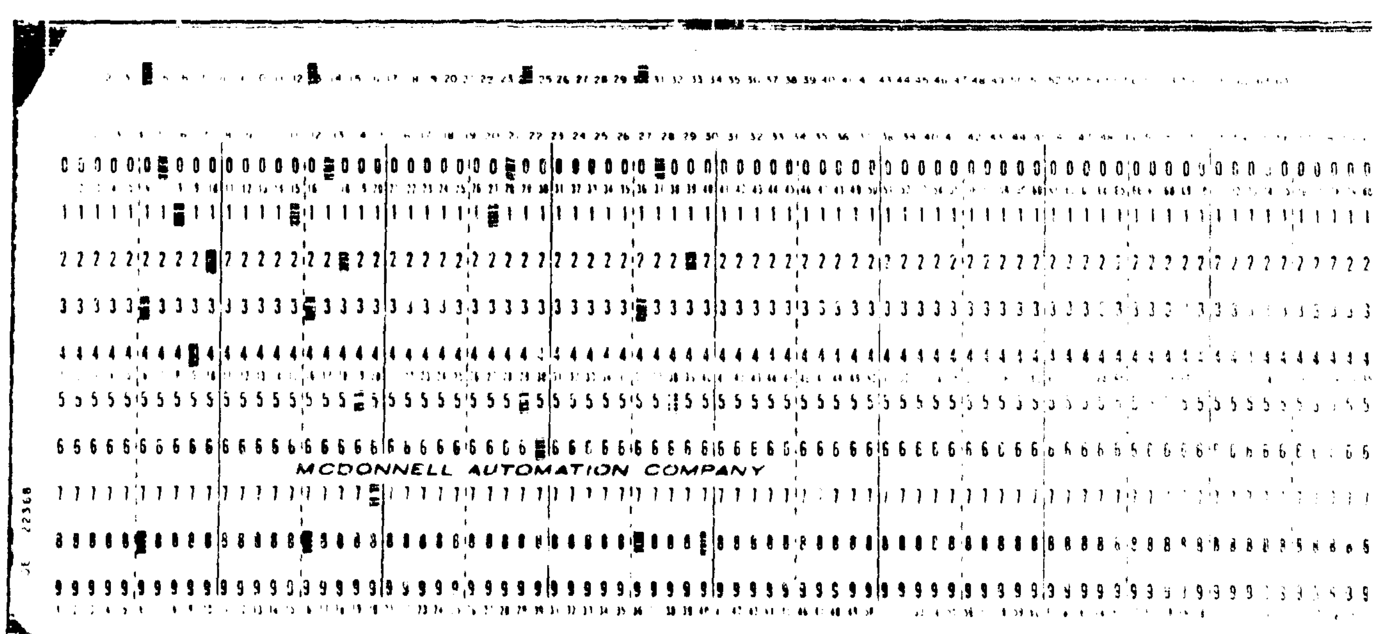
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	CED3	--
11-20	E10.0	CED4	--
21-30	E10.0	Time to Fail APU	SEC
30-35	E10.0	Gear Box Ratio	--

EXAMPLE CARD



On the fourth card and subsequent ones if needed the values of U/C (from the APU efficiently vs U/C curves). The number of U/C values correspond to the number in columns 26-30 of the first data card.

CARD NUMBER 4

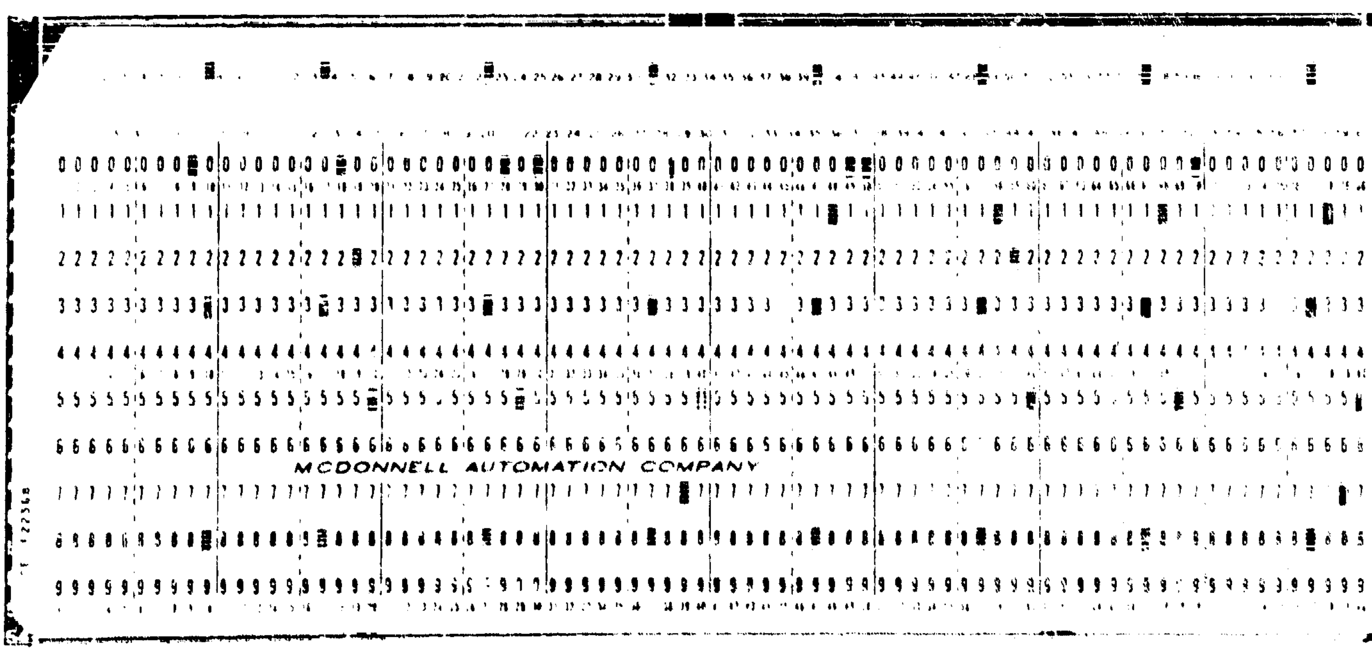
COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First U/C Value	--
11-20	E10.0	Second U/C Value	--

One or More Cards Can be Used

	E10.0	Final U/C Value	--

Note: It is not necessary to re-enter this data if it has been input for another APU.

EXAMPLE CARD



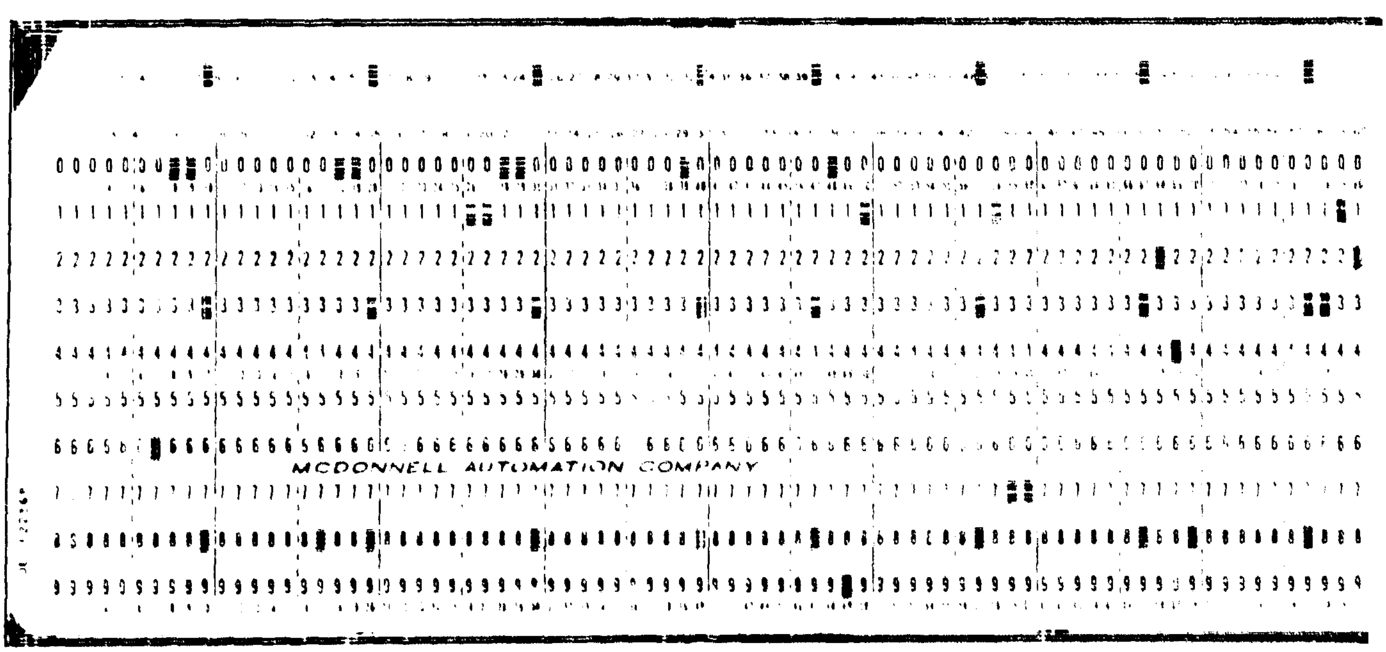
The next group of data to be entered are the inlet pressures. These values are entered in the next available data field after the final U/C values. The number of inlet pressures is the same as the number in columns 21-25 of the first APU data card.

COLUMN	FORMAT	DATA	DIMENSIONS
	E10.0	First Inlet Pressure Value	PSI
	E10.0	Second Inlet Pressure Value	PSI
		One or More Cards Can be Used	
	E10.0	Final Inlet Pressure Value	PSI

The final set of data entered is the efficiencies. The number of efficiency values equals the product of card columns 21-25 and 26-30 on the first APU card.

	E10.0	First Efficiency Value	--
	E10.0	Second Efficiency Value	--
		One or More Cards Can be Used	
	E10.0	Final Efficiency Value	--

EXAMPLE CARD



6.98 CAD98 INPUT CONTROL DATA

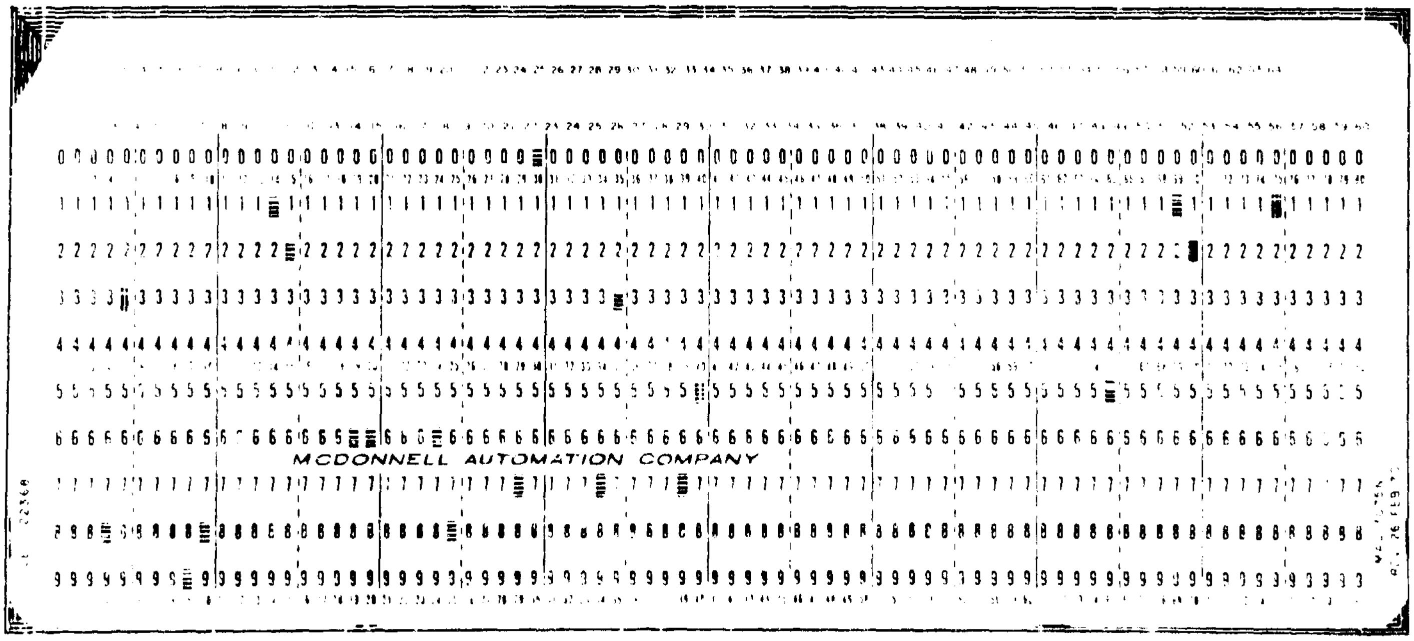
CAD98 is used as a dummy input subroutine for actuator position commands for multiple actuator systems. Up to nine actuators may be controlled by CAD98. Unlike CAD92, hinge moments are not supplied to the actuators. Commands are updated at .020 second intervals.

The input data is used as a time history of the actuator input position command, using a linear interpolation for times between the data points. The number of input time data points and position command data points should be both equal to the number input on the first card columns 65-70.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 98
11-15	I5	Number of Real Data Cards = 2 or more
16-20	I5	Actuator Component Number
21-25	I5	Actuator Component Number
26-30	I5	Actuator Component Number
31-35	I5	Actuator Component Number
36-40	I5	Actuator Component Number
41-45	I5	Actuator Component Number
46-50	I5	Actuator Component Number
51-55	I5	Actuator Component Number
56-60	I5	Actuator Component Number
61-65	I5	Total Number of Actuators (9 Maximum)
66-70	I5	Number of Data Points in Time (and Input) Data
71-75	I5	
76-80	I5	

EXAMPLE CARD



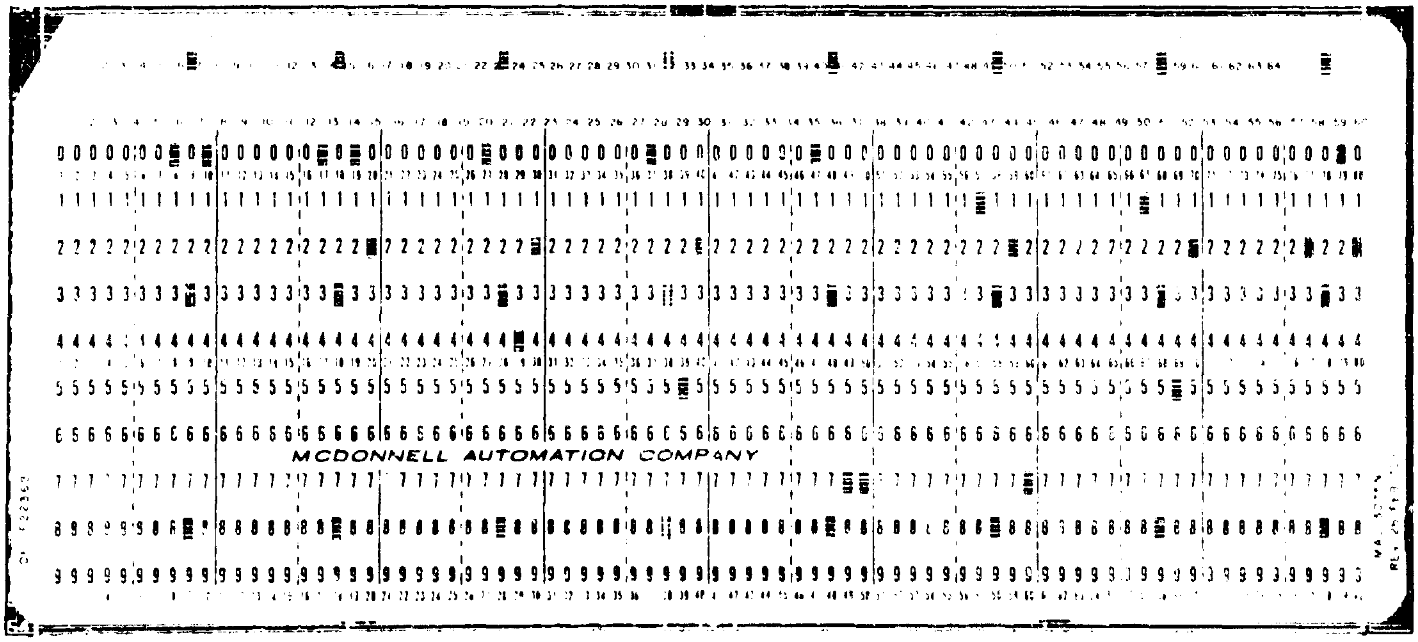
CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Value (Should Be Zero)	sec
11-20	E10.0	Second Time Value	sec
21-30	E10.0		
31-40	E10.0		

One or More Cards Can Be Used

51-60	E10.0	Final Time	sec
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



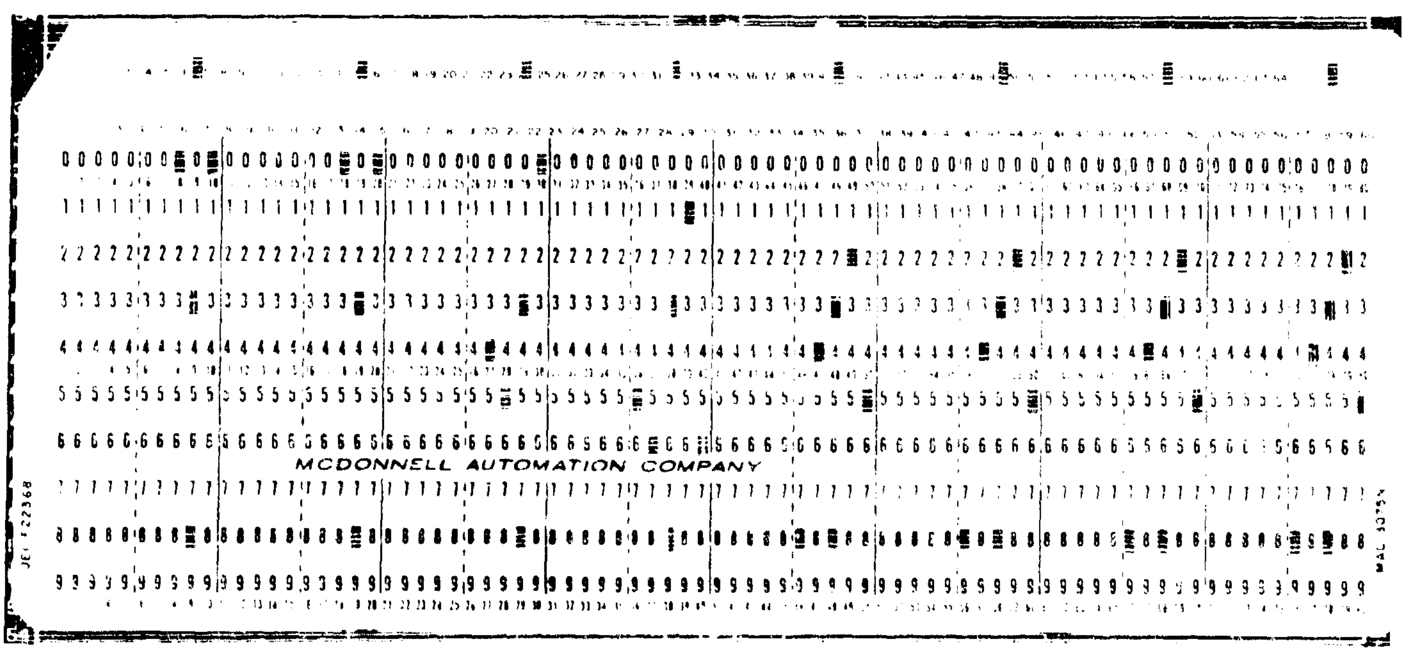
CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Input Position @ T=0	deg
11-20	E10.0	Subsequent Input Commands	deg
21-30	E10.0		
31-40	E10.0		

One or More Cards Can Be Used

51-60	E10.0	Final Input Command	deg
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD

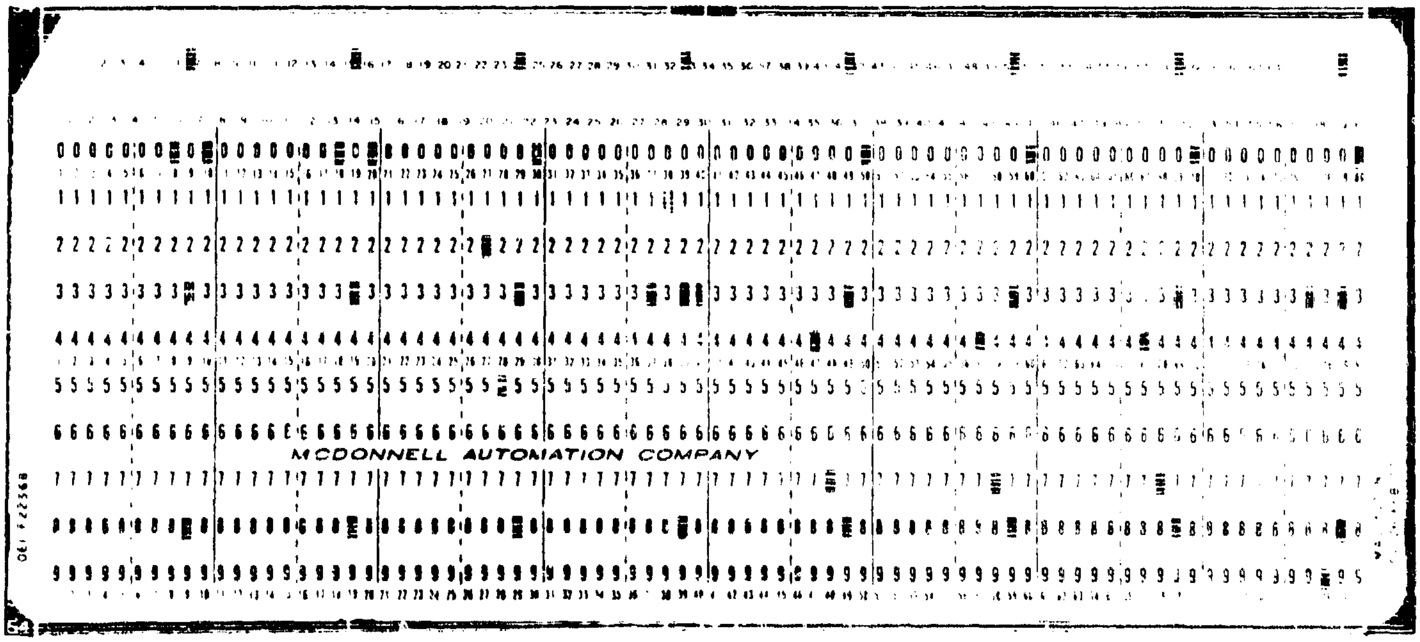


FOR SUBSEQUENT ACTUATORS

CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Input Position @ T=0	deg
11-20	E10.0	Subsequent Input Commands	deg
21-30	E10.0		
31-40	E10.0		
		One or More Cards Can Be Used	
51-60	E10.0	Final Input Command	deg
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.99.1 TYPE99 SDF INTERFACE

CAD99 is a special component which provides the necessary interface between HYTRAN and SDF.

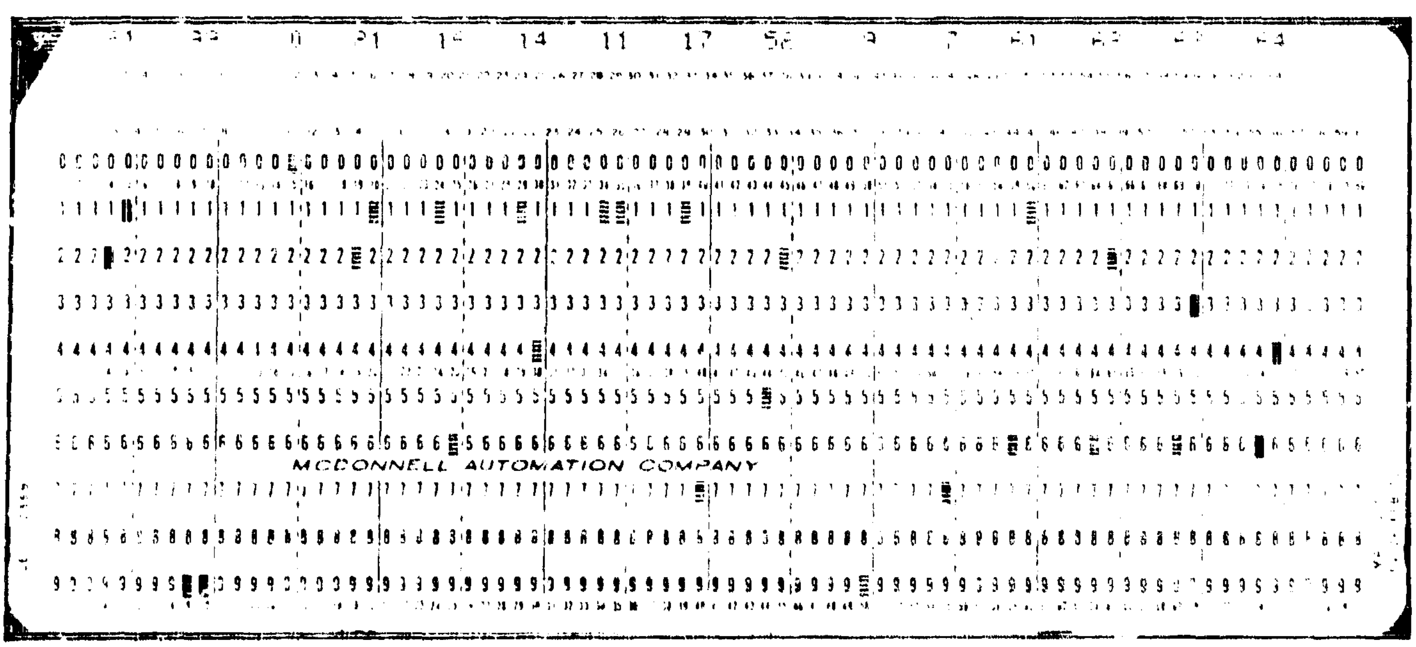
The CAD99 subroutine used must be either for the ascent flight or the descent flight.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 99
11-15	I5	Number of Real Data Cards = 0
16-20	I5	Left Outboard Elevon Component Number
21-25	I5	Left Inboard Elevon Component Number
26-30	I5	Right Outboard Elevon Component Number
31-35	I5	Right Inboard Elevon Component Number
36-40	I5	Rudder/Speedbrake Component Number
41-45	I5	Body Flap Component Number
46-50	I5	No. 1 Pitch TVC Component Number *
51-55	I5	No. 1 Yaw TVC Component Number *
56-60	I5	No. 2 Pitch TVC Component Number *
61-65	I5	No. 2 Yaw TVC Component Number *
66-70	I5	No. 3 Pitch TVC Component Number *
71-75	I5	No. 3 Yaw TVC Component Number *
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

* Note: Not used in descent simulation

EXAMPLE CARD



6.100 ACTUATORS

The actuator models are setup for a specific actuator or for a general type. The general type can be used to simulate actuators by using the appropriate input data, if the general configuration is close enough to be acceptable. The following types are currently available.

Type #101	Valve Controlled Actuator (ACT101)
Type #102	Utility Actuator (ACT102)
Type #103	Shuttle Elevon Actuator (ACT103)
Type #104	Engine Control Actuator (ACT104)
Type #105	Thrust Vector Control Actuator (ACT105)
Type #106	Shuttle Body Flap (ACT106)
Type #107	Shuttle Rudder/Speedbrake (ACT107)

Note: Zero stroke (noted in the input data) is defined as the piston position when actuator is fully retracted.

6.101 TYPE #101 VALVE CONTROLLED ACTUATOR

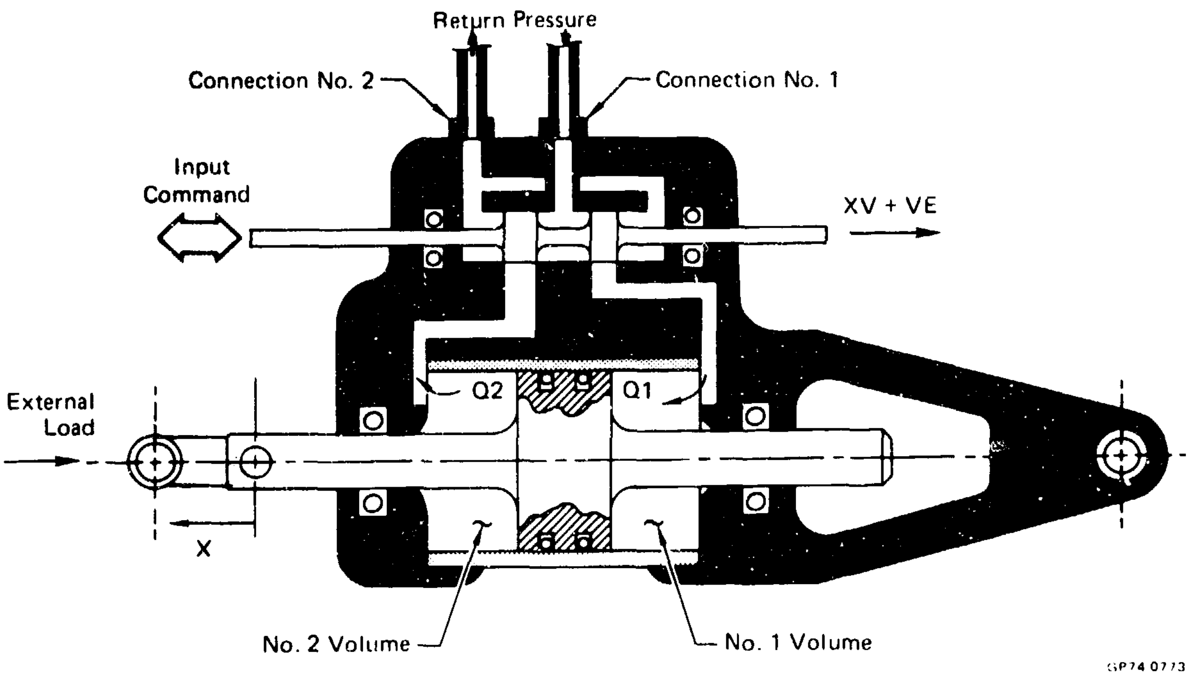


FIGURE 6.101-1
TYPE NO. 101 VALVE CONTROLLED ACTUATOR

The valve controlled actuator is an actuator with an integral valve that is typical of servoactuators. One line is connected to pressure port and one line is connected to return port. Actuator designs that can be used are as follows:

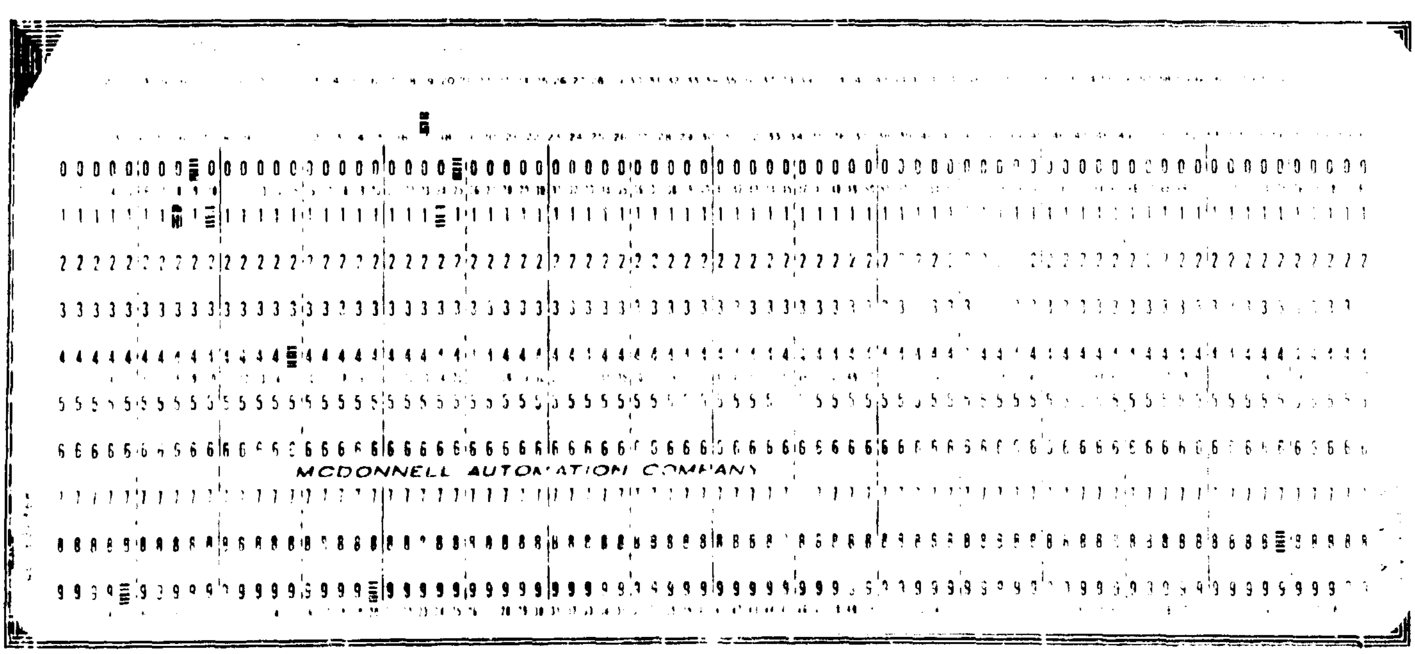
- o Balanced actuator
- o Unbalanced actuator
- o Partially balanced actuator
- o Tandem balanced or unbalanced actuator
- o Parallel balanced or unbalanced actuator (provided all piston rods react a common load).

Unbalanced actuators require a node in Volume No. 1, see Section 7.0.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 101
11-15	I5	Number of Real Data Cards = 4 or more
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	Number of Data Points on the Time Data Table
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

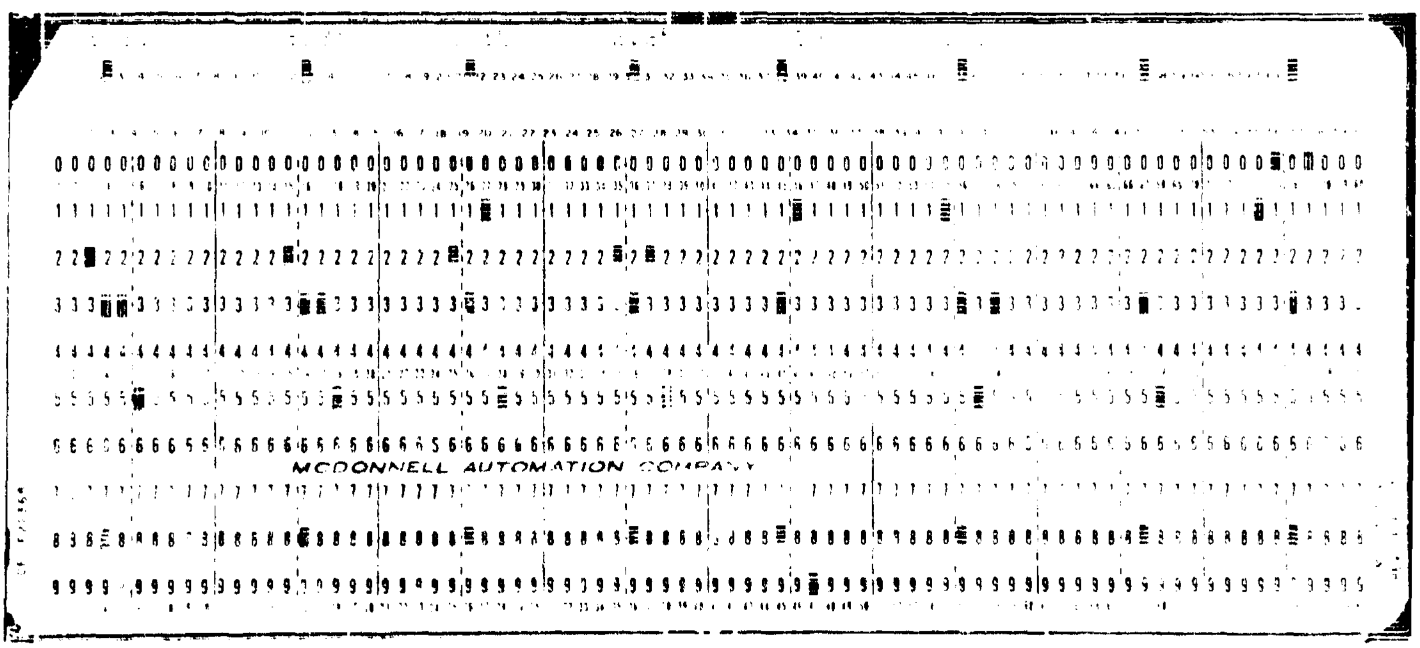
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	NO. 1 AREA	IN^2
11-20	E10.0	NO. 2 AREA	IN^3
21-30	E10.0	NO. 1 VOLUME AT ZERO STROKE	IN^3
31-40	E10.0	NO. 2 VOLUME AT ZERO STROKE	IN^3
41-50	E10.0	STROKE WITH ACTUATOR FULLY RETRACTED	IN
51-60	E10.0	STROKE WITH ACTUATOR FULLY EXTENDED	IN
61-70	E10.0	VELOCITY DAMPING	LBS SEC/IN
71-80	E10.0	LOAD MASS	LBS SEC^2/IN

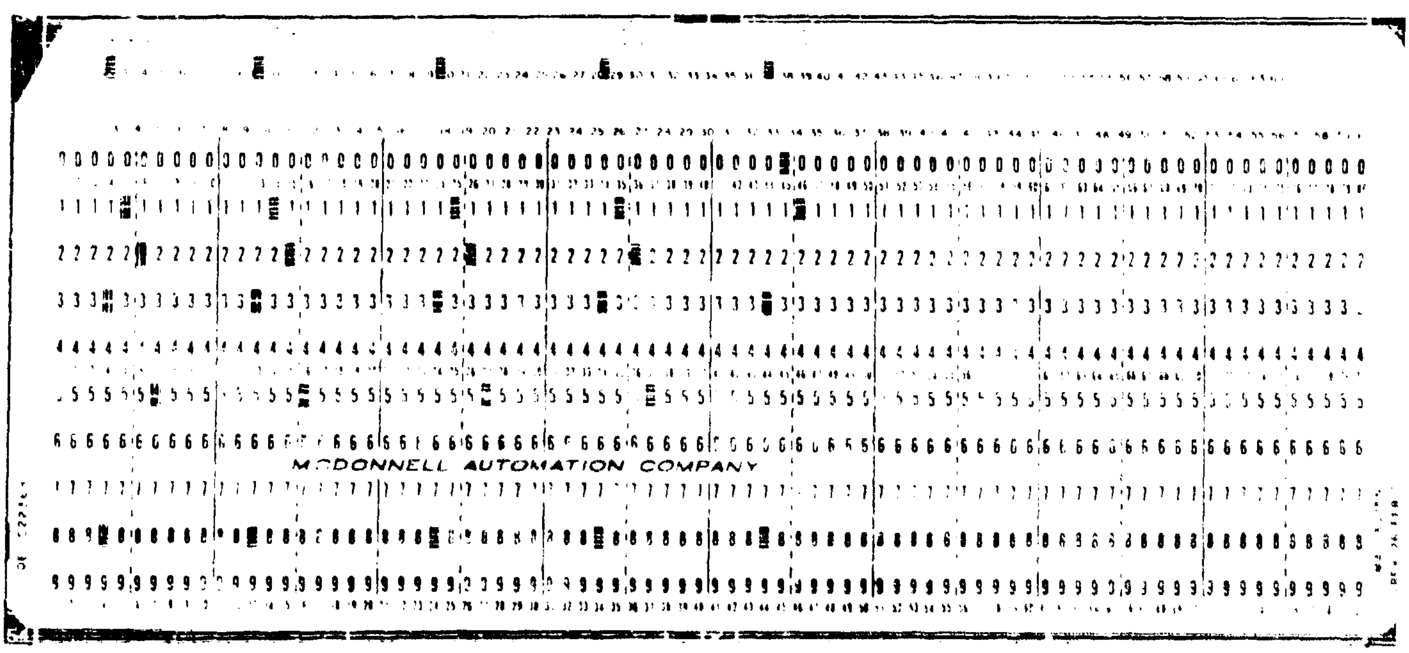
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	SLOT WIDTH VOL #1 TO CON #1 (when xv is positive	IN
11-20	E10.0	SLOT WIDTH VOL #1 TO CON #2 (when xv is negative)	IN
21-30	E10.0	SLOT WIDTH VOL #2 TO CON #1 (when xv is negative)	IN
31-40	E10.0	SLOT WIDTH VOL #2 TO CON #2 (when xv is positive	IN
41-50	E10.0	COMPRESSIVE LOAD WITH ACTUATOR FULLY RETRACTED	LBS
51-60	E10.0	COMPRESSIVE LOAD WITH ACTUATOR FULLY EXTENDED	LBS
61-70	E10.0	INITIAL ACTUATOR POSITION	IN
71-80	E10.0		

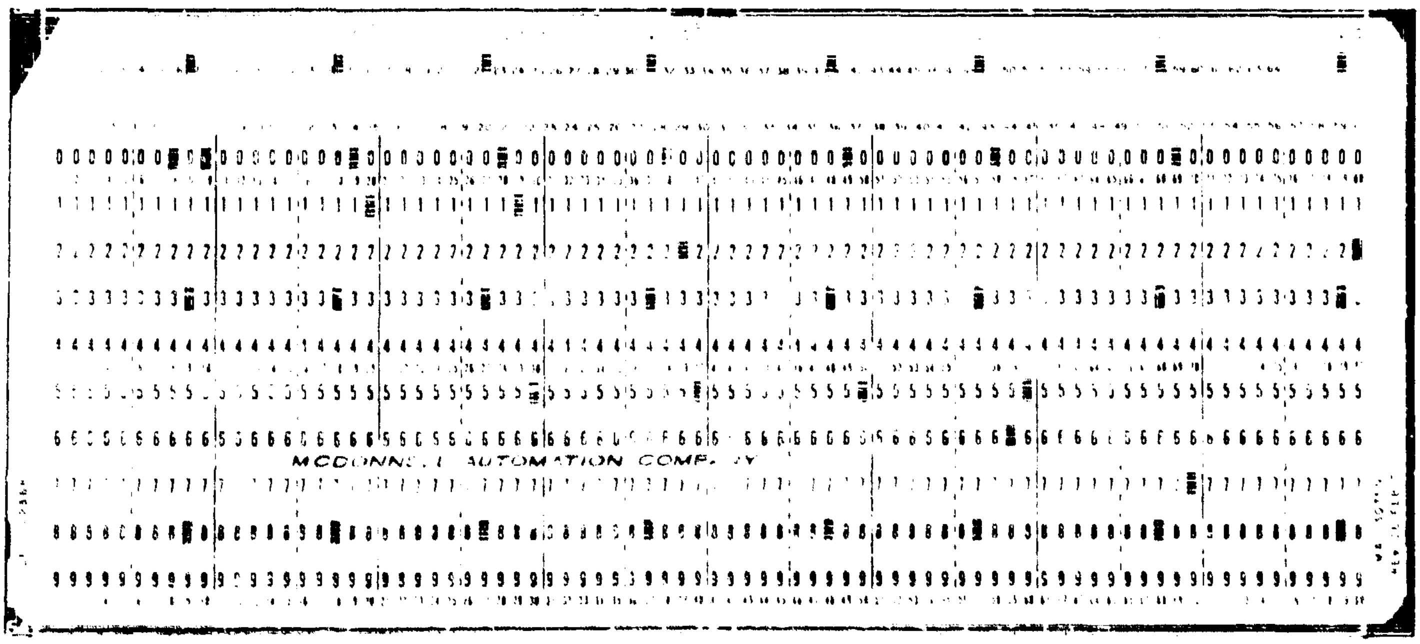
EXAMPLE CARD



CARD NUMBER 4

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	First Time Value - Should be 0.0	sec
11-20	E10.0	(Enter as many time values as	sec
21-30	E10.0	required using as many columns	
31-40	E10.0	and cards as necessary - Final	
41-50	E10.0	time should be final calculation time).	
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

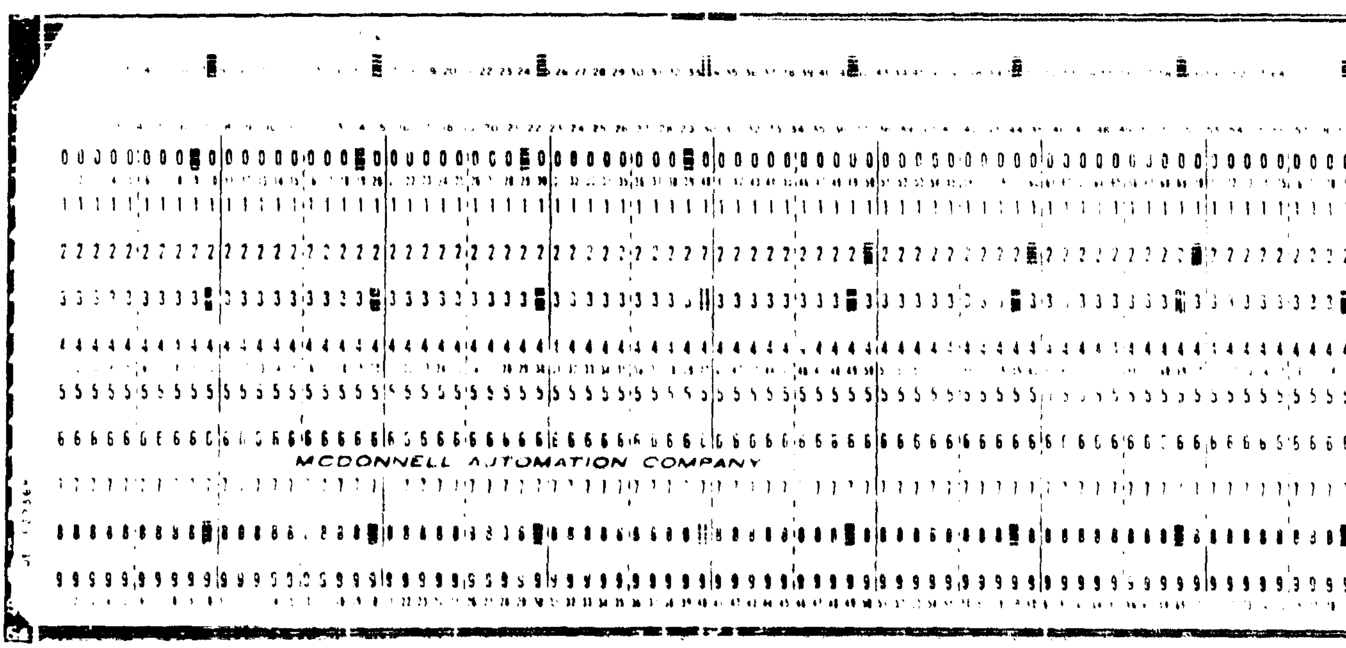
EXAMPLE CARD



CARD NUMBER 5

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Initial Valve Position @ T = 0.0	in
11-20	E10.0	(Enter as many valve positions as	
21-30	E10.0	time values).	
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.102 TYPE #102 UTILITY ACTUATOR

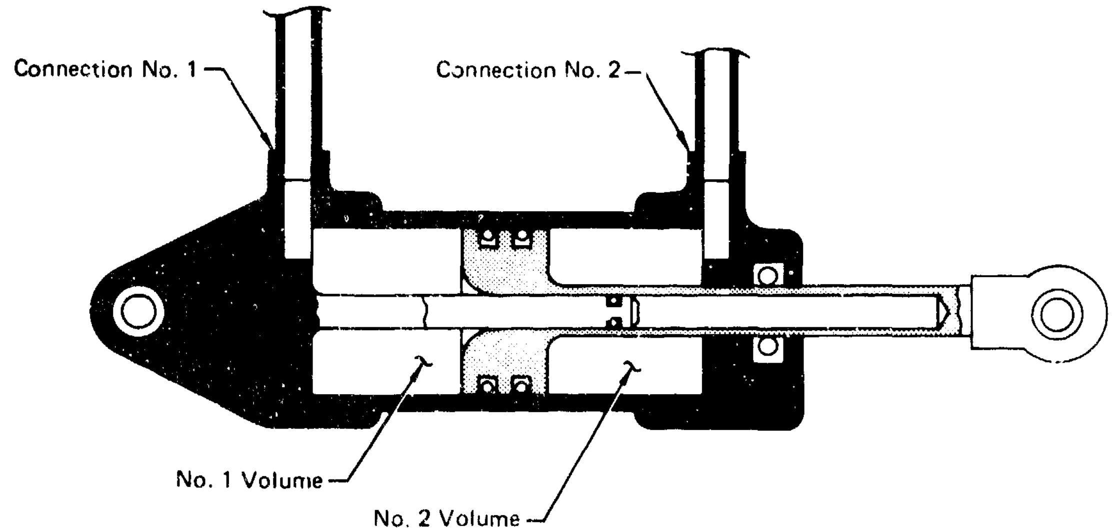


FIGURE 6.102-1
TYPE NO. 102 UTILITY ACTUATOR

This is a simple utility type actuator with a line connected to the extend port and a line connected to the retract port. Actuator designs that can be used are as follows:

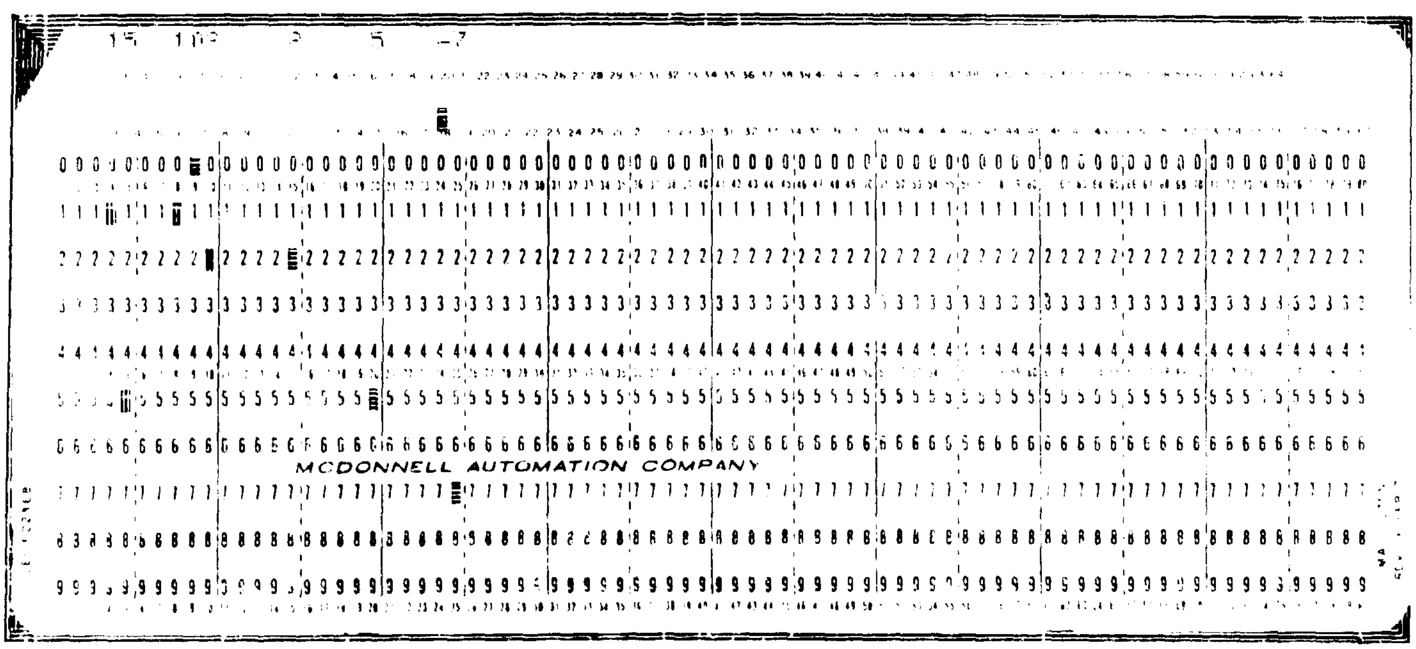
- o Balanced actuator
- o Unbalanced actuator
- o Partially balanced actuator
- o Tandem balanced or unbalanced actuator
- o Parallel balanced or unbalanced actuator (provided piston rods react a common load).

Unbalanced actuators require a node in Volume No. 1, see Section 7.0.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 102
11-15	I5	Number of Real Data Cards = 2
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

EXAMPLE CARD

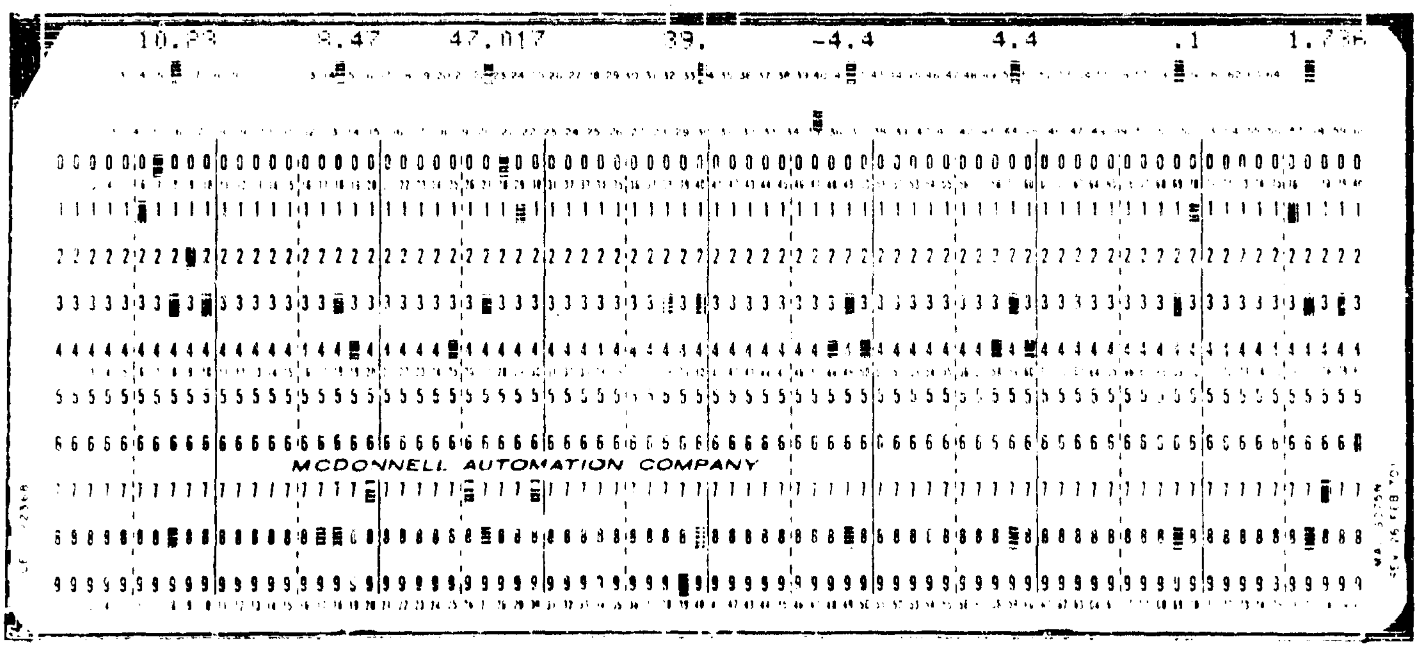


CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	#1 Piston Area (Extend)	in^2
11-20	E10.0	#2 Piston Area (Retract)	in^2
21-30	E10.0	#1 Volume at Zero Stroke *	in^3
31-40	E10.0	#2 Volume at Zero Stroke *	in^3
41-50	E10.0	Stroke to Minimum Position (-ve or zero)	in
51-60	E10.0	Stroke to Maximum Position (+ve or zero)	in
61-70	E10.0	Seal Friction	$\frac{\text{lb-sec}}{\text{in}}$
71-80	E10.0	Piston Mass	$\text{lb-sec}^2/\text{in}$

* Zero stroke may be at one of the limits.

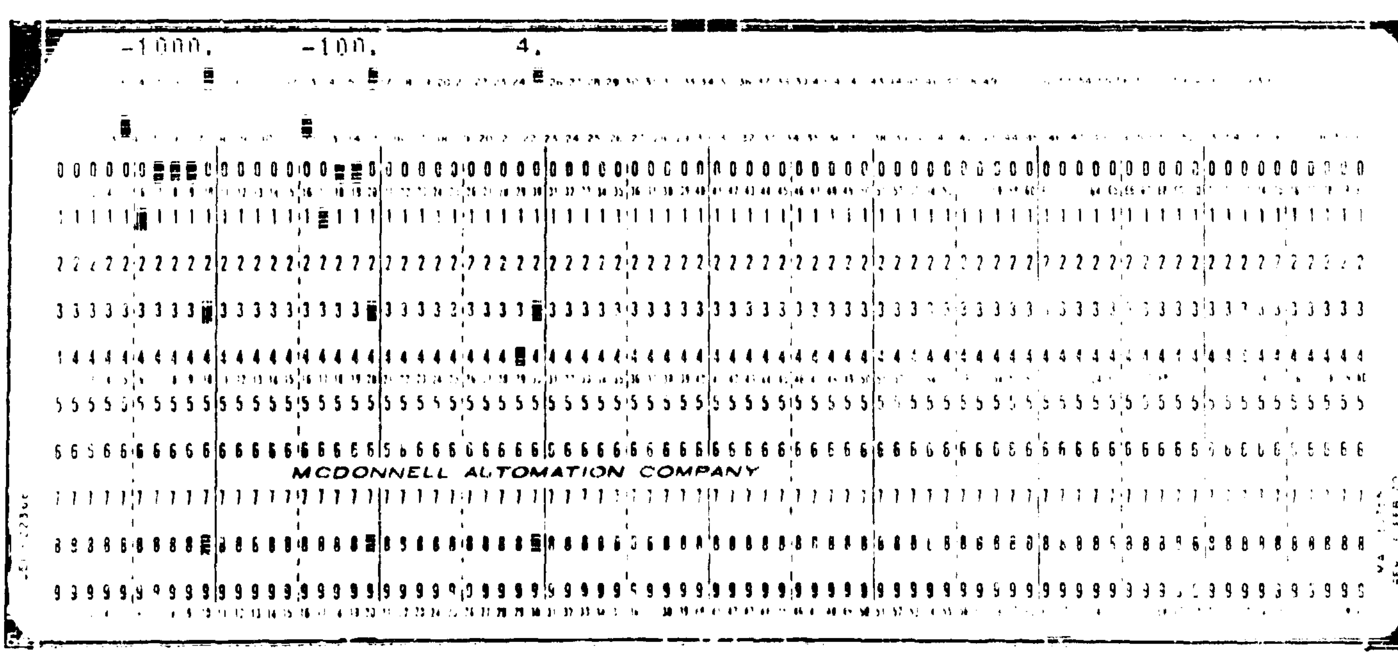
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Load at Min. Stroke (retracted)	lb
11-20	E10.0	Load at Max. Stroke (extended)	lb
21-30	E10.0	Initial Stroke at Time T = 0.0	in
31-40	E10.0		
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

EXAMPLE CARD



6.103 TYPE #103 SHUTTLE ELEVON ACTUATOR

Subroutine ACT103 models the shuttle elevon actuators, the layout of which is shown in Figure 6.103-1. The elevon actuators operate from a single pair of hydraulic supply and return lines. This supply and return is normally supplied by the three hydraulic systems via a switching valve module as shown in Figure 6.103-2. For the purposes of modeling the switching valve module is considered to be a separate component. The input command and hinge moments are supplied by a Guidance and Control subroutine which updates the values at each sample time interval of the guidance system which is .04 seconds. The initial position of the elevon actuator and the aerodynamic load on the elevon, which are inputted, are used to calculate an initial value for VC. This computed value is then used as the initial command to the system. All other variables are initialized to zero.

ELEVON ACTUATION CONTROL SYSTEM MODEL

REVISION A

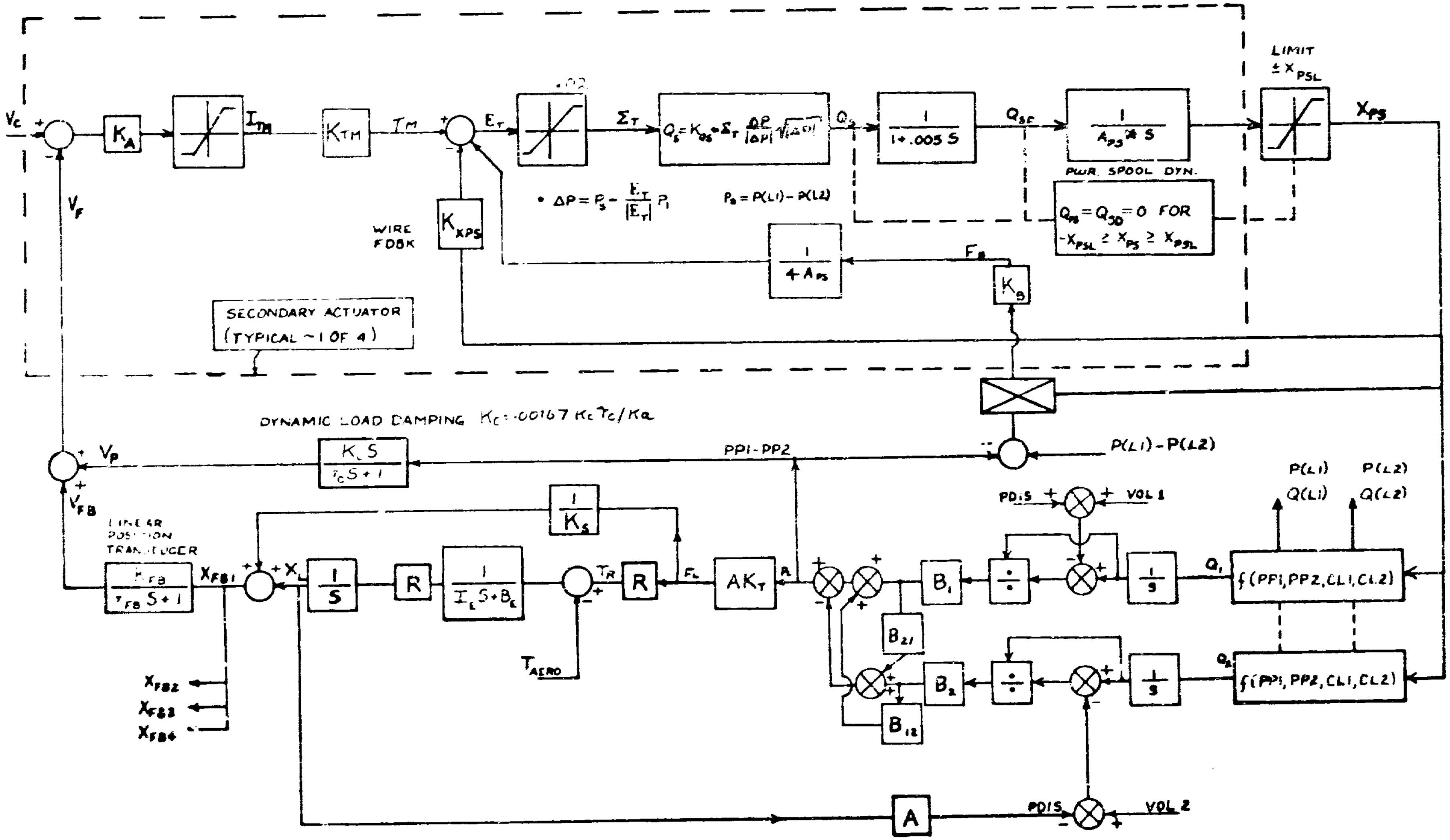


FIGURE 6.103-1

ELEVON HYDRAULIC CONTROL SYSTEM

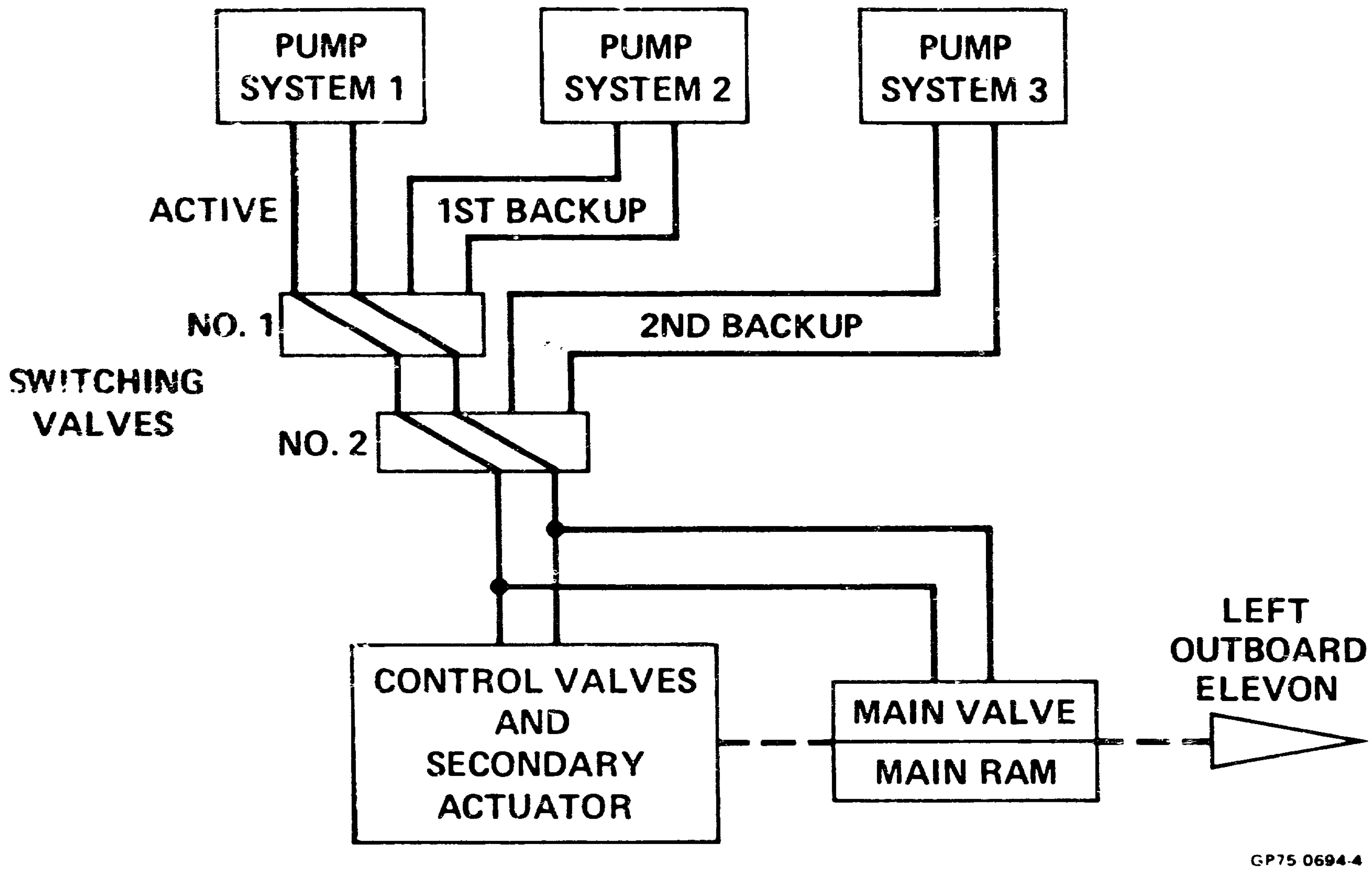
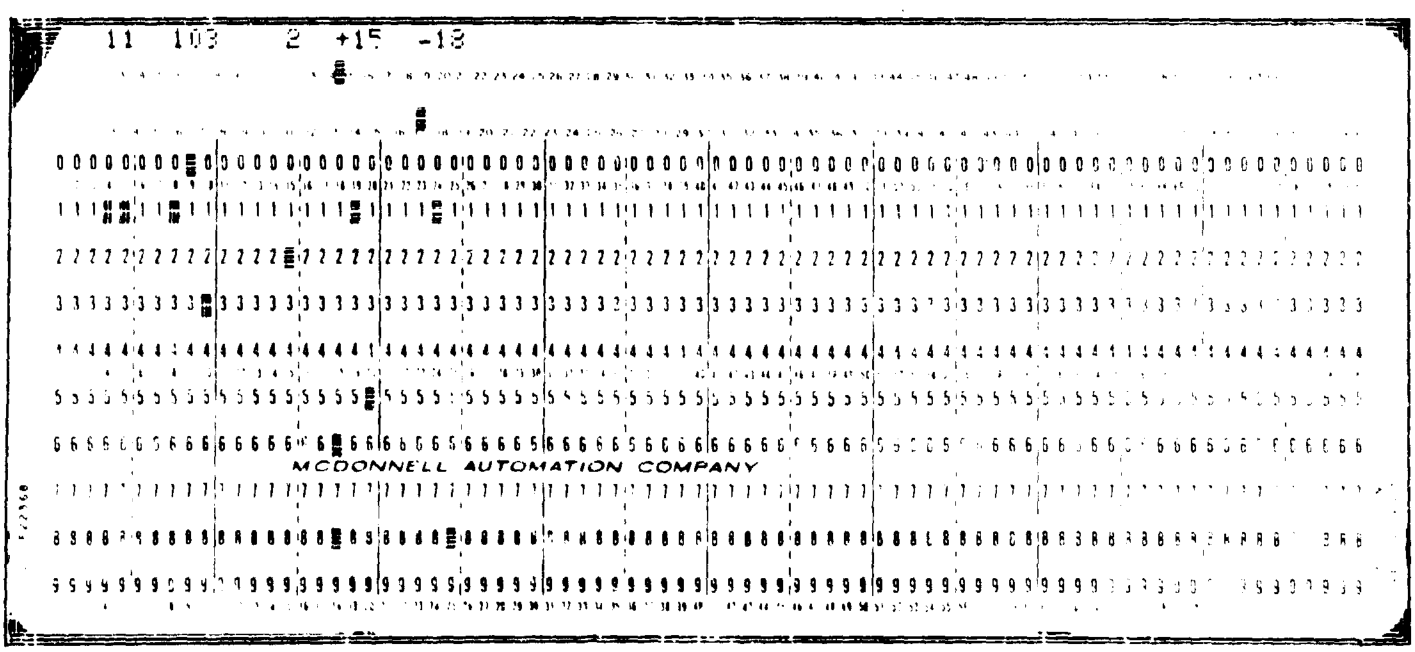


FIGURE 6.103-2

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 103
11-15	I5	Number of Real Data Cards = 2
16-20	I5	Line Number (with sign) attached to Connection 1 (Primary)
21-25	I5	Line Number (with sign) attached to Connection 2 (Primary)
26-30	I5	Line Number (with sign) attached to Connection 3 (Standby #1)
31-35	I5	Line Number (with sign) attached to Connection 4 (Standby #1)
36-40	I5	Line Number (with sign) attached to Connection 5 (Standby #2)
41-45	I5	Line Number (with sign) attached to Connection 6 (Standby #2)
46-50	I5	
51-55	I5	
56-60	I5	Primary Hydraulic System No.
61-65	I5	Standby #1 Hydraulic System No.
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

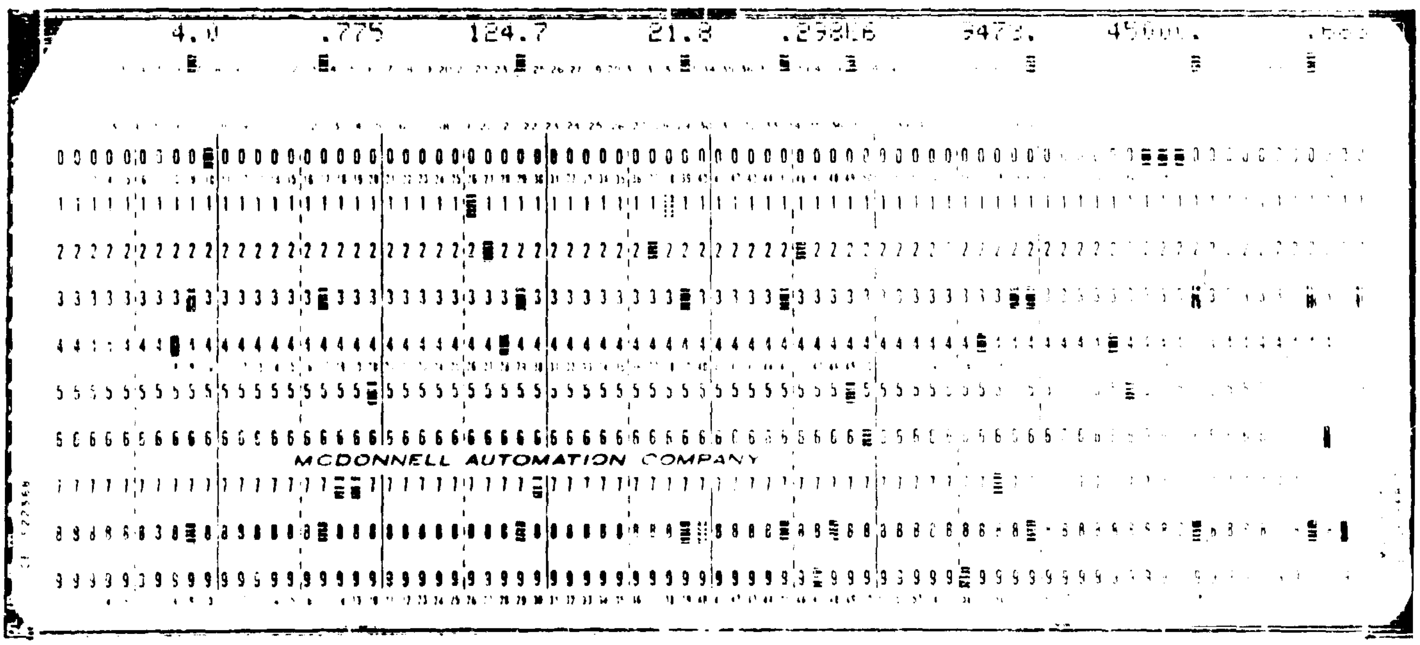
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Number of Operative Channels	-
11-20	E10.0	Bernoulli Force Coefficient	in
21-30	E10.0	Power Spool Flow Gain	in^3/(sec lb)
31-40	E10.0	Effective Surface Actuator Area	in^2
41-50	E10.0	Structural Stiffness	lb/in
51-60	E10.0	Elevon Moment of Inertia About Hinge Line	in-lb-sec^2
61-70	E10.0	Effective Elevon Damping Coefficient	in-lb-sec
71-80	E10.0	Linear Position Transducer Gain	volts/in

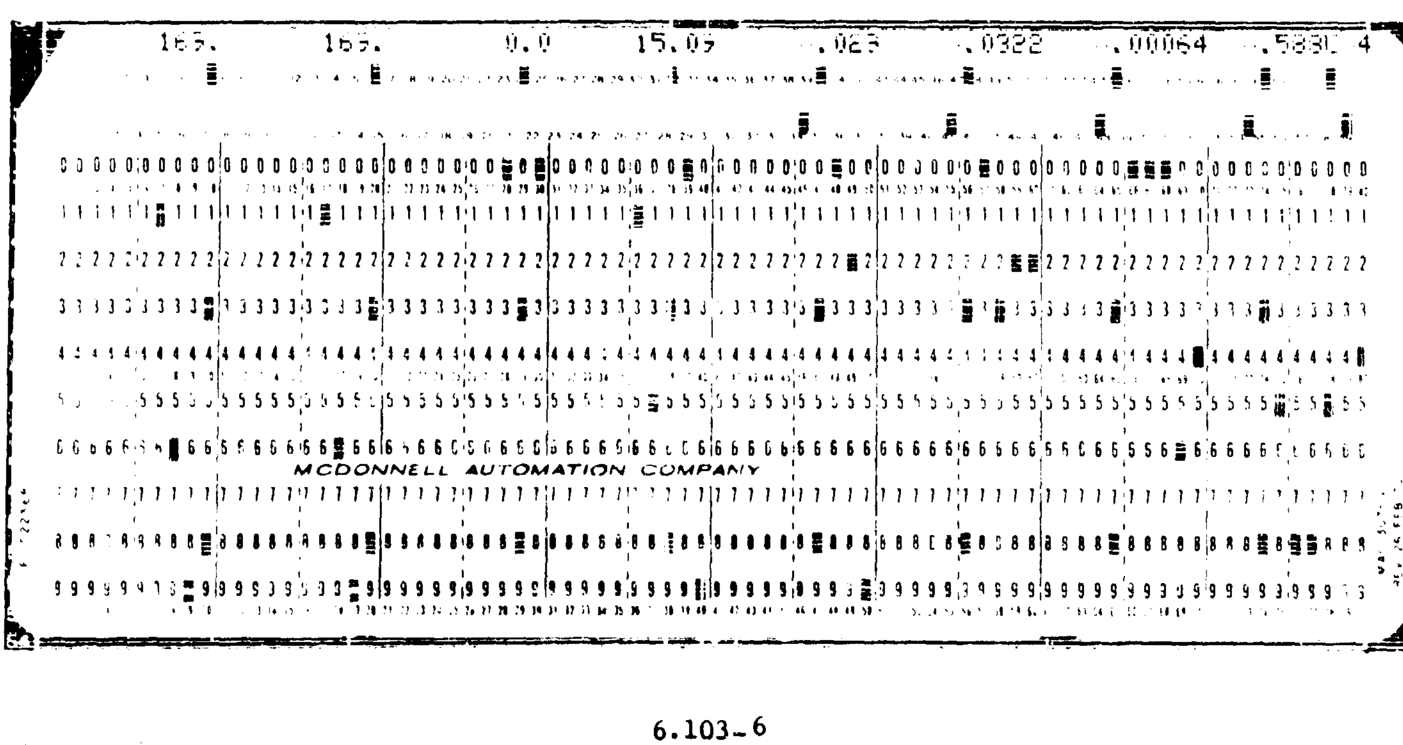
EXAMPLE CARD



CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	#1 Cavity Volume at Mid-Stroke	in^3
11-20	E10.0	#2 Cavity Volume at Mid-Stroke	in^3
21-30	E10.0		
31-40	E10.0	Initial Position of Elevon Actuator	in
41-50	E10.0	1st Moment Arm Constant (XL)	in/in
51-60	E10.0	2nd Moment Arm Constant $(XL)^2$	in/in^2
61-70	E10.0	3rd Moment Arm Constant $(XL)^3$	in/in^3
71-80	E10.0	4th Moment Arm Constant $(XL)^4$	in/in^4

EXAMPLE CARD



6.104 TYPE #104 SHUTTLE ENGINE CONTROL ACTUATOR

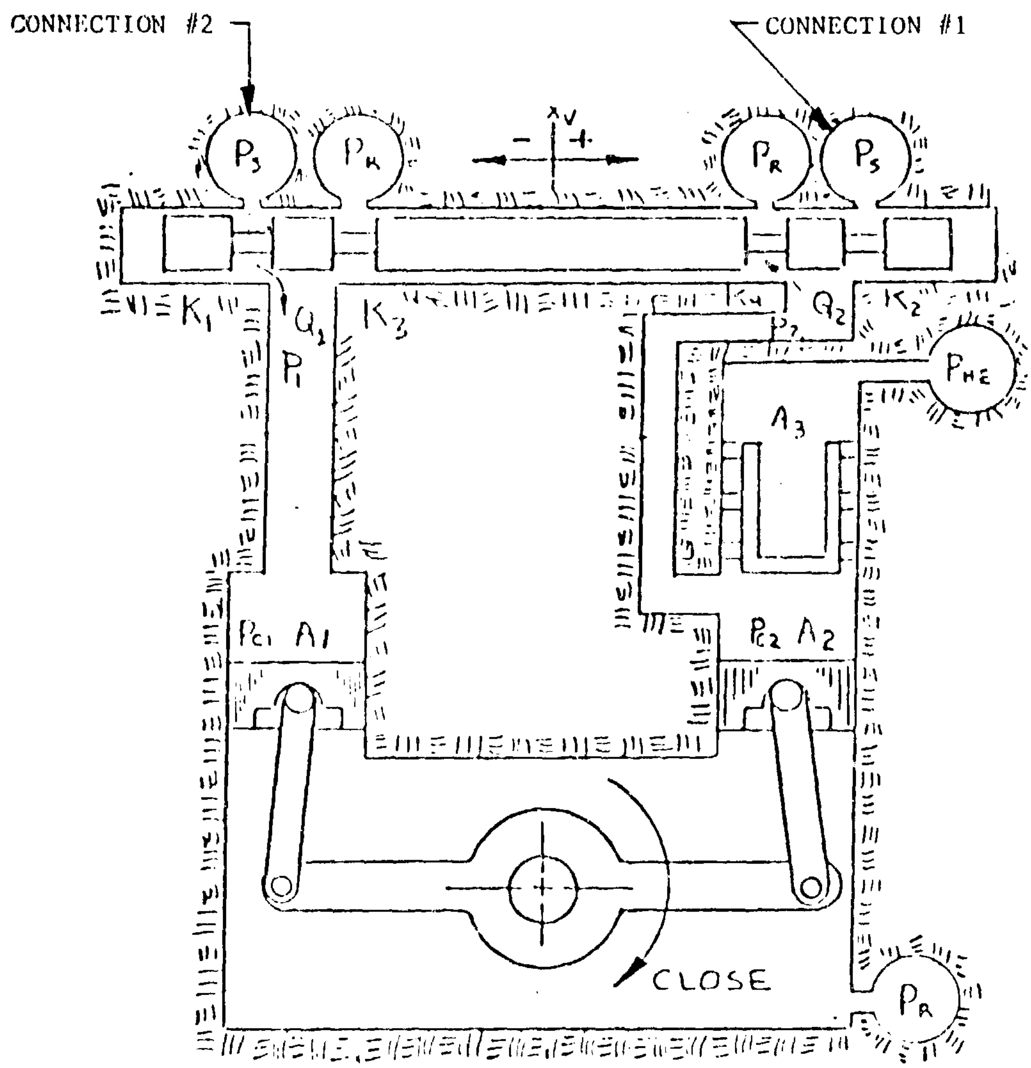


FIGURE 6.104-1

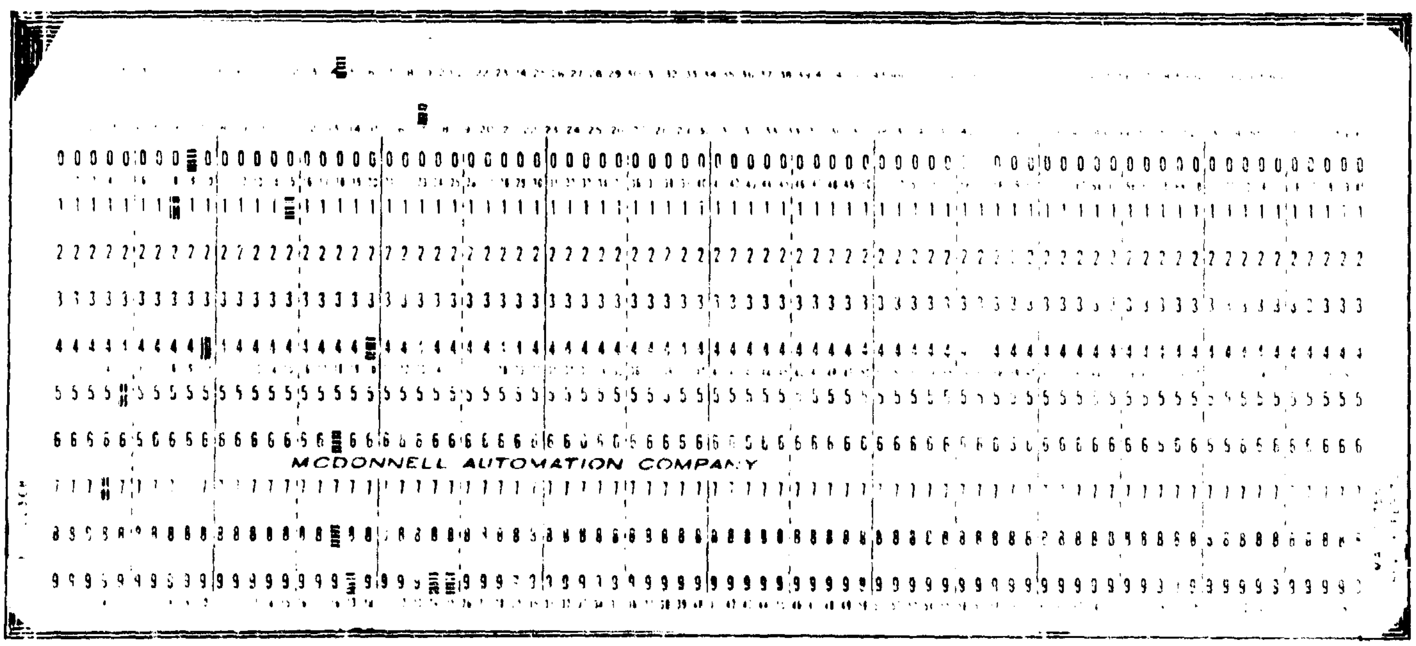
TYPE NO. 104 SHUTTLE ENGINE CONTROL ACTUATOR

The No. 104 actuator is a model of a push-push servoactuator. External loads as well as friction are not included in the model. Data inputs required are position transducer gain, servovalve gain constant, average effective moment arm and piston area.

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number =
11-15	I5	Number of Real Data Cards =
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

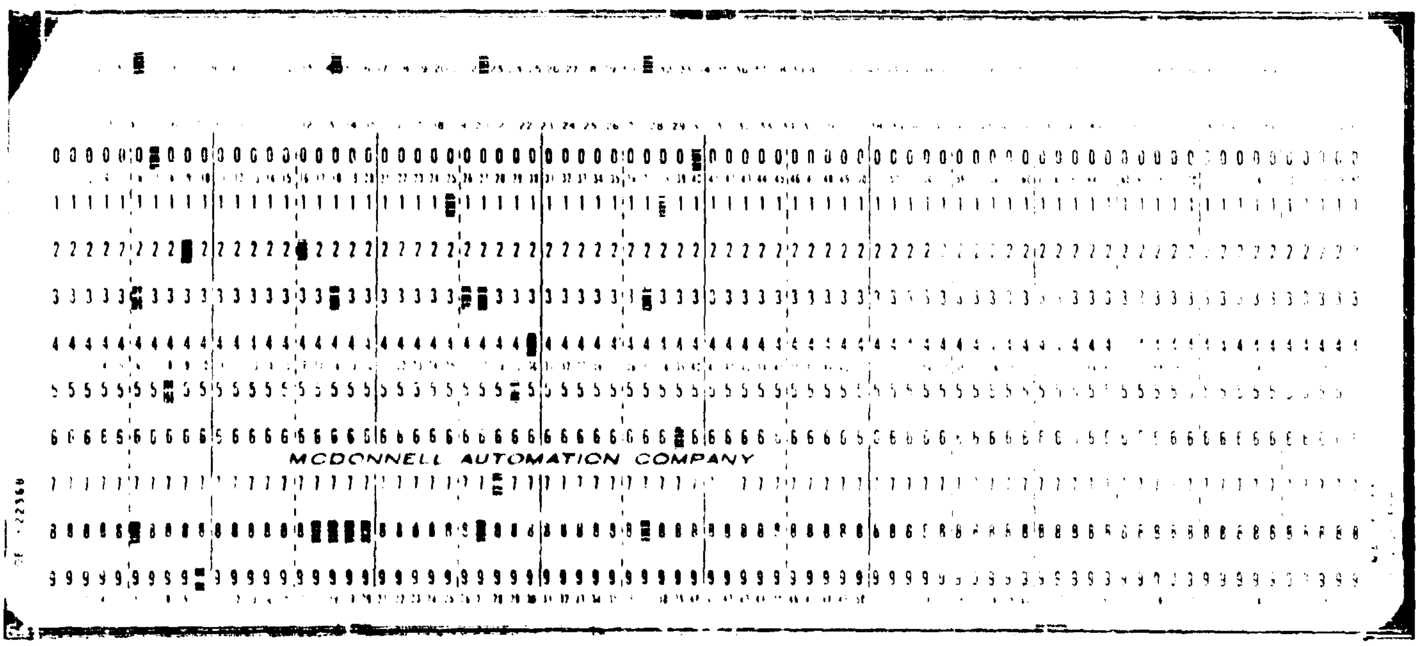
EXAMPLE CARD



CARD NUMBER

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Position Transducer Gain	V/DEG
11-20	E10.0	Servovalve Gain Constant	*
21-30	E10.0	57.3/(Effective Lever Arm * Piston Area)	DEG/IN^3
31-40	E10.0	Input 1st Order Lag Time Constant	SEC
41-50	E10.0		
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

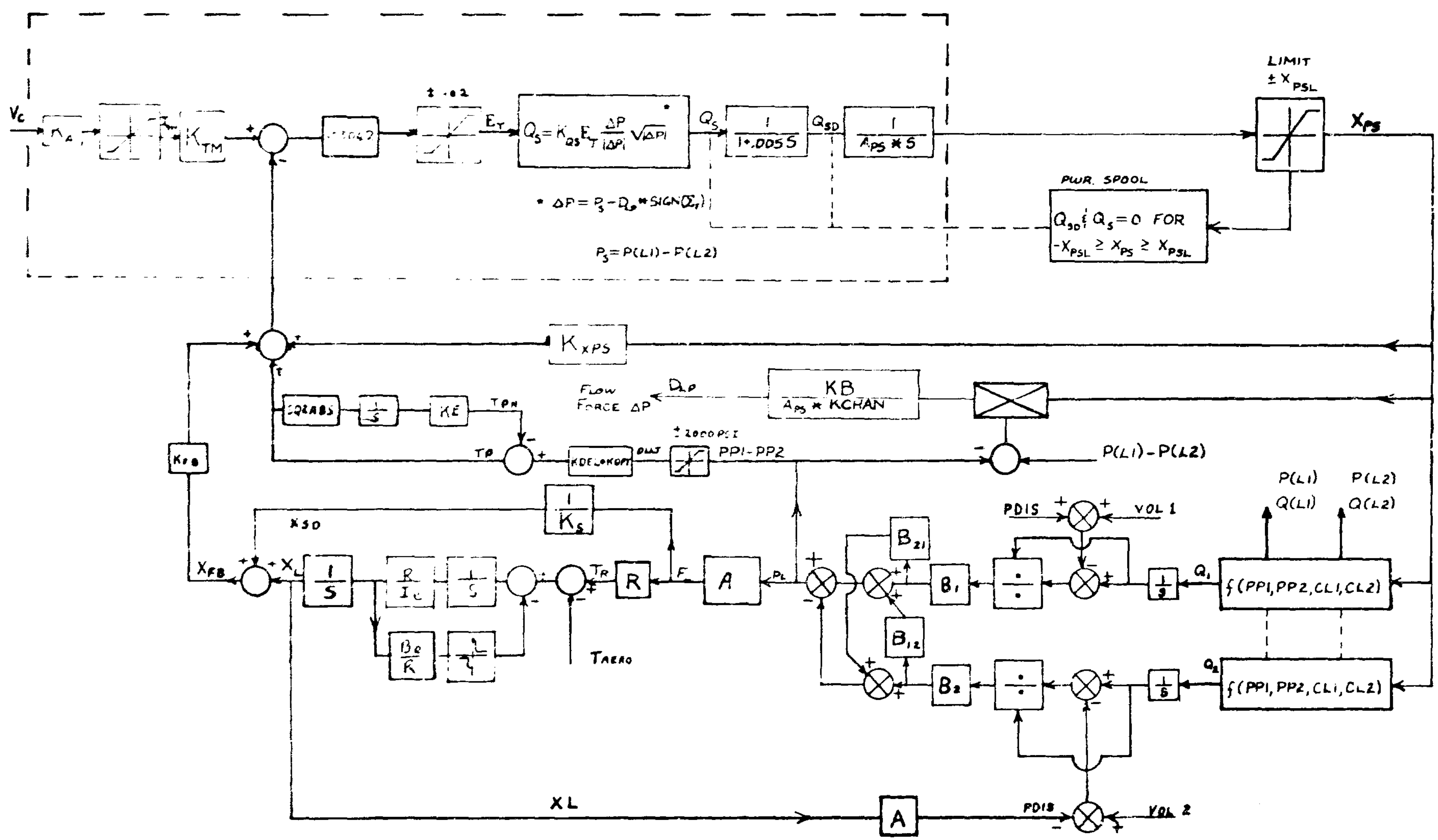
EXAMPLE CARD



6.105 TYPE #105 THRUST VECTOR CONTROL ACTUATOR

Subroutine ACT105 models the shuttle Thrust Vector Control (TVC) actuators, Figure 6.105-1. The TVC actuators operate from a single pair of hydraulic supply and return lines. This supply and return is normally supplied by the three hydraulic systems via a switching valve module as shown in Figure 6.105-2. The input command and hinge moments are supplied by a Guidance and Control subroutine which updates the values at each sample time interval of the guidance system which is .04 seconds. The initial position of the TVC actuator and the dynamic load on the actuator are calculated from the initial command supplied by the Guidance and Control subroutine. All other variables are initialized relative to the initial actuator position.

SSME TVC ACTUATION CONTROL SYSTEM MODEL



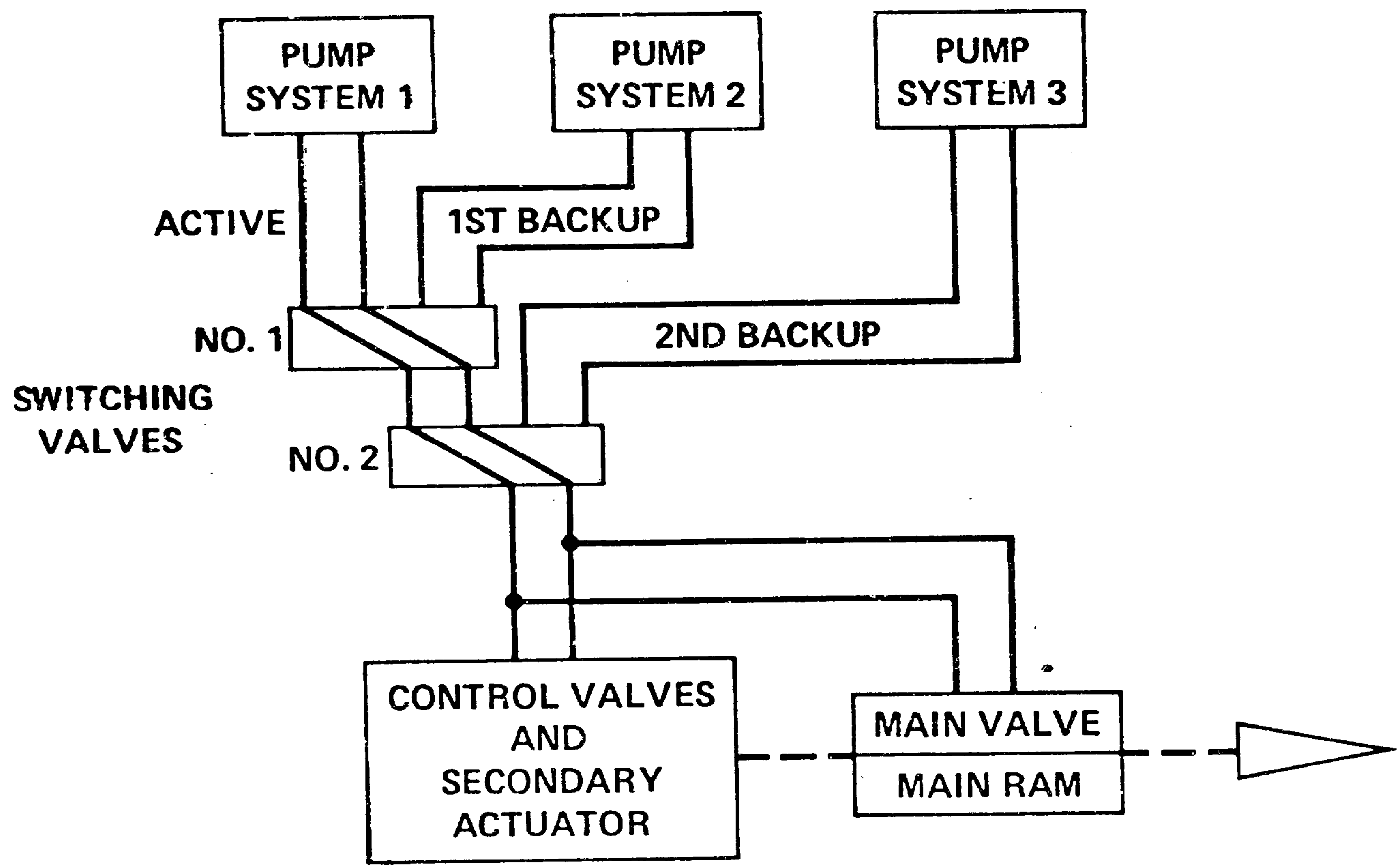
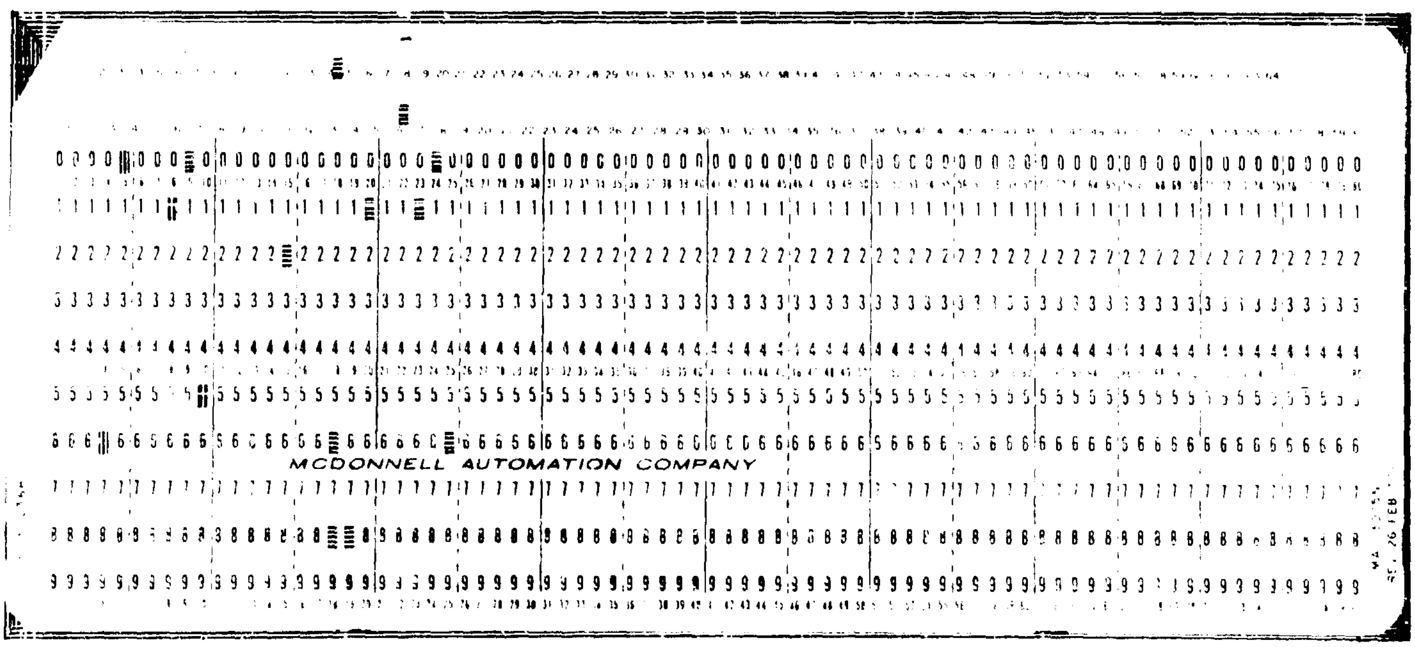


FIGURE 6.105-2

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 105
11-15	I5	Number of Real Data Cards = 2
16-20	I5	Line Number (with sign) attached to Connection 1 (Primary)
21-25	I5	Line Number (with sign) attached to Connection 2 (Primary)
26-30	I5	Line Number (with sign) attached to Connection 3 (Standby #1)
31-35	I5	Line Number (with sign) attached to Connection 4 (Standby #1)
36-40	I5	Line Number (with sign) attached to Connection 5 (Standby #2)
41-45	I5	Line Number (with sign) attachet to Connection 6 (Standby #2)
46-50	I5	
51-55	I5	
56-60	I5	Primary Hydraulic System No.
61-65	I5	Standby #1 Hydraulic System No.
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

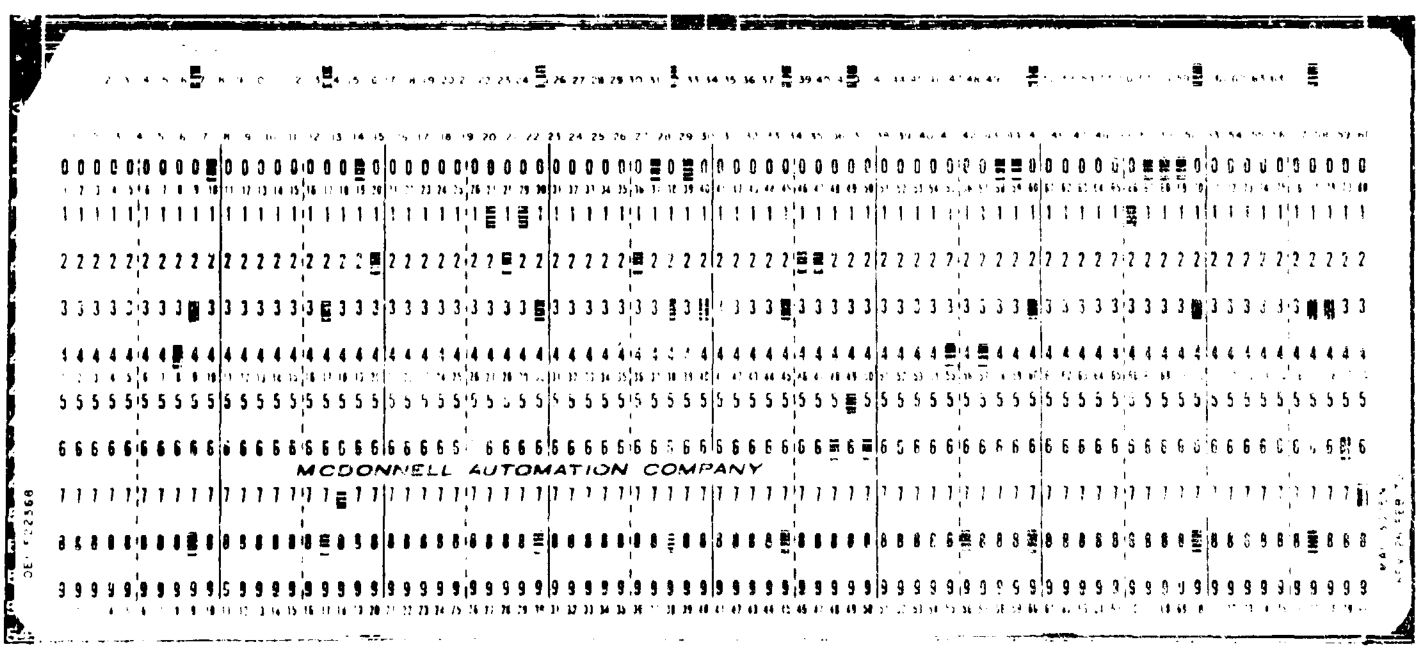
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	Number of Operative Channels	-
11-20	E10.0	Bernoulli Force Coefficient	in
21-30	E10.0	Power Spool Flow Gain	CIS/lb
31-40	E10.0	Effective TVC Actuator Area	in^2
41-50	E10.0	Structural Stiffness	lb/in
51-60	E10.0	Engine Moment of Inertia About Hinge Line	$in\text{-}lb\text{-}sec^2$
61-70	E10.0	Effective Engine Damping Coefficient	$\frac{lb\text{-}sec}{in}$
71-80	E10.0	Actuator Feedback Gain	$\frac{in\text{-}lb}{in}$

EXAMPLE CARD

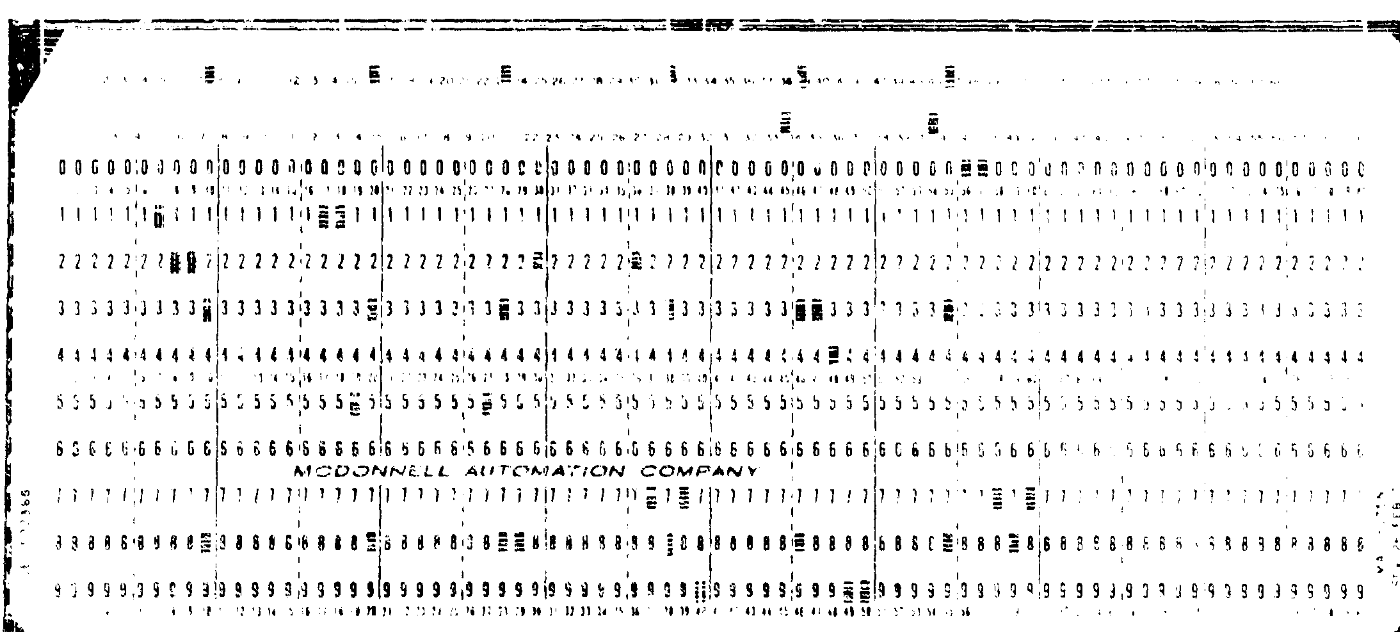


CARD NUMBER 3

COLUMN	FORMAT	DATA	DIMENSIONS
1-10	E10.0	#1 Cavity Volume at Mid-stroke	in^3
11-20	E10.0	#2 Cavity Volume at Mid-stroke	in^3
21-30	E10.0	Power Spool Feedback Gain	$\frac{in\text{-}lb}{in}$
31-40	E10.0	1st Moment Arm Constant	in
41-50	E10.0	2nd Moment Arm Constant f(XL)	in/in
51-60	E10.0	3rd Moment Arm Constant $f(XL)^2$	in/in^2
61-70	E10.0		
71-80	E10.0		

Note: All other actuator variables are inputted as data in the TVC subroutine.

EXAMPLE CARD

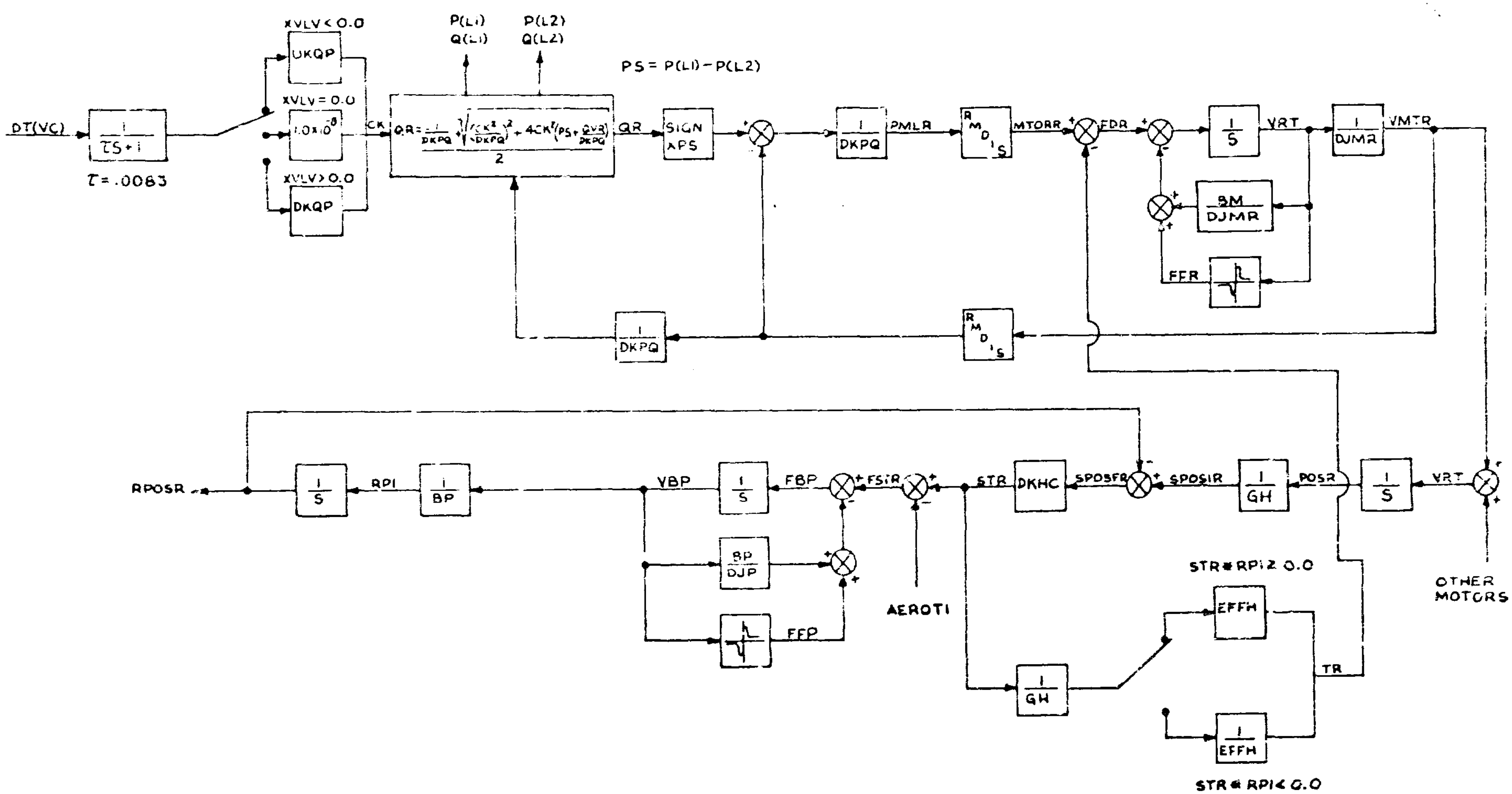


6.106 TYPE #106 BODY FLAP

Subroutine ACT106 is a model of the space shuttle body flap actuation subsystem, a schematic of which is shown in Figure 6.106-1. The subsystem basically consists of three hydraulic motors, a valve, a mechanical drive unit and rotary surface actuators. The component has six hydraulic connections, two for each hydraulic system attached to it. Each system powers a motor. The output of the motors is summed in the mechanical drive which in turn drives the rotary surface actuators to position the body flap.

A single valve controls the flow to all three motors. The guidance and control subroutine provides the input commands and hinge moments at each sample time interval of the guidance system, which is .04 seconds. The valve may be commanded to open in the extend direction, open in the retract direction or close.

The body flap subsystem is essentially an open loop system with no feedback between the body flap and the valve. The position of the body flap is supplied to the command and control subroutine which commands the position of the valve.



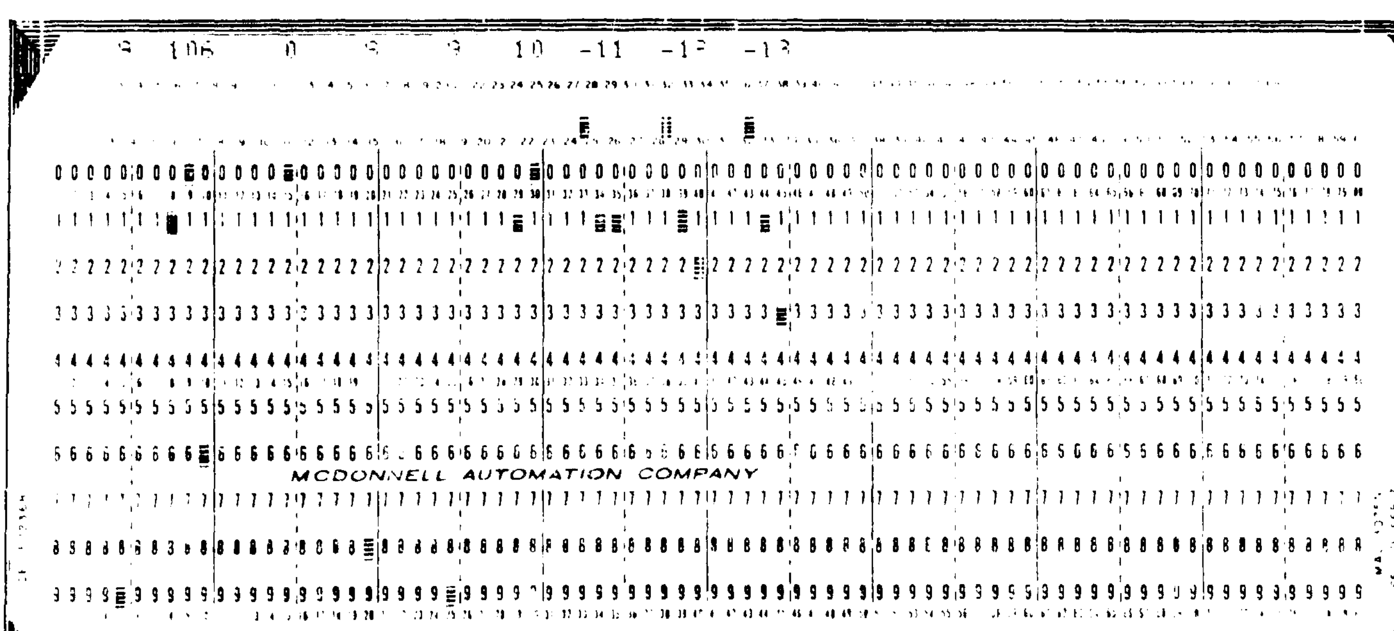
BODY FLAP ACTIO6

Figure 6.106-1

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 106
11-15	I5	Number of Real Data Cards = 0
16-20	I5	Line Number (with sign) attached to Connection 1
21-25	I5	Line Number (with sign) attached to Connection 2
26-30	I5	Line Number (with sign) attached to Connection 3
31-35	I5	Line Number (with sign) attached to Connection 4
36-40	I5	Line Number (with sign) attached to Connection 5
41-45	I5	Line Number (with sign) attached to connection 6
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

EXAMPLE CARD

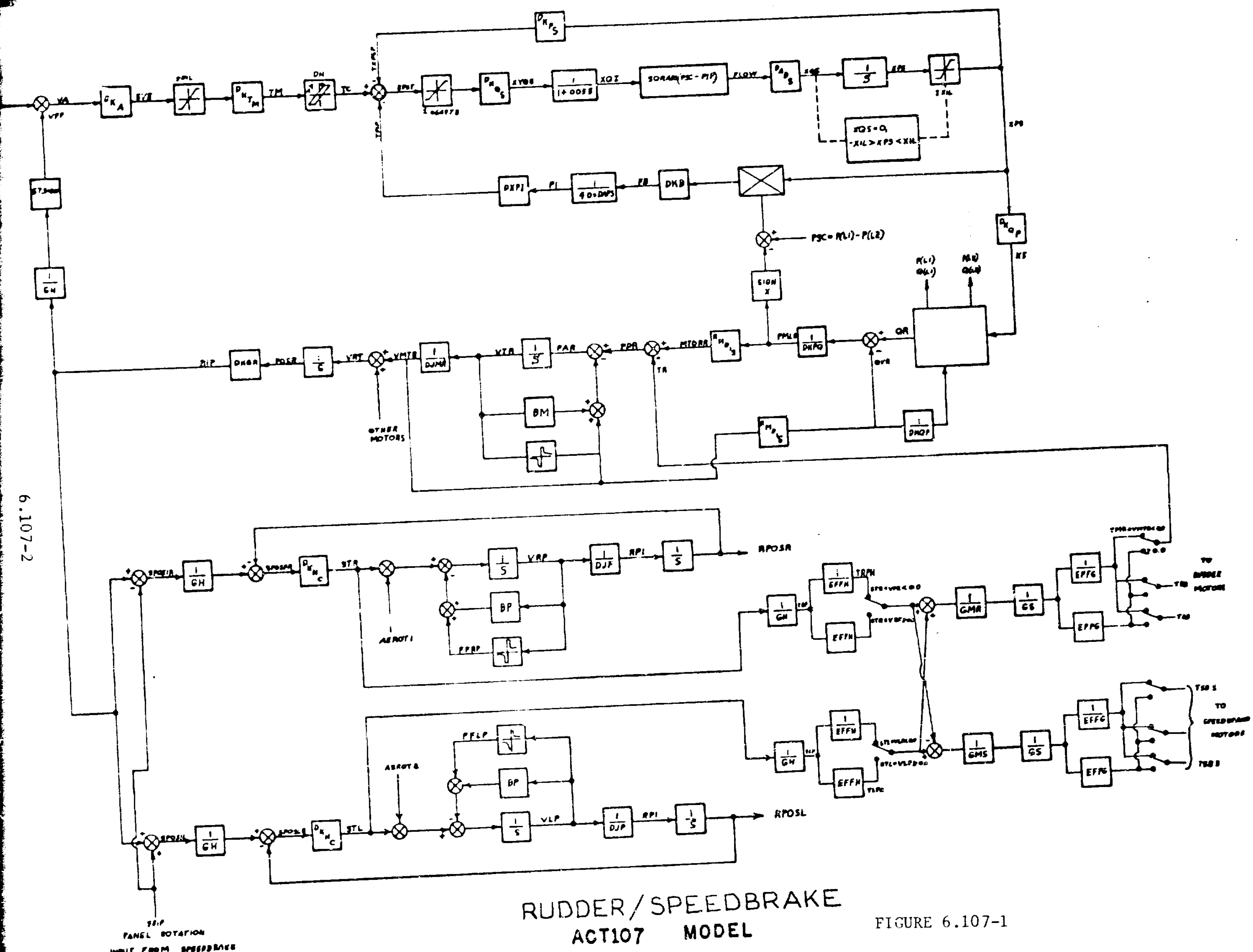


6.107 TYPE #107 RUDDER/SPEEDBRAKE ACTUATOR

Subroutine ACT107 models the shuttle Rudder/Speedbrake actuation subsystem, the layout of which is shown in Figure 6.107-1. The subsystem consists of six hydraulic motors, two power valves and two 4 channel servo actuators. Each system powers two motors, one for the rudder and one for the speedbrake. The control valves are powered by a single system. All three hydraulic systems power the motors and a switching valve selects one of the three systems to supply the control valves. A single power valve controls all three rudder motors and a single power valve controls all three speedbrake motors. The rudder and speedbrake power valves are each controlled by a 4 channel servo actuator.

The input command and hinge moments are supplied by a guidance and control subroutine which updates the values at each sample time interval of the guidance system which is .04 seconds.

Since the complete rudder/speedbrake system is contained in the ACT107 model, and since this model is unique to the shuttle, all the values for the constants have been placed within the subroutine itself eliminating the need for any input data.



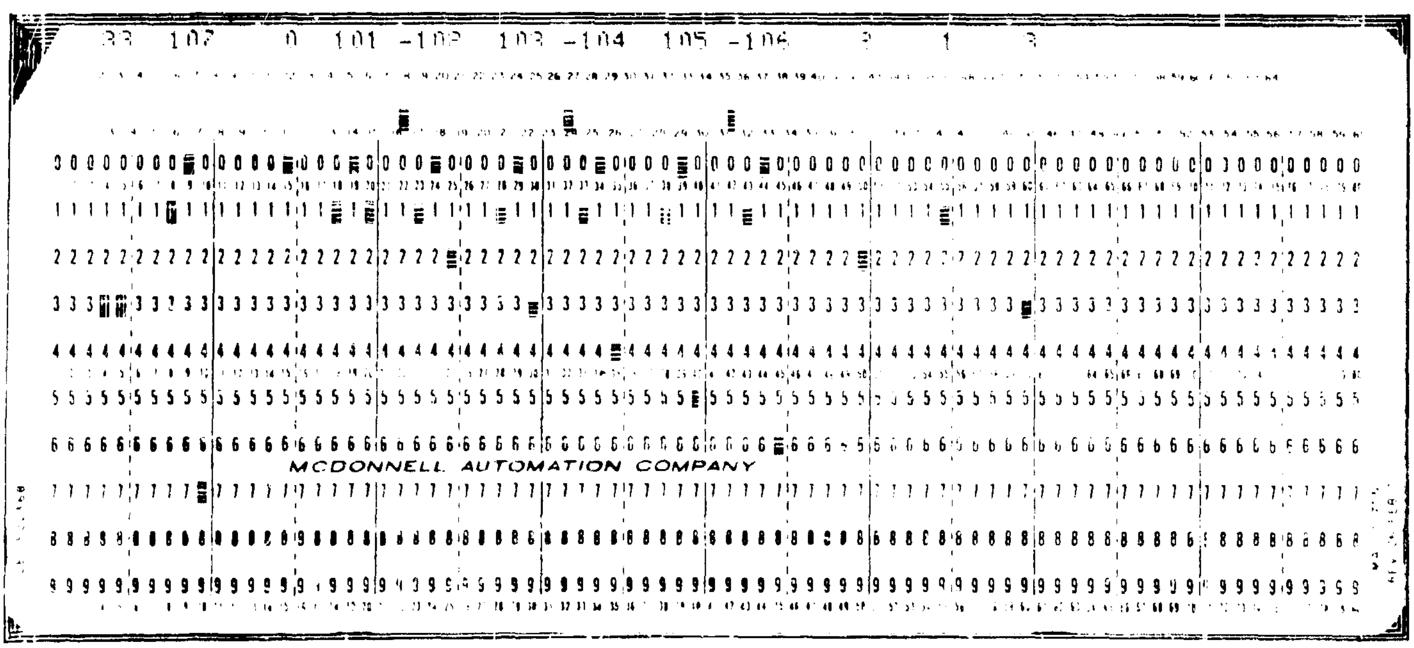
RUDDER/SPEEDBRAKE
ACT107 MODEL

FIGURE 6.107-1

CARD NUMBER 1

COLUMN	FORMAT	DATA
1-5	I5	Component Number
6-10	I5	Type Number = 107
11-15	I5	Number of Real Data Cards = 0
16-20	I5	Line Number (with sign) attached to Connection 1(primary sys)
21-25	I5	Line Number (with sign) attached to Connection 2(primary sys)
26-30	I5	Line Number (with sign) attached to Connection 3(standby sys #1)
31-35	I5	Line Number (with sign) attached to Connection 4(standby sys #1)
36-40	I5	Line Number (with sign) attached to Connection 5(standby sys #2)
41-45	I5	Line Number (with sign) attached to Connection 6(standby sys #2)
46-50	I5	Primary System
51-55	I5	Standby System 1
56-60	I5	Standby System 2
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	Temperature/Pressure Code (See Page 4.0-2)

EXAMPLE CARD



7.0 SYSTEM ARRANGEMENT DATA

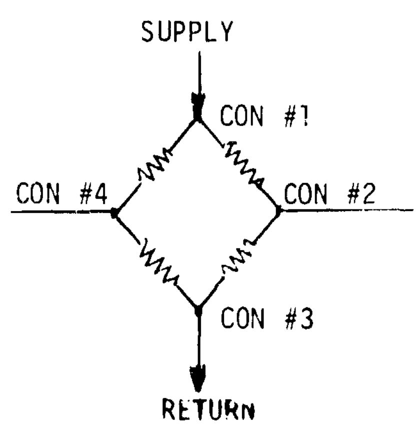
This section of input data is used to describe the system arrangement. Having input the necessary information for all system lines and components, one must now input the way in which these components and lines are interconnected.

Special Cases

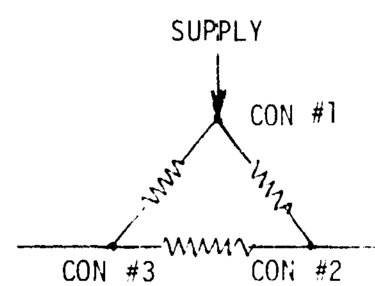
If a leg is terminated by a constant pressure source, the constant pressure has to be input along with the leg connection information. A current restriction requires that only nodes with a single leg can have a constant pressure termination. A second restriction is that there must be at least one variable node. Nodes should not be placed in the center of any component having a pressure loss since each leg connected to the node will include the pressure drop of the component.

Other component restrictions are as follows:

Valves - VALV22 can require anywhere from zero to 4 nodes depending upon the valve usage. The four-way and three-way versions of VALV22 are described as follows:



FOUR-WAY



THREE-WAY

The valve schematic should be established for steady state operation including any interflow paths. A node is then required at every connection that splits or merges flow (including interflow leakage) and at any connection that terminates flow.

Actuators - Unbalanced actuators must include a node which is used to account for any flow gain or loss in event the actuator is in motion during steady state conditions.

Reservoirs -

- o RSVR61 requires one node which should not be a constant pressure node.
- o RSVR62 requires two nodes open ended (not connected by a leg). One node is considered to be on the low pressure side with the other node considered on the high pressure side.

7.1 GENERAL DATA

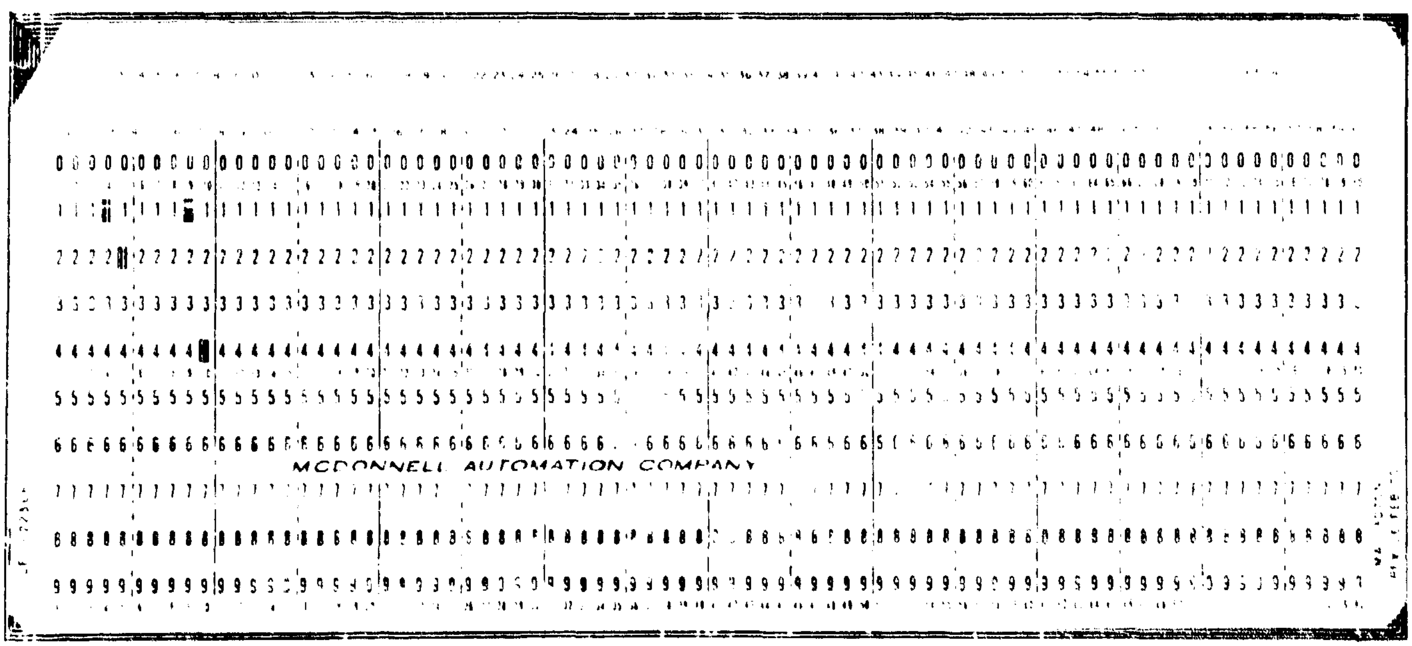
On this card input the number of nodes, the number of legs and the number of constant pressure points, the number of zero flow legs and the number of hydraulic systems.

A zero flow leg is a dead ended line with no steady state flow. The pressure at the end of the leg is determined by the steady state program.

GENERAL DATA CARD

COLUMN	FORMAT	DATA
1-5	I5	Number of Nodes
6-10	I5	Number of Legs
11-15	I5	Number of Constant Pressure Points
16-20	I5	Number of Zero Flow Legs
21-25	I5	Number of Systems
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	

EXAMPLE CARD



7.2 LEG INPUT DATA

Two or more cards are required to input the data for each leg. The first card contains the leg number, upstream node number, downstream node number, number of elements in the leg, initial flow guess, constant pressure at upstream node if applicable and constant pressure at downstream node, if applicable.

The second card or cards contains the leg connection details. Starting with the component or line at the upstream node and progressing along the flo path to the downstream node, the element number and type are input. Because of the mixture of lines and components, the need to differentiate between the element numbering system is as follows:

First Pair of Data

First value	>0	Component number
	=0	Element is a line
Second value	=	*Component connection number or line number

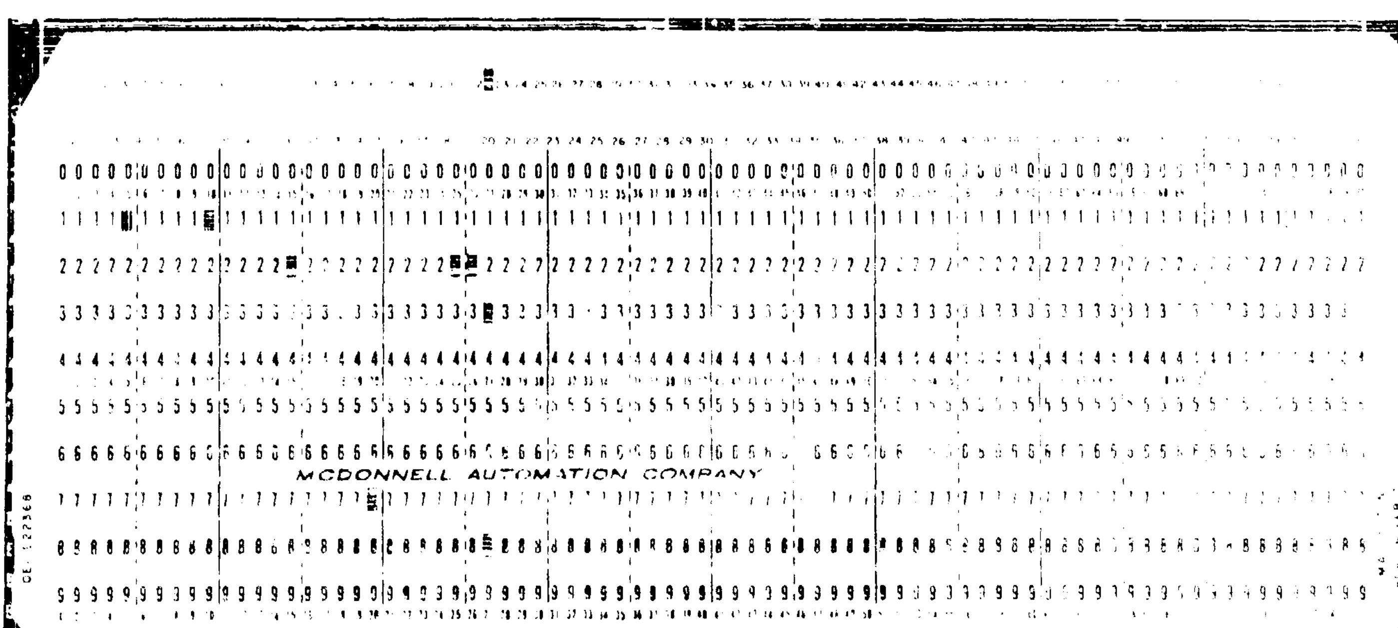
*Use upstream connection if the component has upstream and downstream connect in the same leg.

This is repeated N times for the N elements in the leg.

CARD NUMBER 1

COLUMN	FORMAT	DATA	DIMENSIONS
1-5	I5	Leg Number	--
6-10	I5	Upstream Node Number	--
11-15	I5	Downstream Node Number	--
16-20	I5	Number of Elements in Leg	--
21-30	E10.0	Initial Flow Guess	cis
31-40	E10.0	Constant Pressure at Upstream Node	psi
41-50	E10.0	Constant Pressure at Downstream Node	psi
51-60	E10.0		
61-70	E10.0		
71-80	E10.0		

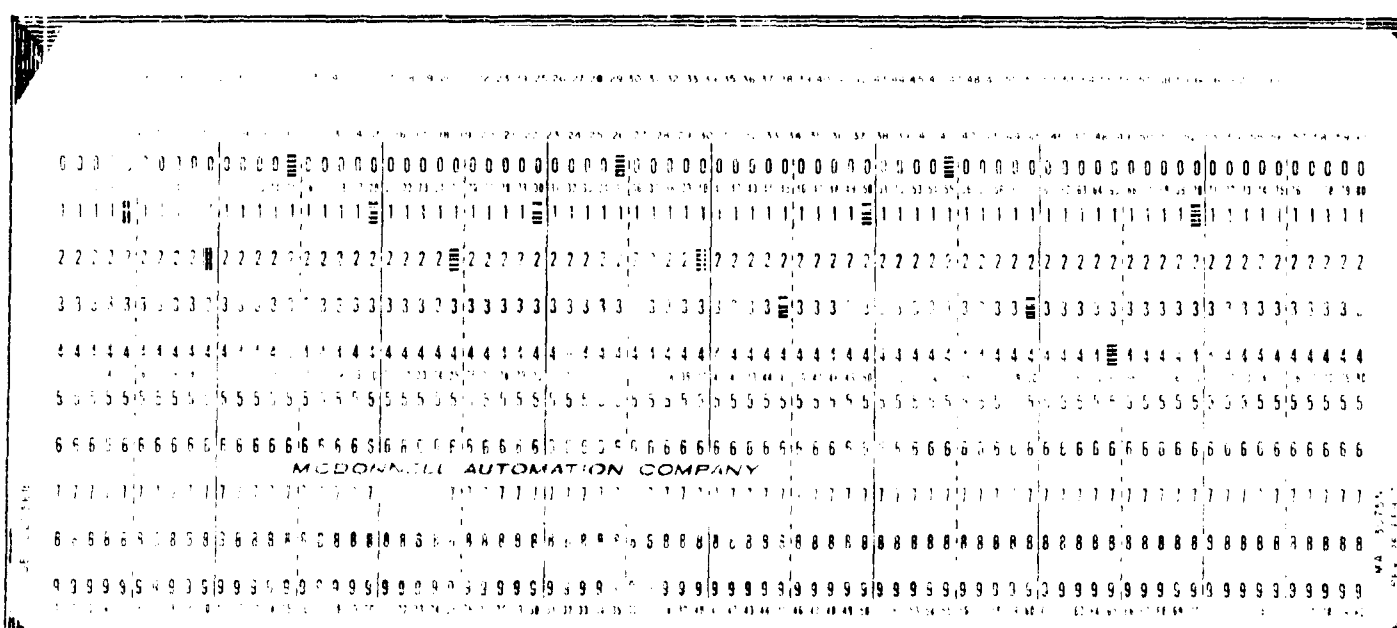
EXAMPLE CARD



CARD NUMBER 2

COLUMN	FORMAT	DATA
1-5	I5	Component Number or Zero if Line
6-10	I5	Connection or Line Number
11-15	I5	Repeat in Pairs for
16-20	I5	the Number of Elements
21-25	I5	in a Leg - Use as Many
26-30	I5	Cards as Necessary
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	

EXAMPLE CARD



8.0 OUTPUT REQUIREMENTS DATA

The program will output in a print plot form, any calculated system variable versus time. The time interval between plotted points is input on the first general control card.

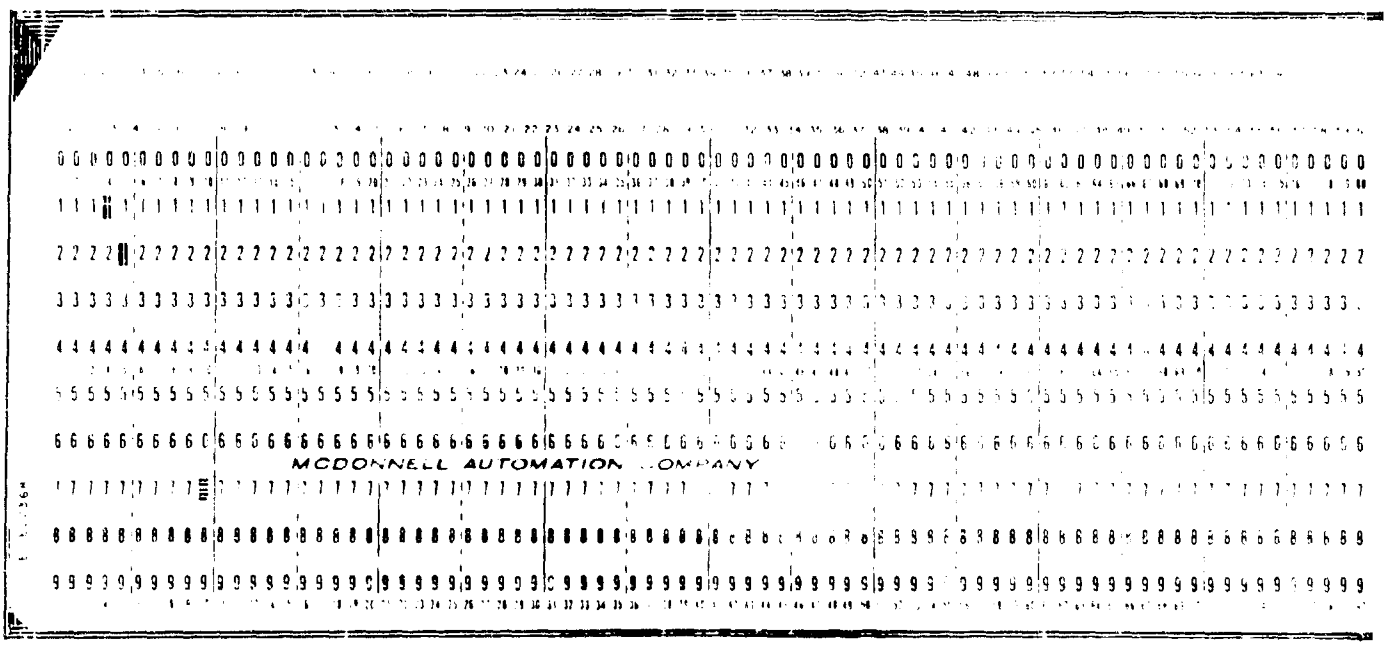
When using the print plot routine, it should be noted that 101 points are the maximum that can be plotted on one page. When more than 101 points are requested, the plot is continued on an additional page(s).

The line variables which can be selected are the pressures and flows calculated for each line point. The component variables which can be selected are listed in paragraph 8.2.

PLOT DATA CARD

COLUMN	FORMAT	DATA
1-5	I5	Number of Line Plot Data Cards
6-10	I5	Number of Component Variables to be Plotted
11-15	I5	+1 - Provides graphs that reflect all maximum values calculated
		-1 - Provides graphs that reflect all minimum values calculated
		0 or - Provides graphs that reflect values calculated at
		Default plot intervals, only
16-20	I5	+1 - Provides a list of all calculated values in addition to
		plots
		0 or - Does not provide a list of calculated values
		Default
21-25	I5	+1 - Stops for a cavitation error
		0 - Does not stop
26-30	I5	+1 - Prints cavitation error message
		0 - No message
31-35	I5	+1 - No graphs
		0 - Normal graphs

EXAMPLE CARD



8.1 OUTPUT OF LINE VARIABLES

To output pressures and flows at any of the calculated points along a line, the line #, number of plots along the line, and distances along that line from the assumed upstream end have to be input. Unfortunately since the speed of sound varies with temperature, the line is not always divided into the same number of segments.

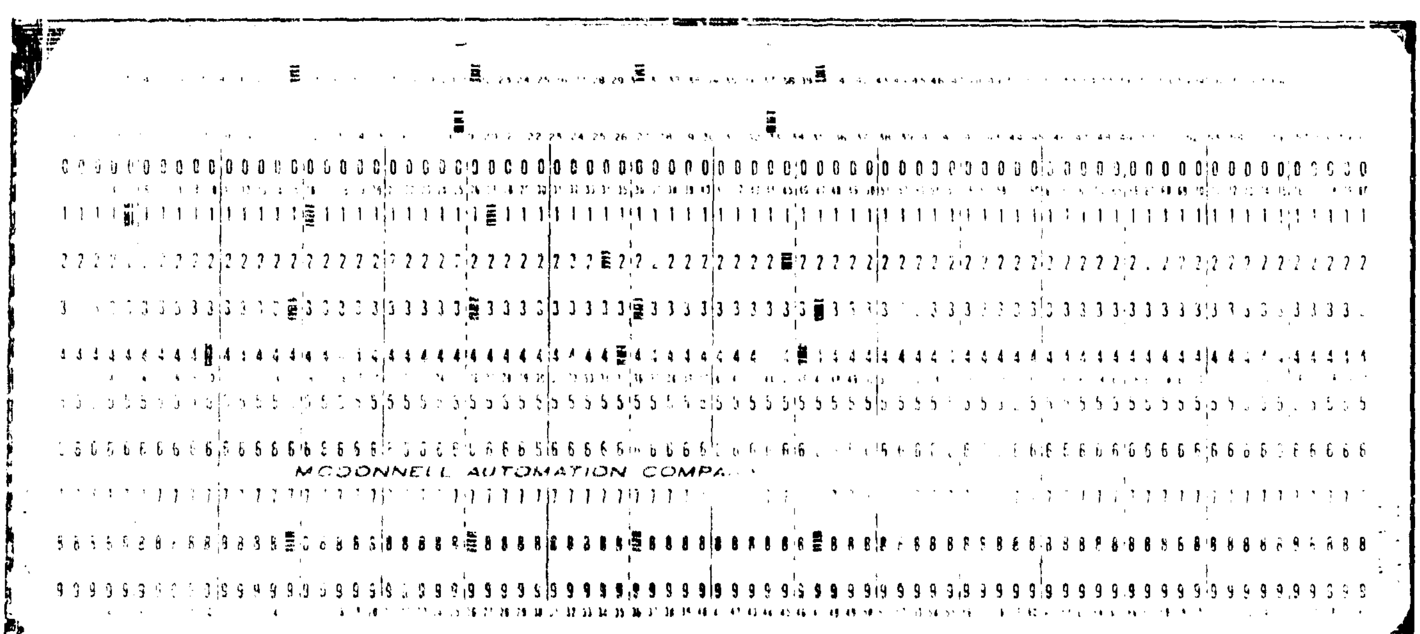
Hence, when a distance along a line is selected, it is unlikely to be a junction point between line segments. The program picks the nearest junction point and outputs on the plot the distance of this junction from the upstream end of the line. The distance is input normally for a pressure plot and as a negative distance for a flow plot. NOTE: The number of cards used must equal the number of "line plot data cards."

LINE PLOT CARD

COLUMN	FORMAT	DATA	DIMENSIONS
1-5	I5	Line Number	
6-10	I5	Number of Plots Along the Line	
11-20	F10.0	Distance Along Line for 1st Plot *	in.
21-30	F10.0	Ditto for up to Seven Points	in.
31-40	F10.0		
41-50	F10.0		
51-60	F10.0		
61-70	F10.0		
71-80	F10.0		

* Distances must be greater than zero.

EXAMPLE CARD



8.2 OUTPUT OF COMPONENT VARIABLES

The component variables to be output are selected from Tables 8.2-1 through 8.2-102.

The total number of component variables to be plotted should equal the number of pairs of data on the following cards.

COMPONENT PLOT CARD

COLUMN	FORMAT	DATA
1-5	I5	Component Number Assigned
6-10	I5	Variable Number to be Plotted
11-15	I5	(This is repeated using additional cards,
16-20	I5	if necessary, until all component variables
21-25	I5	to be plotted have been listed.)
26-30	I5	
31-35	I5	
36-40	I5	
41-45	I5	
46-50	I5	
51-55	I5	
56-60	I5	
61-65	I5	
66-70	I5	
71-75	I5	
76-80	I5	

EXAMPLE CARD

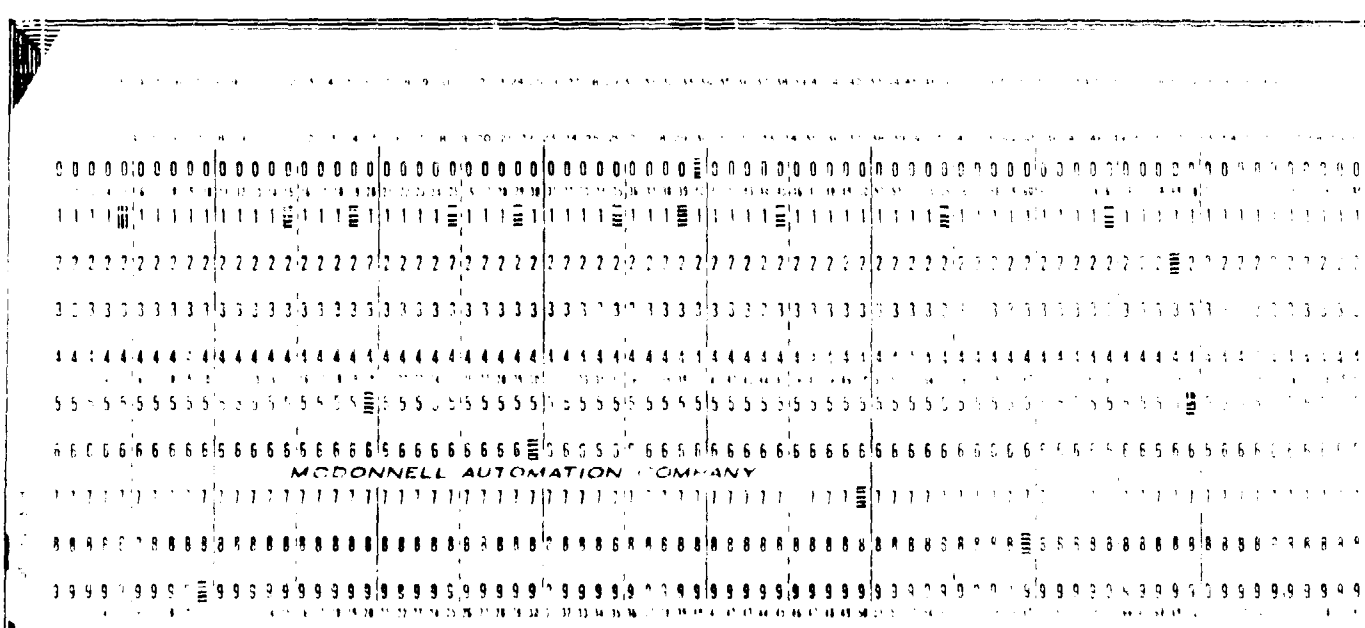


TABLE 8.2-11

BRAN11
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
1	--	Cavatation Volume when Multiplied by Calculation Time Interval	in^3

TABLE 8.2-22

VALV22
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
8	--	Cavatation Volume - When Multiplied by Calculation Time Interval	in^3

TABLE 8.2-31

CVAL31
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
4	VNEW	Poppet Velocity	in/sec
5	ANEW	Poppet Acceleration	in/sec^2
6	XNEW	Poppet Position	in.

TABLE 8.2-51

PUMP51
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Units
7	PACTU	Pressure in Actuator	psi
14	VELACT	Compensator Actuator Velocity	in/sec
15	DISACT	Compensator Actuator Position	in
16	DISVLV	Compensator Valve Spool Displacement	in
4	QACTU	Flow from Outlet to the Actuator	cis
25	QOUTLT	Net Pumping Flow into Outlet Volume	cis
5	QACTC	Flow from Actuator to the Case	cis
1	PRPM	Pump Speed	rpm
2	TORQUE	Pump Torque	in-lb

TABLE 8.2-54

PUMP54
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Units
7	PACTU	Pressure in Actuator	psi
14	VELACT	Compensator Actuator Velocity	in/sec
15	DISACT	Compensator Actuator Position	in
16	DISVLV	Compensator Valve Spool Displacement	in
4	QACTU	Flow from Outlet to the Actuator	cis
25	QOUTLT	Net Pumping Flow into Outlet Volume	cis
5	QACTC	Flow from Actuator to the Case	cis
1	PRPM	Pump Speed	rpm
2	TORQUE	Pump Torque	in-lb

TABLE 8.2-62

RSVR62
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
9	P2	Reservoir Pressure	psi
1	QNET	Net Reservoir Flow	in^3/sec
10	DUM	Reservoir Volume	in^3

TABLE 8.2-71

ACUM71
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
4	PO	Oil Pressure	psi
6	PG	Gas Pressure	psi
8	IVOLO	Oil Volume	in^3

TABLE 8.2-81

FILT81
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
3	PRESSB	Pressure Outside of Element	psi
4	PRESSE	Pressure Inside of Element	psi

TABLE 8.2 - 99

CAD 99

PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
3	-	Left Outlet Elevon Position	deg
4	-	Left Inbd Elevon Position	deg
5	-	Right Outbd Elevon Position	deg
6	-	Left Inbd Elevon Position	deg
7	-	Rudder Command (rate limited)	deg
8	-	Speedbrake Command (rate limited)	deg
13	-	Angle of attack	deg
14	-	Sideslip angle	deg

TABLE 8.2-101

ACT101
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
5	PP1	No. 1 Cylinder Pressure	psi
6	PP2	No. 2 Cylinder Pressure	psi
1	X	Piston Position	in
2	VEL	Piston Velocity	in/sec
18	LOADEX	External Load	lb

TABLE 8.2-102

ACT102
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
1	X	Piston Position	in.
2	VEL	Piston Velocity	in./sec
5	LOADEX	External Load	lb.
6	P1	No. 1 Cylinder Pressure	psi
7	P2	No. 2 Cylinder Pressure	psi

Table 8.2 - 106

ACT106
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
1	VC	Body Flap Command	--
2	--	Body Flap Position	deg
9	VRT	Body Flap Motor Velocity	rpm

Table 8.2 - 107

ACT107
PROGRAMMED VARIABLE SELECTION

Number	Name	Description	Dimension
1	VC	Rudder command	volts
2	VC+1	Speedbrake command	volts
8	RPOSL	Left panel position	deg
9	RPOSR	Right panel position	deg
12	VRT	Rudder motor velocity	rpm
13	VSBT	Speedbrake motor velocity	rpm

9.0 COMPUTER OUTPUT

The time history print plots of flow, pressure, and component state variables form the basic output of the program. By the addition of simple write statements, the output can also be written to files for storage and subsequent processing or to the output for printing. Since there are so many ways of handling the output information, each dependent on the user's local facilities, it is pointless to discuss the details of how to transfer files, etc.

In looking at the time history plots, it is a mistake to think in terms of a steady-state type response. The flow at one end of a line is often grossly different from that at the other end due to the charge and discharge effects that can occur. The user should also beware of inputting unrealistic rates of valve opening and closure, since these can exaggerate any latent transient problems.

In system design, the user should be on the lookout for transients due to the sudden filling of closed end lines in both the pressure and return systems. The user will soon become aware of what problems to look for, and the experience gained in using HYTRAN will help in both the detailed analysis or the intuitive approach to solving problems.

Figures 9.0-1 through 9.0-14 show output for the example system, Figure 3.0-1. Several iterations have been omitted in the calculated steady state values (Figure 9.0-4) and only the first and last groups of calculated data are shown. Pressure and flow plots are taken at various points throughout the system initially showing steady state conditions with only leakage flow for .01 seconds.

```
********** EXAMPLE SYSTEM IN HYTRAN MANUAL **********

THE TRANSIENT RESPONSE IS FROM T=0.0  TO T=   .200 SECONDS AT TIME INTERVALS OF DELT= .00050
          WITH OUTPUT POINTS PLOTTED AT INTERVALS OF   ,   .00200  SECONDS

FLUID DATA FOR  MIL-H-5606  AT  3000.0 PSIG, -    50.0 PSIG AND 150.0 DEG F  IN   10.0 DEG F STEPS
                VISCOSITY     -  .144E-01       .116E-01IN**2/SEC
                DENSITY       -  .807E-04       .798E-04(LB-SEC**2)/IN**4
                BULK MODULUS  -  .209E+06       .174E+06PSI
                VAPOUR PRESS.-   .200E+01 AT  150.0 DEG F
FIX-UP TAKEN AT LINE 18,VEL OF SOUND IN LINE   4  IS    58.4PER CENT IN ERROR
```

LINE DATA LINE NO.	LENGTH	INTERNAL DIA	WALL THICKNESS	MODULUS OF ELASTICITY	DELX	CHARACTERISTIC IMPEDANCE	VELOCITY OF SOUND
1	24.5000	.8750	.0390	.100E+07	24.5000	6.2119	46279.4697
2	440.0000	.9220	.0390	.300E+08	24.4444	5.7698	47231.1566
3	130.0000	.6720	.0390	.300E+08	26.0000	10.9394	48070.7267
4	10.0000	.6720	.0390	.300E+08	10.0000	10.9394	20000.0000
5	230.0000	.6720	.0390	.300E+08	25.5556	10.9394	48070.7267
6	330.0000	.4220	.0390	.300E+08	25.3845	28.2514	48956.7218
7	30.0000	.4220	.0390	.300E+08	30.0000	28.2514	48956.7218
8	30.0000	.4220	.0390	.300E+08	30.0000	28.2514	48956.7218
9	430.0000	.3290	.0280	.300E+08	25.2941	46.3559	46825.2108
10	230.0000	.3290	.0280	.300E+08	25.5556	46.3559	46825.2108
11	130.0000	.6720	.0390	.300E+08	26.0000	10.9394	48070.7267
12	130.0000	.3190	.0280	.300E+08	26.0000	49.3585	46675.5166
13	230.0000	.6720	.0390	.300E+08	25.5556	10.9394	48070.7267
14	30.0000	.6720	.0390	.300E+08	30.0000	10.9394	48070.7267
15	30.0000	.9160	.0420	.300E+08	30.0000	5.8137	47460.5540
16	30.0000	.1940	.0280	.300E+08	30.0000	135.2141	49519.1564

FIGURE 9.0-1
FLUID AND LINE DATA FOR EXAMPLE SYSTEM

```
 COMP#,    1  INTEGER DATA        1   54    4   15   -1  -12   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .2925E+04   .2480E+03   .1910E-01   .4660E-01  0.              .1000E-02   .6500E+00   .6500E+00
REAL DATA CARD #    2   .6900E+03   .4000E+03   .7600E+02   .1300E+03   .4700E+03   .2200E+03   .3500E-01   .2500E+02
REAL DATA CARD #    3   .4300E+01   .8000E+00  -.1600E+00   .1000E-02   .2000E-02   .3000E-02   .2000E-01   .5000E+02
REAL DATA CARD #    4   .5000E+01   .4175E+04   .6900E-01  0.          -0.          -0.          -0.          -0.
 COMP#,    2  INTEGER DATA        2   31    1    1   -2   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .6000E+00   .9000E+00   .1000E-02   .1050E+02   .3500E+00   .3500E+01 -0.          -0.
 COMP#,    3  INTEGER DATA        3   81    1    2   -3   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .1000E+02   .1000E+02   .1000E+00   .2000E-02 -0.          -0.          -0.          -0.
 COMP#,    4  INTEGER DATA        4   11   -0    3    4   -5   15   -0   -0   -0   -0   -0   -0   -0   -0   -0
 COMP#,    5  INTEGER DATA        5   72    1   -4   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .1000E+02   .1000E+03   .1600E+02   .1500E+04 -0.          -0.          -0.          -0.
 COMP#,    6  INTEGER DATA        6   11   -0    5   -9   -6   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
 COMP#,    7  INTEGER DATA        7   23    3    6   -7   -0   -0   -0   -0   -0   -0   -0   -0    8   -0   -0
REAL DATA CARD #    1   .1000E-01   .6250E+00 -0.          -0.          -0.          -0.          -0.          -0.
REAL DATA CARD #    2  0.           .2000E-01   .2500E-01   .3000E-01   .4000E-01   .6500E-01   .7000E-01   .2000E+00
REAL DATA CARD #    3  0.          0.          0.           .1000E+00   .2000E+00   .2000E+00   .2000E+00   .2000E+00
 COMP#,    8  INTEGER DATA        8   41    1    7   -8   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .1000E+00   .6250E+00 -0.          -0.          -0.          -0.          -0.          -0.
 COMP#,    9  INTEGER DATA        9  101    4    9  -10   -0   -0   -0   -0   -0   -0   -0   -0   -0    8   -0
REAL DATA CARD #    1   .2350E+01   .2350E+01   .2150E+01   .2250E+01   .1900E+00   .1530E+01   .5000E+00   .1000E+02
REAL DATA CARD #    2   .1250E+00   .1250E+00   .1250E+00   .1250E+00   .1000E-01 -0.          -0.          -0.
REAL DATA CARD #    3  0.           .1000E-01   .1500E-01   .2500E-01   .5000E-01   .6500E-01   .7000E-01   .2000E+00
REAL DATA CARD #    4  0.          0.          0.          0.           .2000E+00   .2000E+00   .2000E+00   .2000E+00
 COMP#,   10  INTEGER DATA       10   11   -0   10    8  -11   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
 COMP#,   11  INTEGER DATA       11   11   -0   12   11  -13   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
 COMP#,   12  INTEGER DATA       12   81    1   13  -14   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .1000E+02   .1000E+02   .1000E+00   .2000E-02 -0.          -0.          -0.          -0.
 COMP#,   13  INTEGER DATA       13   63    1  -16   14  -15   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
REAL DATA CARD #    1   .1500E+01   .1227E+03   .4800E+02   .1000E+02   .1500E+02   .5000E+01 -0.          -0.
    CPU TIME IN SECONDS =     6.691
```

FIGURE 9.0-2
COMPONENT INPUT DATA FOR EXAMPLE SYSTEM

STEADY STATE INPUT DATA

NUMBER OF NODES = 12   NUMBER OF LEGS = 14   NUMBER OF CONSTANT PRESSURE NODES = -0

LEG CONNECTION INPUT DATA

LEG NO	UPST NODE NO	DWST NODE NO	NO OF ELEMENTS	FLOW GUESS	UPST PRESS	DWST PRESS
1	1	2	7	22.00000	-0.00000	-0.00000
2	2	3	3	22.00000	-0.00000	-0.00000
3	3	4	2	15.00000	-0.00000	-0.00000
4	4	5	1	15.00000	-0.00000	-0.00000
5	5	8	4	15.00000	-0.00000	-0.00000
6	5	6	2	7.00000	-0.00000	-0.00000
7	6	7	1	7.00000	-0.00000	-0.00000
8	7	8	3	7.00000	-0.00000	-0.00000
9	8	9	3	22.00000	-0.00000	-0.00000
10	1	9	3	3.00000	-0.00000	-0.00000
11	9	10	5	25.00000	-0.00000	-0.00000
12	10	1	3	22.00000	-0.00000	-0.00000
13	11	2	3	3.00000	-0.00000	-0.00000
14	12	2	3	.10000	-0.00000	-0.00000

LEG NO	ELEMENTS IN LEG----
1	1 -- 2, 0 -- 1, 2 -- 1, 0 -- 2, 3 -- 1, 0 -- 3, 4 -- 1,
2	4 -- 3, 0 -- 5, 6 -- 1,
3	6 -- 3, 0 -- 6,
4	7 -- 1,
5	0 -- 7, 8 -- 1, 0 -- 8, 10 -- 2,
6	[illegible] -- 2, 0 -- 9,
7	9 -- 1,
8	9 -- 2, 0 -- 10, 10 -- 1,
9	10 -- 3, 0 -- 11, 11 -- 2,
10	1 -- 3, 0 -- 12, 11 -- 1,
11	11 -- 3, 0 -- 13, 12 -- 1, 0 -- 14, 13 -- 2,
12	13 -- 3, 0 -- 15, 1 -- 1,
13	13 -- 1, 0 -- 16, 4 -- 4,
14	5 -- 1, 0 -- 4, 4 -- 2,

FIGURE 9.0-3
STEADY STATE INPUT DATA FOR EXAMPLE SYSTEM

STEADY STATE CALCULATION DATA

LEG FORMULAE GENERATED BY LEGCAL

LEG NUMBER--FLOW GUESS-LOWER LIMIT-UPPER LIMIT-CONST DELTP------Q TERM-Q**1.75TERM---Q**2 TERM

LEG NO 1	22.000	12.552	194.314	2956.374	.086	.009	.002	.44641481E+01
LEG NO 2	22.000	9.143	1000000.000	0.000	0.000	.009	0.000	.10869544E+02
LEG NO 3	15.000	5.745	1000000.000	0.000	0.000	.118	0.000	.11076534E+01
LEG NO 4	15.000	0.000	1000000.000	0.000	1000000.000	0.000	0.000	.10000000E-05
LEG NO 5	15.000	5.745	1000000.000	0.000	0.000	.022	1.675	.39945568E-01
LEG NO 6	7.000	4.479	1000000.000	0.000	0.000	.504	0.000	.46140701E+00
LEG NO 7	7.000	0.000	1000000.000	0.000	0.000	0.000	400000.000	.35714286E-06
LEG NO 8	7.000	4.479	1000000.000	-.005	0.000	.209	400000.000	.35714271E-06
LEG NO 9	22.000	9.143	1000000.000	0.000	0.000	.005	0.000	.15230732E+02
LEG NO 10	3.000	0.000	4.343	464.015	50.596	0.000	0.000	.19754261E-01
LEG NO 11	25.000	9.143	1000000.000	0.000	.051	.010	.002	.46459252E+01
LEG NO 12	22.000	12.470	1000000.000	0.000	0.000	.000	0.000	.36292540E+03
LEG NO 13	3.000	2.641	1000000.000	0.000	0.000	.432	0.000	.10158934E+01
LEG NO 14	.100	0.000	9.148	0.000	.002	0.000	0.000	.42931360E+03

NODE PRESSURES 50.824 3007.206 3007.206 3007.203 52.891 3007.204 1530.013 52.816

NODE PRESSURES 52.816 50.849 3007.242 3007.206

LEG NO 1	10.983	9.143	11.912	3200.389	.117	.005	.002	.58896178E+01
LEG NO 2	11.002	9.143	1000000.000	0.000	0.003	.009	0.000	.18278152E+02
LEG NO 3	7.501	5.745	1000000.000	0.000	0.000	.118	0.000	.16625684E+01
LEG NO 4	7.501	0.000	1000000.000	0.000	1000000.000	0.000	0.000	.10000000E-05
LEG NO 5	7.501	5.745	1000000.000	0.000	0.000	.022	1.675	.78930609E-01
LEG NO 6	3.500	0.000	4.479	0.000	1.743	0.000	0.000	.57350468E+00
LEG NO 7	3.500	0.000	1000000.000	0.000	0.000	0.000	400000.000	.71423188E-06
LEG NO 8	3.500	0.000	4.479	-.005	.932	0.000	400000.000	.71423141E-06
LEG NO 9	11.002	9.143	1000000.000	0.000	0.000	.005	0.000	.32338268E+02
LEG NO 10	6.066	4.343	1000000.000	464.050	50.000	.175	0.000	.19731136E-01
LEG NO 11	17.068	9.143	1000000.000	0.000	.051	.010	.002	.55519646E+01
LEG NO 12	15.549	12.470	1000000.000	0.000	0.000	.000	0.000	.47031680E+03
LEG NO 13	1.515	0.000	2.641	0.000	1.005	0.000	0.000	.99399275E+00
LEG NO 14	.050	0.000	9.148	0.000	.002	0.000	0.000	.42931360E+03

NODE PRESSURES 50.373 3311.265 3311.265 3311.263 52.494 3311.263 1681.861 52.453

NODE PRESSURES 52.453 50.893 3311.284 3311.265

LEG NO 1	5.485	0.000	9.148	3107.135	.147	0.000	.002	.63215438E+01
LEG NO 2	5.503	0.000	9.148	0.000	.054	0.000	0.000	.16605609E+02
LEG NO 3	3.752	0.000	5.745	0.000	.494	0.000	0.000	.20231748E+01
LEG NO 4	3.752	0.000	1000000.000	0.000	1000000.000	0.000	0.000	.10000000E-05
LEG NO 5	3.752	0.000	5.745	0.000	.090	0.000	1.675	.15667813E+00
LEG NO 6	1.751	0.000	4.479	0.000	1.743	0.000	0.000	.57360468E+00
LEG NO 7	1.751	0.000	1000000.000	0.000	0.000	0.000	400000.000	.14279590E-05
LEG NO 8	1.751	0.000	4.479	-.005	.932	0.000	400000.000	.14279671E-05
LEG NO 9	5.503	0.000	9.148	0.000	.030	0.000	0.000	.33024123E+02
LEG NO 10	7.593	4.343	1000000.000	464.067	50.000	.175	0.000	.19562524E-01
LEG NO 11	13.095	9.143	1000000.000	0.000	.051	.010	.002	.67512470E+01
LEG NO 12	12.330	0.000	12.470	0.000	.002	0.000	0.000	.49403554E+03
LEG NO 13	.705	0.000	2.641	0.000	1.005	0.000	0.000	.99399275E+00
LEG NO 14	.025	0.000	9.148	0.000	.002	0.000	0.000	.42931360E+03

NODE PRESSURES 52.791 3159.927 3159.927 3159.925 54.174 3159.923 1607.042 54.154

NODE PRESSURES 54.154 52.810 3159.936 3159.927

FIGURE 9.0-4
STEADY STATE CALCULATION DATA FOR EXAMPLE SYSTEM

```
LEG NO  14        .000      0.000         9.148       0.000         .002      0.000        0.000      .42931360E+03
NODE PRESSURES        51.064      3006.980     3006.976     3006.975     52.230     3006.870     1529.581      52.230
NODE PRESSURES      52.228      51.102      3006.980     3006.980

LEG NO   1        .065      0.000         9.148    2955.908         .147      0.000         .002      .67565177E+01
LEG NO   2        .066      0.000         9.148       0.000         .054      0.000        0.000      .18555609E+02
LEG NO   3        .065      0.000         5.745       0.000         .494      0.000        0.000      .20231748E+01
LEG NO   4        .065      0.000   1000000.000       0.000  1000000.000      0.000        0.000      .10000000E-05
LEG NO   5        .065      0.000         5.745       0.000         .090      0.000        1.675      .10216108E+02
LEG NO   6        .061      0.000         4.479       0.000        1.743      0.000        0.000      .57360468E+00
LEG NO   7        .061      0.000   1000000.000       0.000        0.000      0.000   400000.000      .41121683E-04
LEG NO   8        .061      0.000         4.479       -.005         .932      0.000   400000.000      .41120107E-04
LEG NO   9        .065      0.000         9.148       0.000         .030      0.000        0.000      .33024123E+02
LEG NO  10       9.091      4.343   1000000.000     464.084       50.000       .175        0.000      .19637539E-01
LEG NO  11       9.155      9.143   1000000.000       0.000         .051       .010         .002      .61320006E+01
LEG NO  12       9.155      0.000        12.470       0.000         .002      0.000        0.000      .49403554E+03
LEG NO  13        .000      0.000         2.641       0.000        1.005      0.000        0.000      .99399275E+00
LEG NO  14        .000      0.000         9.148       0.000         .002      0.000        0.000      .42931360E+03
NODE PRESSURES        51.074      3006.973     3006.970     3006.968     52.221     3006.864     1529.573      52.220
NODE PRESSURES      52.218      51.093      3006.973     3006.973

LEG NO   1        .065      0.000         9.148    2955.908         .147      0.000         .002      .67860012E+01
LEG NO   2        .065      0.000         9.148       0.000         .054      0.000        0.000      .18665809E+02
LEG NO   3        .064      0.000         5.745       0.000         .494      0.000        0.000      .20231748E+01
LEG NO   4        .064      0.000   1000000.000       0.000  1000000.000      0.000        0.000      .10000000E-05
LEG NO   5        .064      0.000         5.745       0.000         .090      0.000        1.675      .10378609E+02
LEG NO   6        .061      0.000         4.479       0.000        1.743      0.000        0.000      .57350468E+00
LEG NO   7        .061      0.000   1000000.000       0.000        0.000      0.000   400000.000      .41153149E-04
LEG NO   8        .061      0.000         4.479       -.005         .932      0.000   400000.000      .41151570E-04
LEG NO   9        .065      0.000         9.148       0.000         .030      0.000        0.000      .33024123E+02
LEG NO  10       9.091      4.343   1000000.000     464.084       50.000       .176        0.000      .19637539E-01
LEG NO  11       9.155      9.143   1000000.000       0.000         .051       .010         .002      .81320059E+01
LEG NO  12       9.155      0.000        12.470       0.000         .002      0.000        0.000      .49403554E+03
LEG NO  13        .000      0.000         2.641       0.000        1.005      0.000        0.000      .99399275E+00
LEG NO  14        .000      0.000         9.148       0.000         .002      0.000        0.000      .42931360E+03
NODE PRESSURES        51.069      3006.963     3006.965     3006.963     52.216     3006.859     1529.568      52.215
NODE PRESSURES      52.213      51.068      3006.968     3006.968

LEG NO   1        .064      0.000         9.148    2955.908         .147      0.000         .002      .67868084E+01
LEG NO   2        .064      0.000         9.148       0.000         .054      0.000        0.000      .18605809E+02
LEG NO   3        .063      0.000         5.745       0.000         .494      0.000        0.000      .20231748E+01
LEG NO   4        .063      0.000   1000000.000       0.000  1000000.000      0.000        0.000      .10000000E-05
LEG NO   5        .063      0.000         5.745       0.000         .090      0.000        1.675      .10545692E+02
LEG NO   6        .061      0.000         4.479       0.000        1.743      0.000        0.000      .57350468E+00
LEG NO   7        .061      0.000   1000000.000       0.000        0.000      0.000   400000.000      .41121686E-04
LEG NO   8        .061      0.000         4.479       -.005         .932      0.000   400000.000      .41120109E-04
LEG NO   9        .064      0.000         9.148       0.000         .030      0.000        0.000      .33024123E+02
LEG NO  10       9.091      4.343   1000000.000     464.084       50.000       .175        0.000      .19637539E-01
LEG NO  11       9.155      9.143   1000000.000       0.000         .051       .010         .002      .81320608E+01
LEG NO  12       9.155      0.000        12.470       0.000         .002      0.000        0.000      .49403554E+03
LEG NO  13        .000      0.000         2.641       0.000        1.005      0.000        0.000      .99399275E+00
LEG NO  14        .000      0.000         9.148       0.000         .002      0.000        0.000      .42931360E+03
      CPU TIME IN SECONDS =       7.437
```

FIGURE 9.0-4 (Continued)

STEADY STATE CALCULATION DATA FOR EXAMPLE SYSTEM

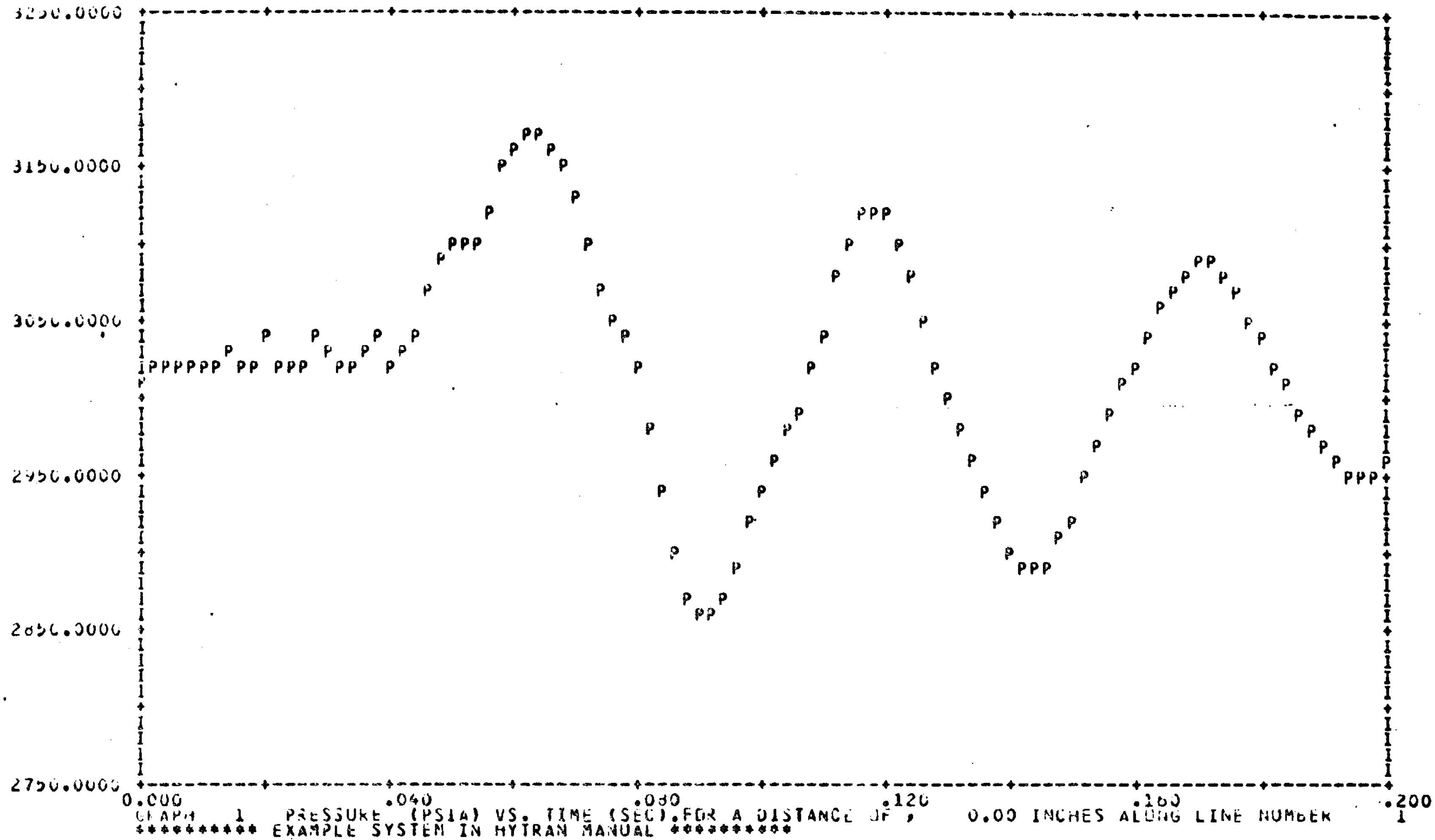


FIGURE 9.0-5
PRESSURE PLOT FOR A POINT 0.0 IN. ALONG LINE 1 OF EXAMPLE SYSTEM

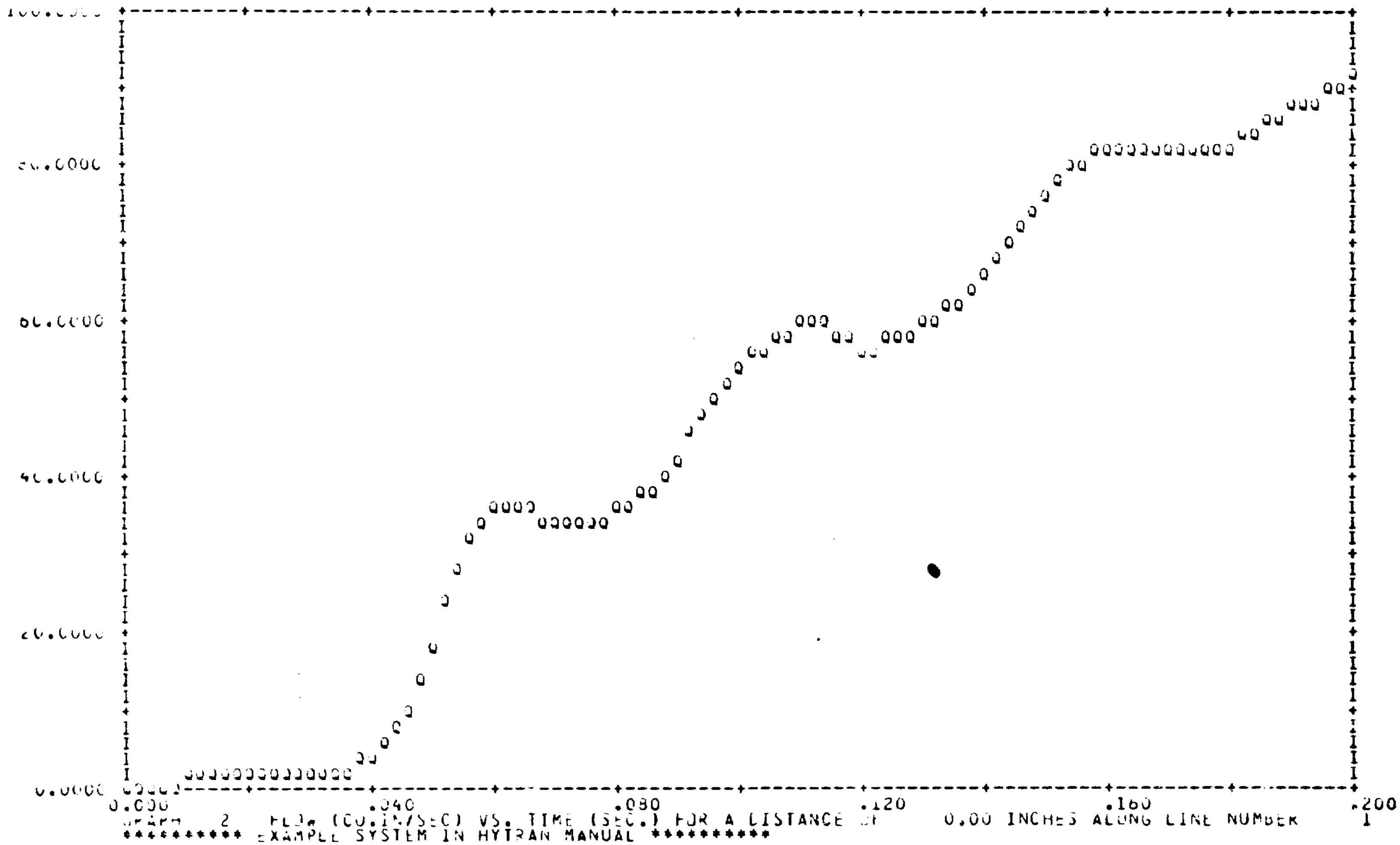


FIGURE 9.0-6
FLOW PLOT FOR A POINT 0.0 IN. ALONG LINE 1 OF EXAMPLE SYSTEM

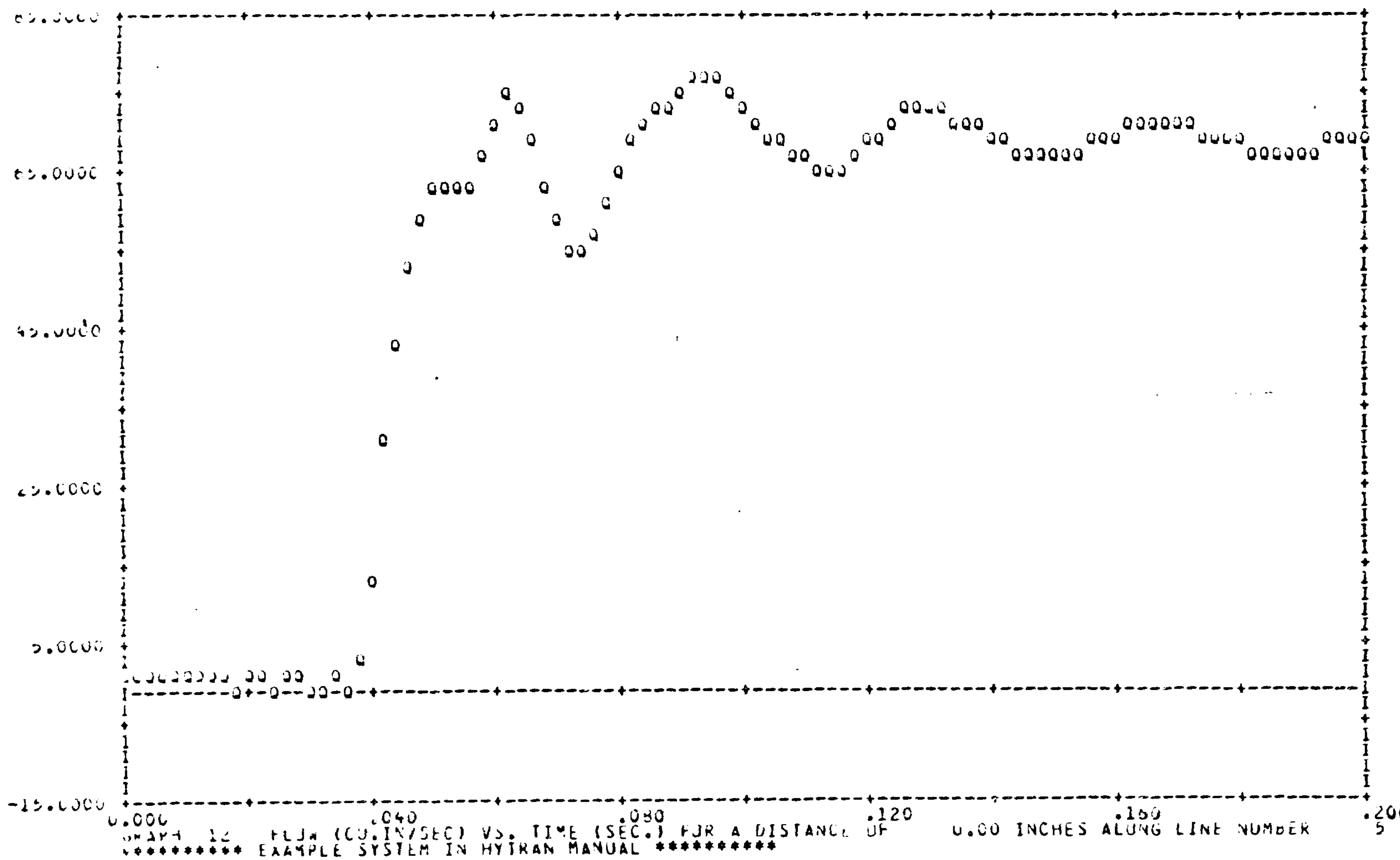


FIGURE 9.0-7
FLOW PLOT FOR A POINT 0.0 IN. ALONG LINE 5 OF EXAMPLE SYSTEM

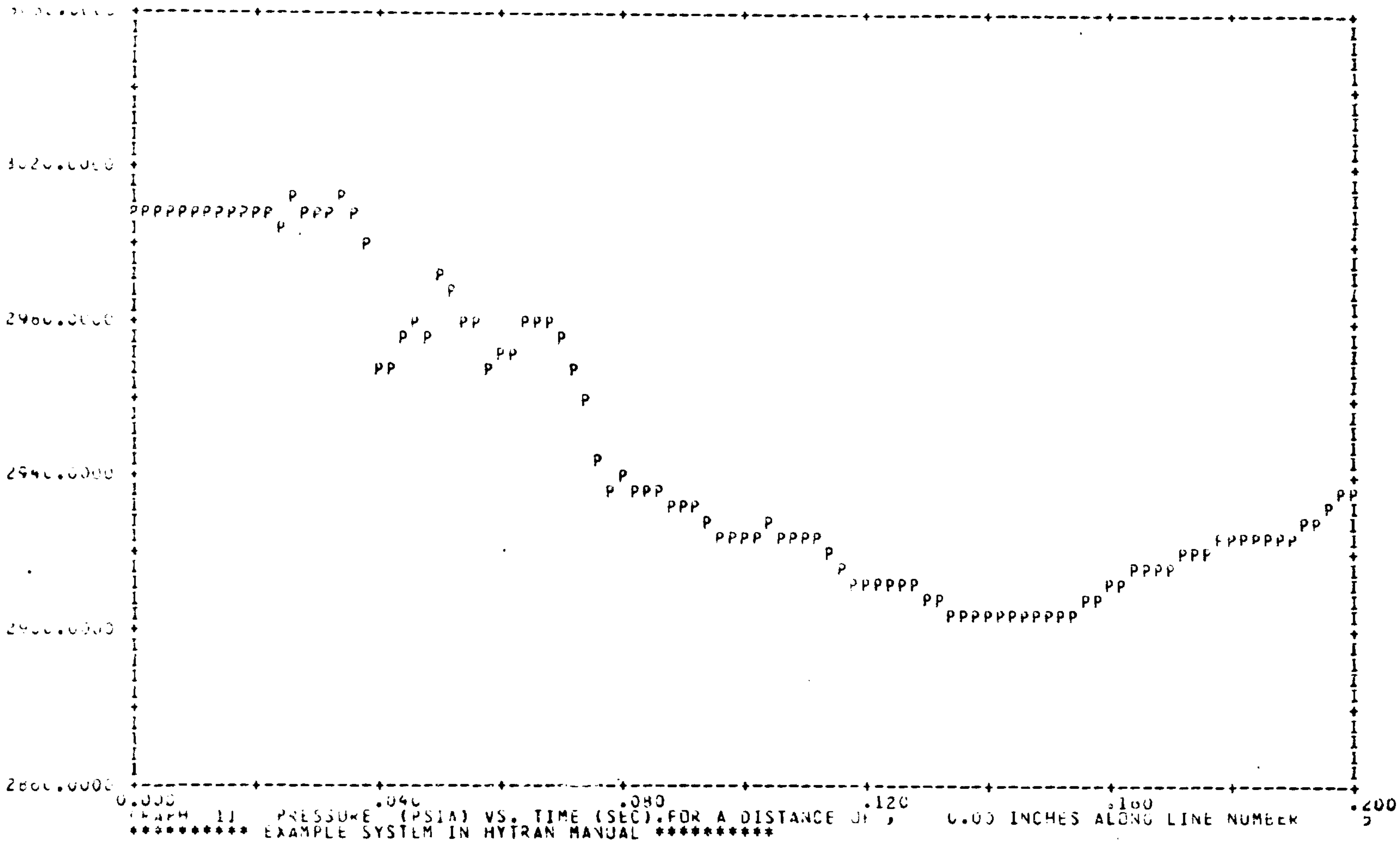


FIGURE 9.0-8
PRESSURE PLOT FOR A POINT 0.0 IN. ALONG LINE 5 OF EXAMPLE SYSTEM

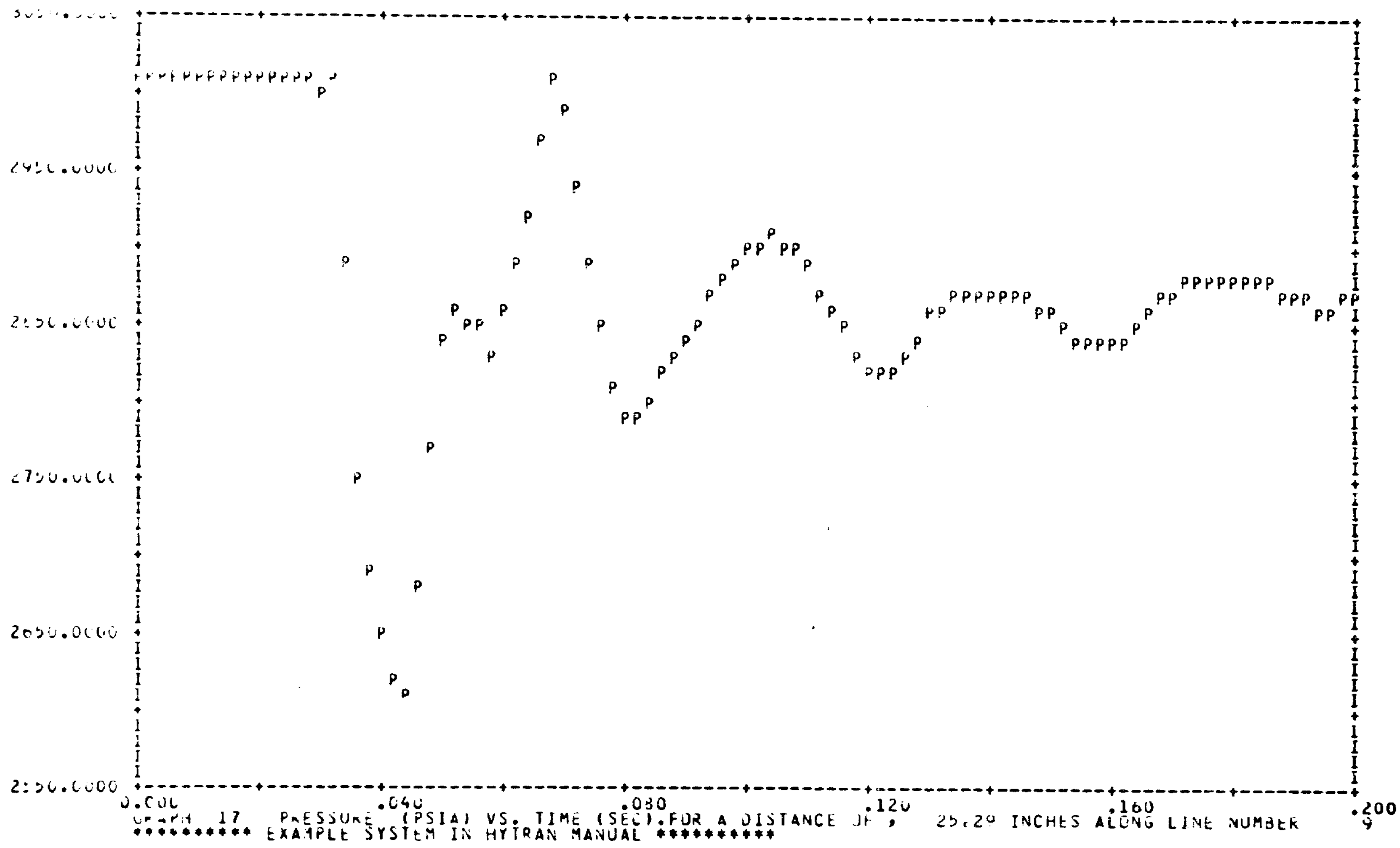


FIGURE 9.0-9
PRESSURE PLOT FOR A POINT 30.0 IN. ALONG LINE 9 OF EXAMPLE SYSTEM

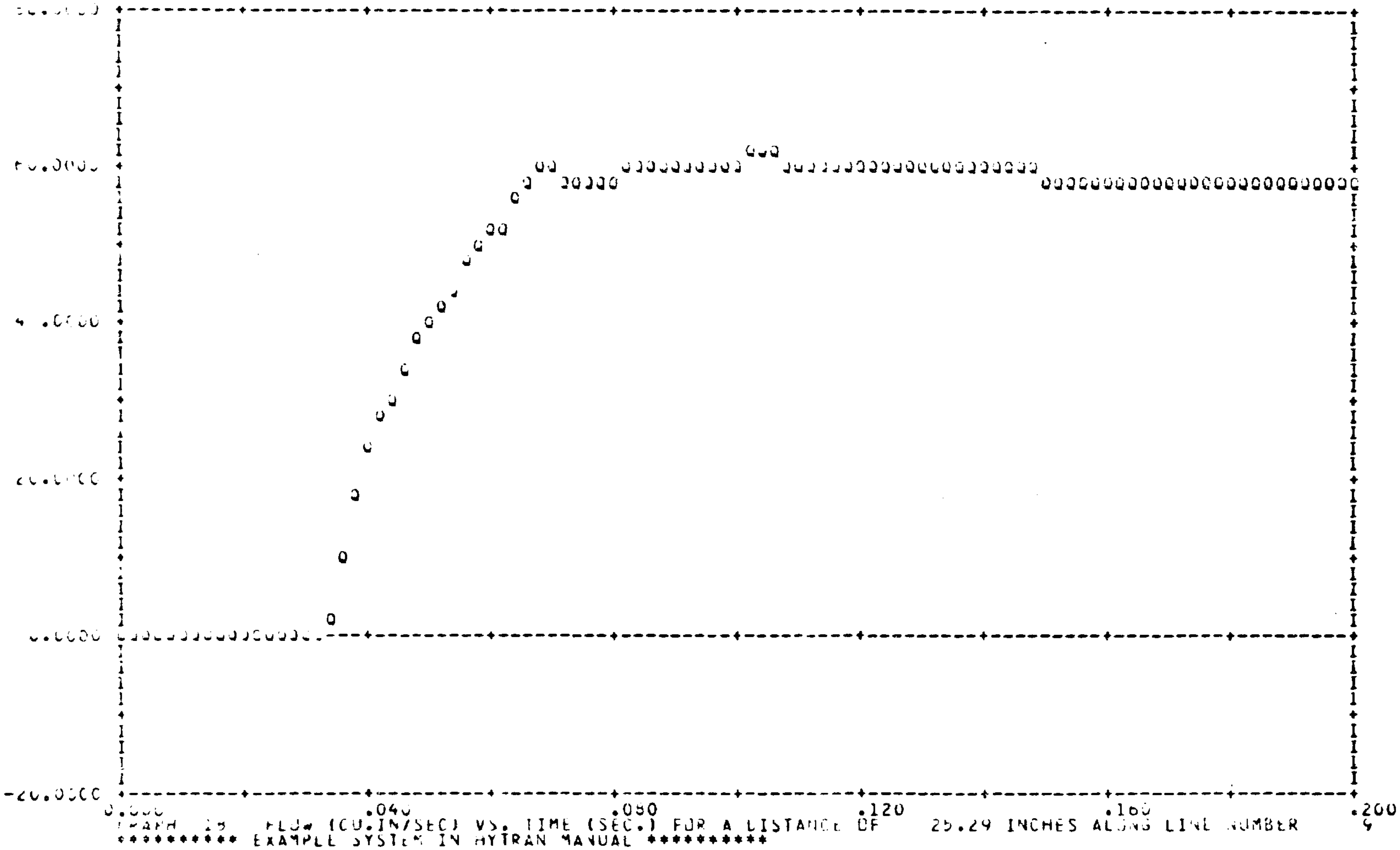


FIGURE 9.0-10
FLOW PLOT FOR A POINT 30.0 IN. ALONG LINE 9 OF EXAMPLE SYSTEM

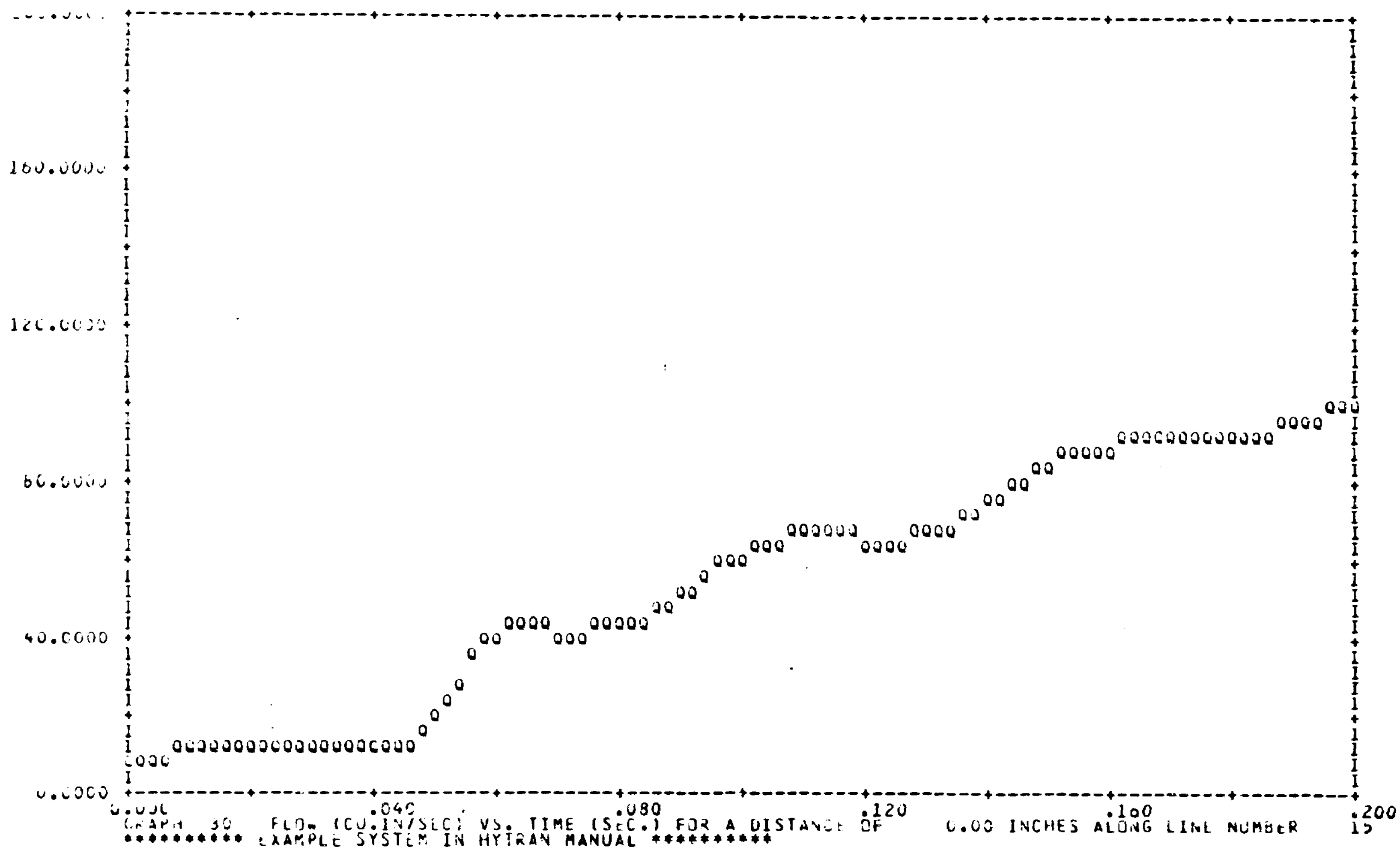


FIGURE 9.0-11
FLOW PLOT FOR A POINT 0.0 IN. ALONG LINE 15 OF EXAMPLE SYSTEM

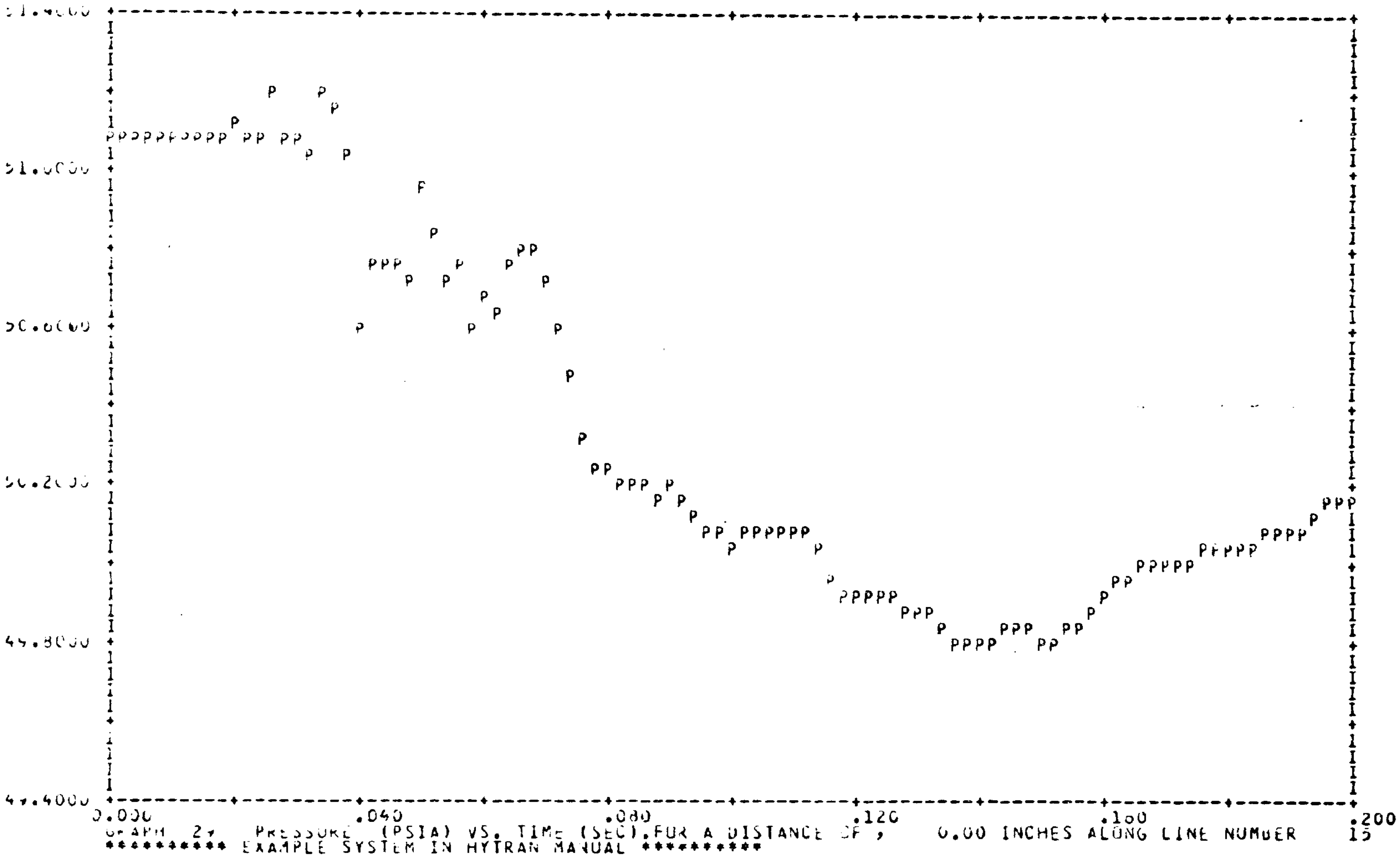


FIGURE 9.0-12
PRESSURE PLOT FOR A POINT 0.0 IN. ALONG LINE 15 OF EXAMPLE SYSTEM

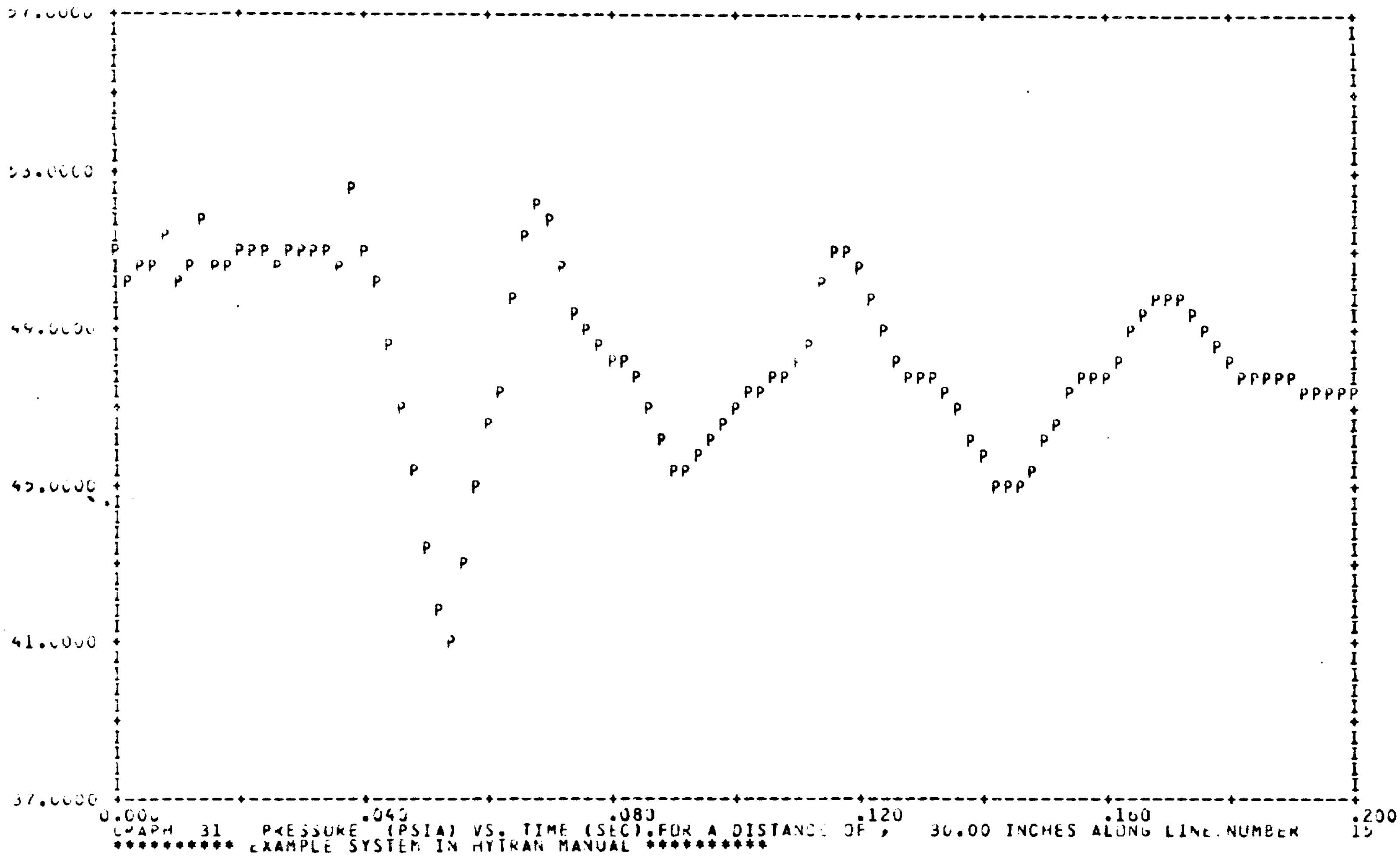


FIGURE 9.0-13
PRESSURE PLOT FOR A POINT 30.0 IN. ALONG LINE 15 OF EXAMPLE SYSTEM

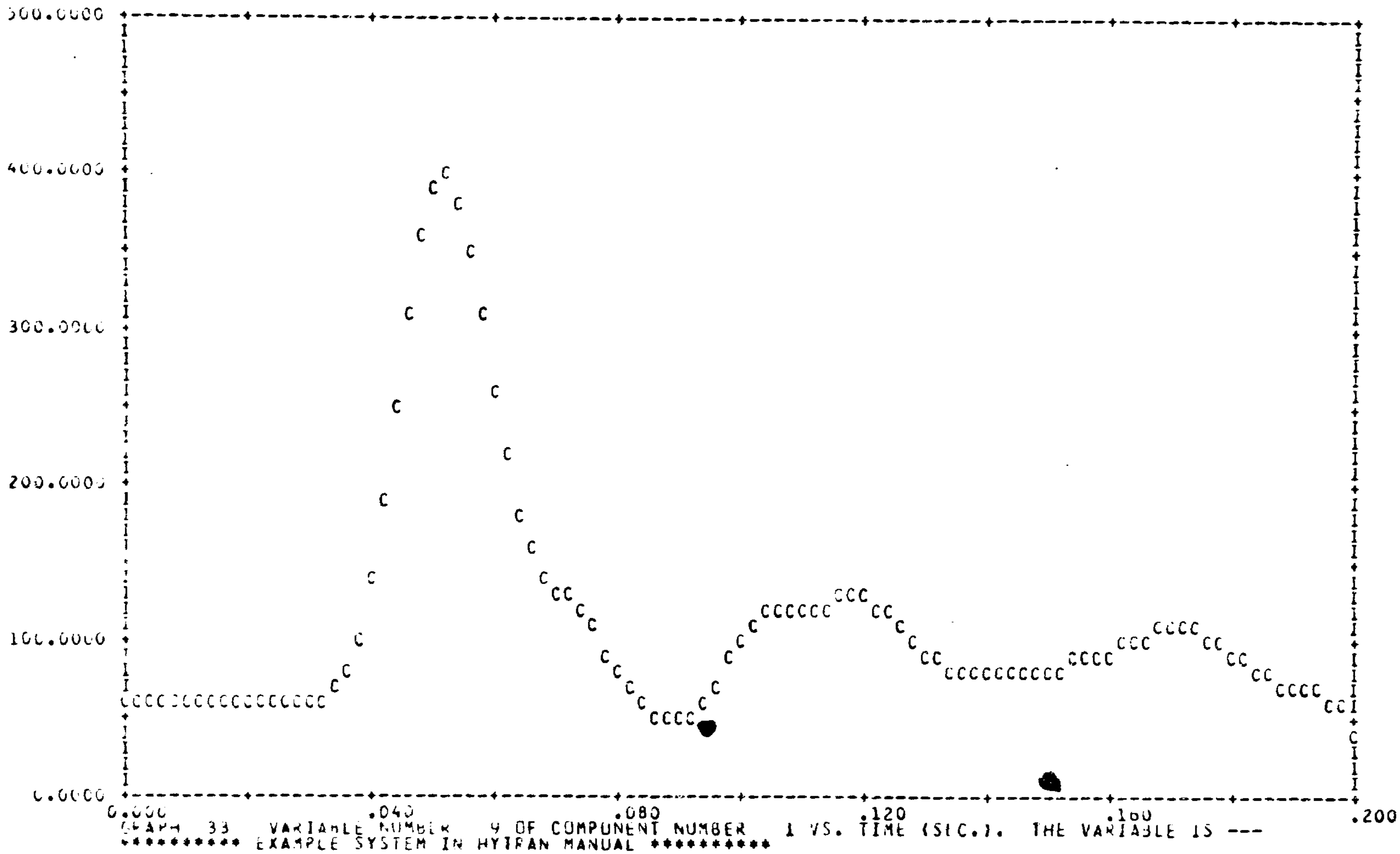


FIGURE 9.0-14
PLOT OF FLOW FROM PUMP CASE TO INLET FOR EXAMPLE SYSTEM