DRF-05423

TECHNICAL REPORT

FOR

THE STUDY OF OPTIMIZATION OF THRUST VECTOR CONTROL SYSTEMS

September 1967

MCR-67-239

Copy No.

Contract NAS8-21041

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THE STUDY OF OPTIMIZATION OF THRUST VECTOR CONTROL SYSTEMS

September 1967

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FOREWORD

This document is submitted in accordance with Item III C, Exhibit A of Contract NAS 8-21041, dated 20 December 1966.

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SUMMARY

A. Purpose and Scope

The purpose of this study was to expand the work conducted under contract NAS 8-11415 and NAS 8-20224. The first phase was concerned with single hydraulic system using standard or non-redundant actuators for thrust vector control of launch vehicles. The second phase was concerned with various schemes for reliability improvement including redundant actuators and hydraulic systems. Both phases had as their primary consideration reliability, weight, and cost while also considering actuator moment arm, hydraulic system pressure and response. The work expansion in this study was to extend the previous work into the coast, or on-orbit, phase of the S-IV B stage operation using the S-IV B stage hydraulic system design parameters. The study was also to include the determination of reliability figures for the system, including autopilot electronics when the "majority vote actuator" is interfaced with the autopilot electronics. The scope of the study was limited to the considerations of systems using linear servo actuators. The autopilot study was limited to considerations of the existing S-IV B autopilot with minimum modifications.

B. System Configurations Investigated

The following is a description of the autopilot and hydraulics system configurations investigated.

Case I - Existing S-IV B autopilot electronics and hydraulic system. The existing S-IV B thrust vector control system utilized a single hydraulic system operating at 3500 psi with standard actuators and a "triple" redundant autopilot connected in a "pair and spare" configuration. This configuration was used as a basis for comparison of the other configurations.

Case II - Majority vote actuator with the existing S-IV B autopilot. This configuration included the use of the existing S-IV B pair and spare autopilot without the comparator circuit and the single hydraulic system operating at 2500 psi with the motorpump and engine driven pump in parallel redundant operation. In this configuration the majority voting actuator replaced the existing standard actuator with the three autopilot channels connected directly to the three majority voting servovalves.

Case III - Majority vote actuator with additional majority voting at the 50 MA Servo Amplifier in the S-IV B autopilot. In this configuration the three channels of the existing S-IV B autopilot would be modified to majority vote the three channels at the 50 MA servo amplifier in addition to majority voting at the actuator servovalves. The hydraulic system would be the same as described in Case II.

Case IV - Majority vote actuator with additional majority voting at the D.C. amplifiers in addition to majority voting at the servo amplifier. This configuration would be the same as Case III with additional majority voting at the D.C. amplifiers.

The comparison of the overall system reliability for the four system configurations investigated shows that the configurations described in Cases II, III, and IV all would result in approximately 49 percent fewer failures than the existing Saturn S-IV B stage autopilot and hydraulic system.

Since the unreliability of the hydraulic system is much greater than the autopilot, the improvement of the autopilot is masked out when the total system reliability is considered.

The total system reliability improvement in Cases II, III, and IV is due primarily to the hydraulic system improvement resulting from the majority voting actuator, operating the motorpump and engine driven pump in paralled and reducing the system pressure from 3500 to 2500 psi.

In each of the above cases with the exception of Case II, the autopilot and the hydraulic systems were examined separately with respect to their reliability. Once the reliability and probability of failures were determined for each subsystem the autopilot and hydraulic systems were combined using the appropriate reliability equations in determining the overall system reliability. Case II posed a special problem since the majority voting of the autopilot output occurs at the majority voting servovalves. It was, therefore, necessary to include the majority voting portion of the servovalves as part of the autopilot.

C. Autopilot Configurations Investigated

The autopilot investigation included the following configurations.

1. Existing S-IV B autopilot with pair and spare redundancy.

2. Majority voting at the 50 MA servo amplifier.

3. Autopilot with majority voting of the 50 MA servo amplifier and majority voting of the D.C. amplifier.

The reliability analysis of the autopilot alone showed that configuration (2) would produce 12 percent fewer failures than the existing autopilot and configuration (3) would produce 40 percent fewer failures than the existing autopilot.

D. Hydraulic System Configuration

The following hydraulic system configurations investigated were the same as in the previous study.

1. Single hydraulic system with standard actuators (existing Saturn S-IV B configuration).

2. Single system with majority vote actuator.

3. Dual system with standard actuator.

4. Dual system with majority vote actuator.

5. Dual system with tandem actuators.

The reliability of these system configurations were determined for the coast or on-orbit phase of the Saturn S-IV B stage operation using the existing S-IV B stage design parameters.

The following table is a list of the total flight reliability of each system for comparison purposes.

Hydraulic System Configuration	Total Flight Reliability
1. Single Actuator System, Standard Actuator	.996573
2. Single Hydraulic System, Majority Vote Actuator	.997800
3. Dual Hydraulic System, Standard Actuator	.997223
4. Dual Hydraulic System, Majority Vote Actuator	.998449
5. Dual Hydraulic System, Tandem	.99858

In addition, an investigation was made to determine the reliability improvement of operating the existing S-IV B stage hydraulic system with the motorpump and engine driven pump in parallel redundant operation at 2500 psi. The computer results showed that this configuration would produce approximately 13 percent fewer failures over the existing S-IV B hydraulic system configuration. The comparison between the above system using majority voting actuators and the existing S-IV B hydraulic system is discussed in Part A.

I. INTRODUCTION

This report is the final technical summary report for Contract NAS 8-21041. The purpose of this study was to extend the work performed under Contract NAS 8-20224 which was concerned with the optimization of redundant hydraulic systems and actuators for thrust vector control of launch vehicles. This study extended the scope of work in the previous study into the coast or on-orbit phase of the Saturn S-IVB stage operation. This study also includes the determination of reliability of the thrust vector control system including the autopilot electronics when the "Majority Vote Actuator" is interfaced with the autopilot.

The general approach used in the study was to determine the reliability of various autopilot configurations which were compatible with a "Majority Voting Actuator" and compare these configurations with the existing Saturn S-IVB stage autopilot and hydraulic thrust vector control system.

In order to accomplish the work required for this study the program was divided into two major tasks:

Task A - Autopilot Electronics
Task B - Thrust Vector Control Hydraulic System

The objective of Task A was to determine the feasibility of modifying the existing autopilot of the Saturn S-IVB stage to be compatible with the "Majority Vote Actuator." An analysis was performed to determine the reliability of the better autopilot configurations and these were then compared with the reliability of the existing autopilot. The objective of Task B was to determine the reliability of the various thrust vector control hydraulic system configurations investigated in the previous study program for the on-orbit phase of the Saturn S-IVB operation. The final objective was to compare the reliability of the existing Saturn S-IVB thrust vector control system including the autopilot electronics with a TVC system which utilizes majority voting actuator and a compatible autopilot.

The general approach used in Task A was to examine the existing Staurn S-IVB stage autopilot in order to determine the feasibility of various autopilot configurations which would be compatible with the Majority Vote Actuator. A conceptual design was made for each scheme and a reliability analysis performed on each autopilot configuration, including the existing S-IVB autopilot. The reliability analysis was performed on each autopilot configuration using NASA supplied data on component failure rates, environmental modifiers, and reliability equation which permitted a direct reliability comparison with the existing autopilot.

The approach used in Task B was to expand and modify the computer program of the previous study to include the coast or on-orbit phase of the Saturn S-IVB stage operation. The input data to the computer program was updated using NASA supplied information on environmental conditions, operating times for coast and burn phases, and hydraulic system design parameters for the S-IVB stage operation.

The reliability data derived from the computer program for the hydraulic system was then combined with the various autopilot configurations for final comparison with the existing S-IVB system.

Included in this report are the following items:

1. Reliability comparison of the autopilot and hydraulic system configurations investigated.
2. Description and analysis of each autopilot configuration investigated including schematic drawings.
3. Derivation and discussion of environmental factors used in updating the computer program.
4. A listing of the IBM cards used in the computer program with general operating instructions.

II. RESULTS

Autopilot and Hydraulics System Configurations

The following is a description of each configuration:

Case I - (See Figure 1) This configuration is the existing S-IV B pair and spare autopilot and 3500 psi single hydraulic system with standard servo actuators.

Case II - (See Figure 2) The second configuration is the existing S-IVB pair and spare autopilot without the comparator circuit and the single hydraulic system operating with the motorpump and engine driven pump in parallel at 2500 psi. In this configuration the majority voting actuator replaced the standard actuator with the three autopilot output channels connected directly to the three servo valves of the majority vote actuator.

Case III - (See Figure 3) This configuration is the same as Case II except that the autopilot output channels are majority voted at the 50 ma servo amplifier. Then the three autopilot outputs connected to the three servo valves of the majority vote actuator. Thus the system has majority voting twice, at the actuator and inside the autopilot at the servo amplifier. The hydraulic system, like Case II, was considered to be operating at 2500 psi with the motorpump and engine driven pump in parallel redundant operation.

Case IV - (See Figure 4) This configuration is the same as Case III except that the autopilot is majority voted twice instead of once. The system then is majority voted three times: the first time at the D.C. Amplifier, the second time at the 50 MA servo amplifier, and again at the majority voting servo valves of the actuator. The hydraulic system like Cases II and III was at 2500 psi with motorpump and engine driven pump in parallel redundant operation.

System Reliability Results

Table I shows the reliability and probability of failures of the four system configurations investigated for the 1st burn, coast, 2nd burn and total flight phase of the Saturn S-IV B stage operation.

CASE I S-IVB TVC & AUTOPILOT EXISTING SYSTEM

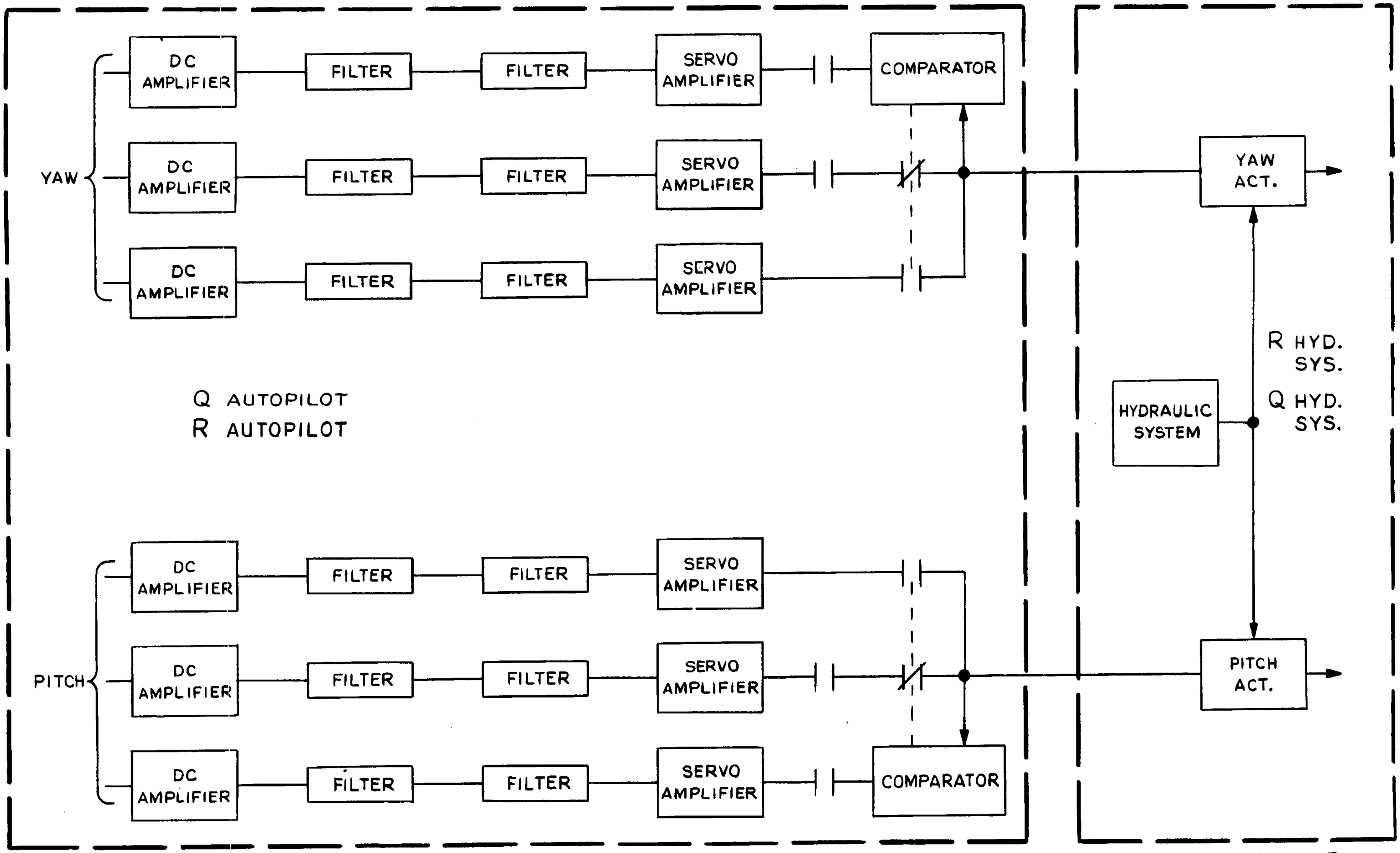


FIGURE I

CASE II 3 CHANNEL AUTOPILOT AND MAJORITY VOTE ACTUATOR

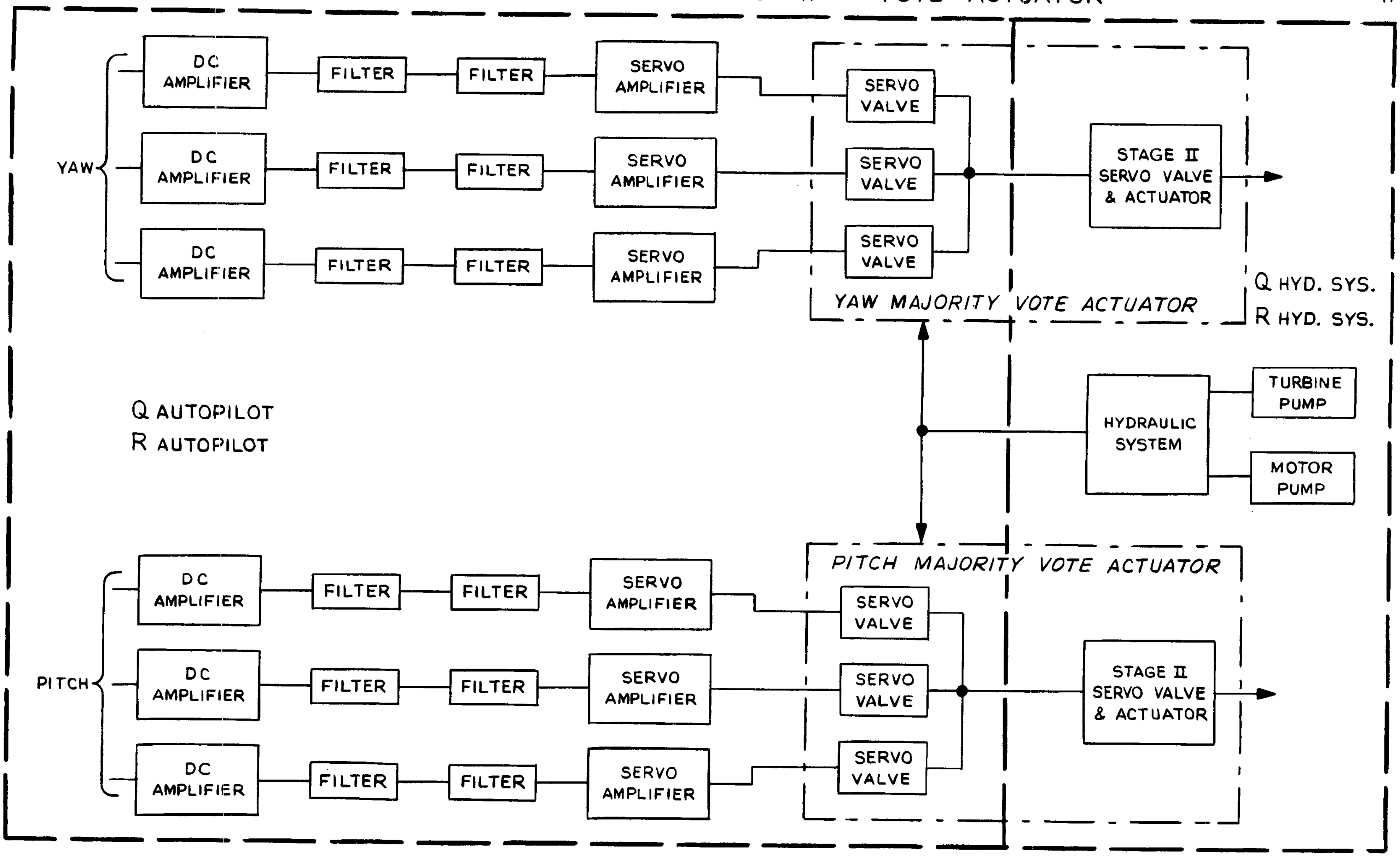


FIGURE 2

CASE III MAJORITY VOTE SERVO AMPLIFIER AND MAJORITY VOTE ACTUATOR

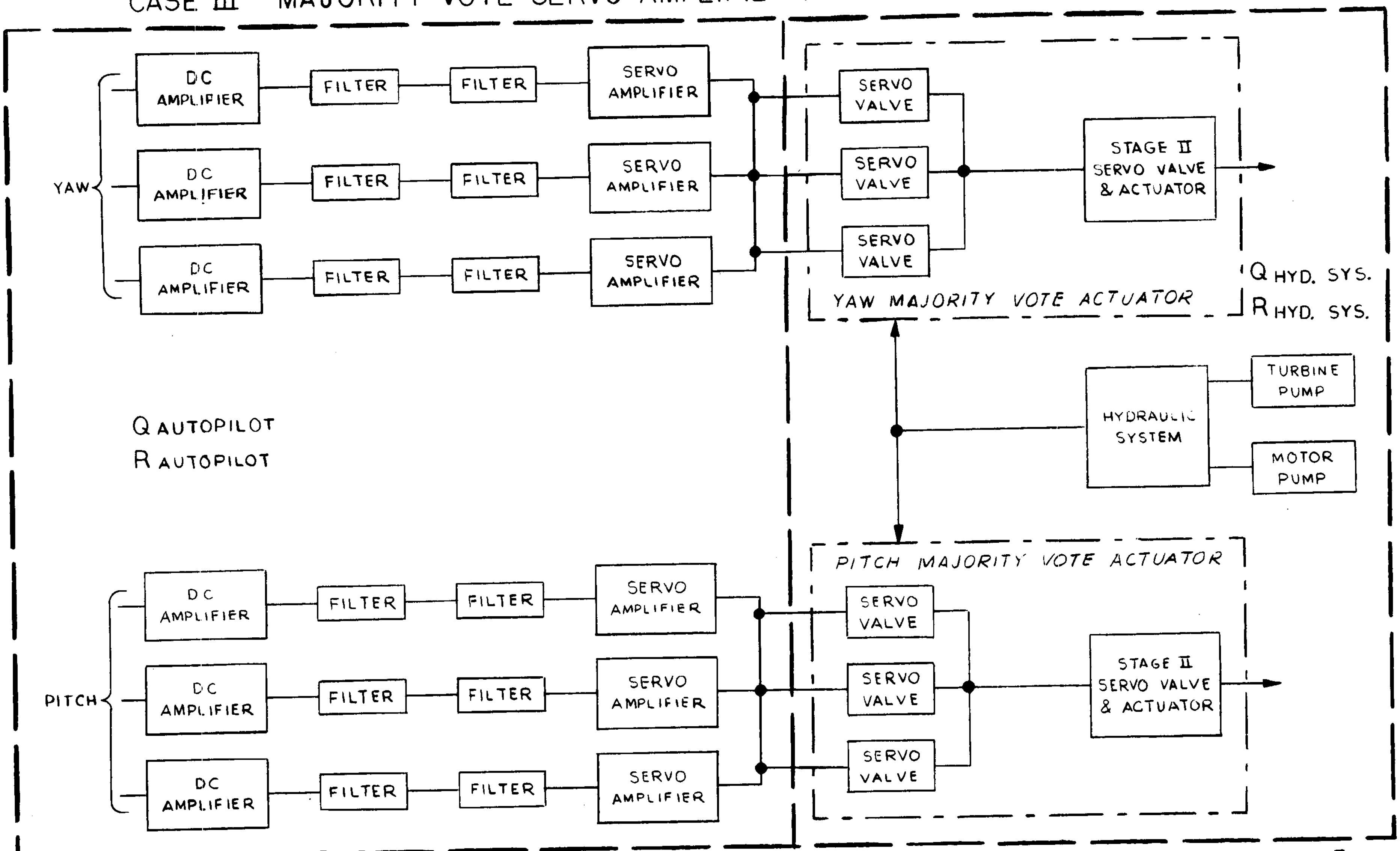


FIGURE 3

CASE IV MAJORITY VOTE SERVO AMPLIFIER & D.C. AMPLIFIER AND MAJORITY VOTE ACTUATOR

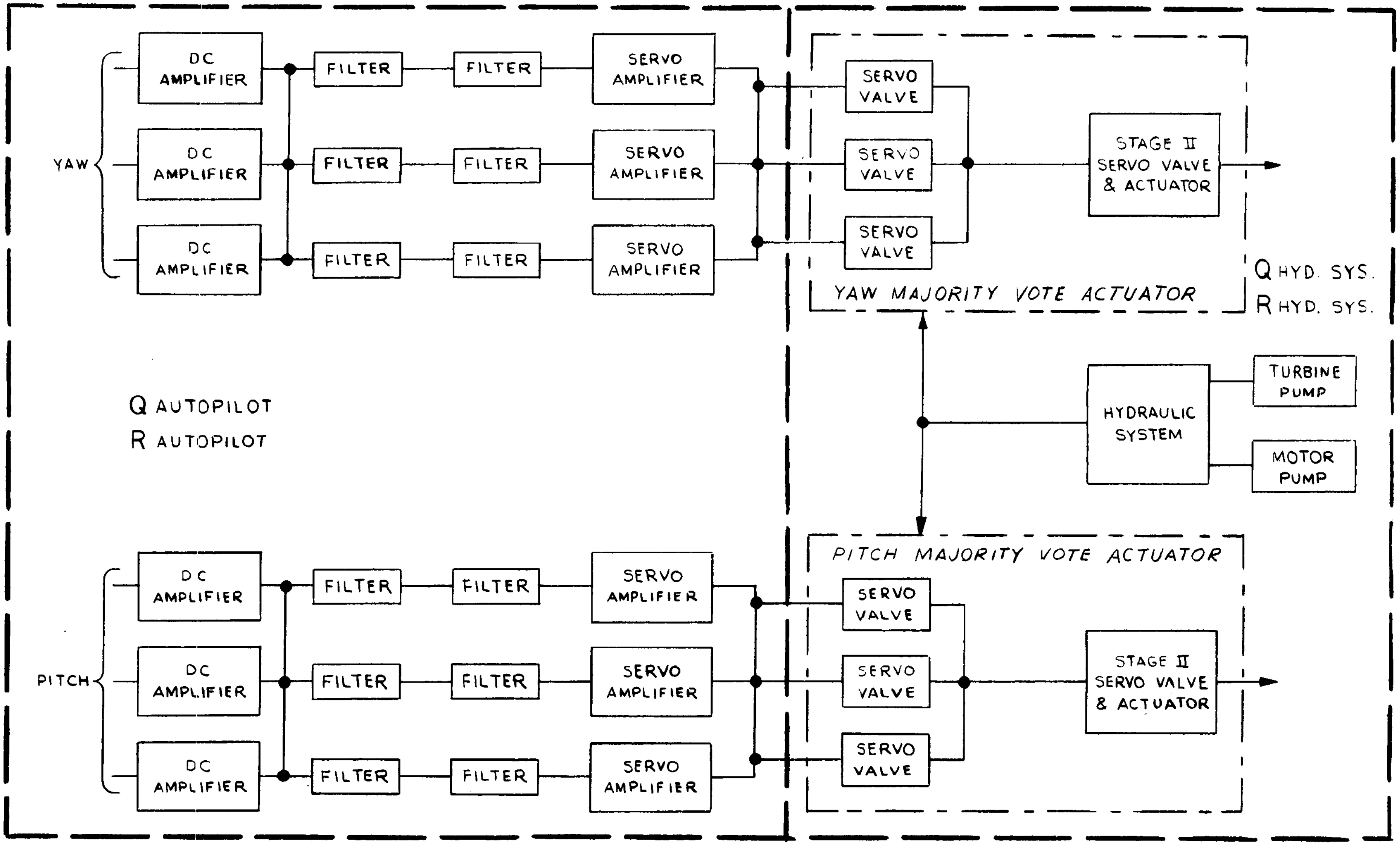


FIGURE 4

TABLE I - AUTOPILOT AND HYDRAULIC SYSTEM RELIABILITY

System Configuration	1st Burn	Coast	2nd Burn	Total Flight
Case I - Existing S-IV B Hydraulic System and Autopilot				
$Q_{Autopilot}$	$.3716872 \times 10^{-8}$	$.2992512 \times 10^{-7}$	$.15785162 \times 10^{-7}$	.0000000496
$R_{Autopilot}$				.9999999504
$Q_{Hydraulic\ System}$	.00129084	.00003529	.00210057	.00352670
$R_{Hydraulic\ System}$				.99779986
$Q_{Case\ I}$	.001290837	.000035399	.002100586	.003426822
$R_{Case\ I}$	.998709163	.999964601	.997899414	.996573178
Case II - Existing S-IV B Autopilot without comparator circuit, majority vote actuator, dual pump and 2500 psi system pressure				
$Q_{Autopilot\ +\ Majority\ Vote\ Valve}$	$.243411990 \times 10^{-6}$	$.22349326 \times 10^{-8}$	$.232804276 \times 10^{-6}$	.0000004804
$R_{Autopilot\ +\ Majority\ Vote\ Valve}$				.9999995196
$Q_{Hydraulic\ System}$	.00067646	.00001920	.00106863	.00176429
$R_{Hydraulic\ System}$				.99823571
$Q_{Case\ II}$	.0006767054	.0000192022	.0010688628	.0017647704
$R_{Case\ II}$	.9993232946	.9999807978	.9989311372	.9982352296

TABLE I - (Continued)

System Configuration	1st Burn	Coast	2nd Burn	Total Flight
Case III - Majority Voting at the 50 ma Servo Amplifier, Majority Vote Actuator, Dual Pumps, and 2500 psi System Pressure				
$Q_{Autopilot}$	$.3259112 \times 10^{-8}$	$.1562469 \times 10^{-7}$	$.2848485 \times 10^{-7}$	.0000000474
$R_{Autopilot}$				.9999999526
$Q_{Hydraulic\ System}$ and Actuator	.0006764856	.0000192	.0010686764	.0017643620
$Q_{Hydraulic\ System}$ and Actuator				.9982356380
$Q_{Case\ III}$	.0006764889	.0000192156	.0010687049	.0017644094
$R_{Case\ III}$	.9993235111	.9999807844	.9989312951	.9982355906

TABLE I - (Continued)

System Configuration	1st Burn	Coast	2nd Burn	Total Flight
Case IV - Majority Voting at the 50 ma Servo Amplifier and at the DC Amplifier, Majority Vote Actuators, Dual Pumps and 2500 psi Hydraulic System Pressure				
$Q_{Autopilot}$	$.3891352 \times 10^{-8}$	$.9137422 \times 10^{-8}$	$.16530796 \times 10^{-7}$	.0000000296
$R_{Autopilot}$				.9999999704
$Q_{Hydraulic\ System\ and\ Actuator}$	.0006764856	.0000192	.0010686764	.0017643620
$R_{Hydraulic\ System\ and\ Actuator}$				.9982356380
$Q_{Case\ IV}$	.0006764895	.0000192091	.0010686929	.0017643915
$R_{Case\ IV}$	.9993235105	.9999803909	.9989313071	.9982356085

Q = Unreliability

R = Reliability

III. DISCUSSION AND ANALYSIS

1.0 AUTOPILOT

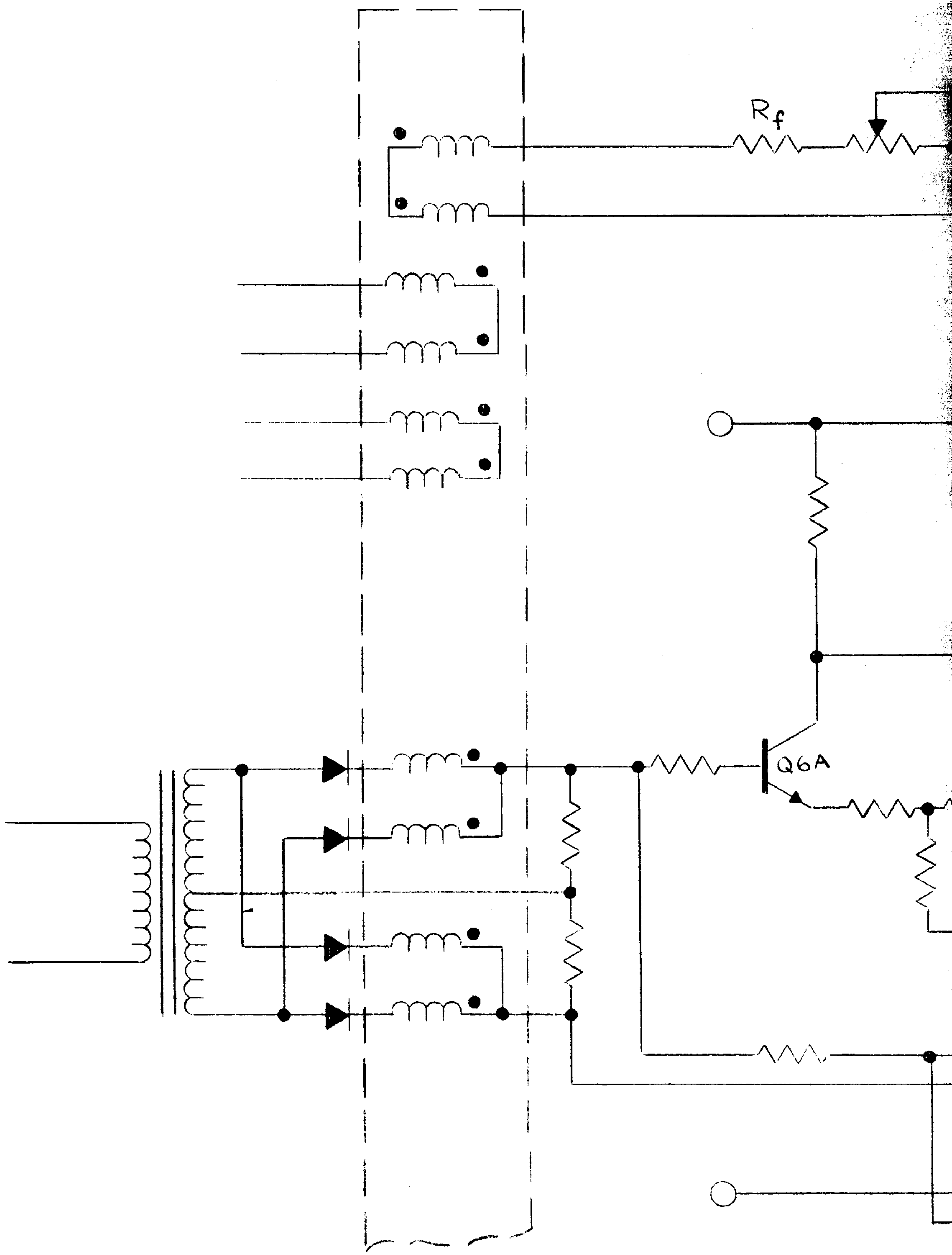
Four autopilot cases were examined with respect to their reliabilities. The following is a description of each case. The block diagrams of all cases show two filters in series. This is not the actual physical configurations (the filters are really in parallel), but since a failure in either filter would cause a channel failure, the series fiction can be used for reliability study purposes.

a. Case I is the existing autopilot which has pair and spare redundancy (see Figure 1).

b. Case II is the autopilot with analog majority voting at the 50 ma servo amplifier without the comparator circuit (see Figure 3). The majority vote 50 ma servo amplifier has a net parts count addition of nine parts over the existing 50 ma servo amplifier. The net parts added are three transistors, one diode and five resistors (see Figure 5, schematic of majority vote 50 ma servo amplifier).

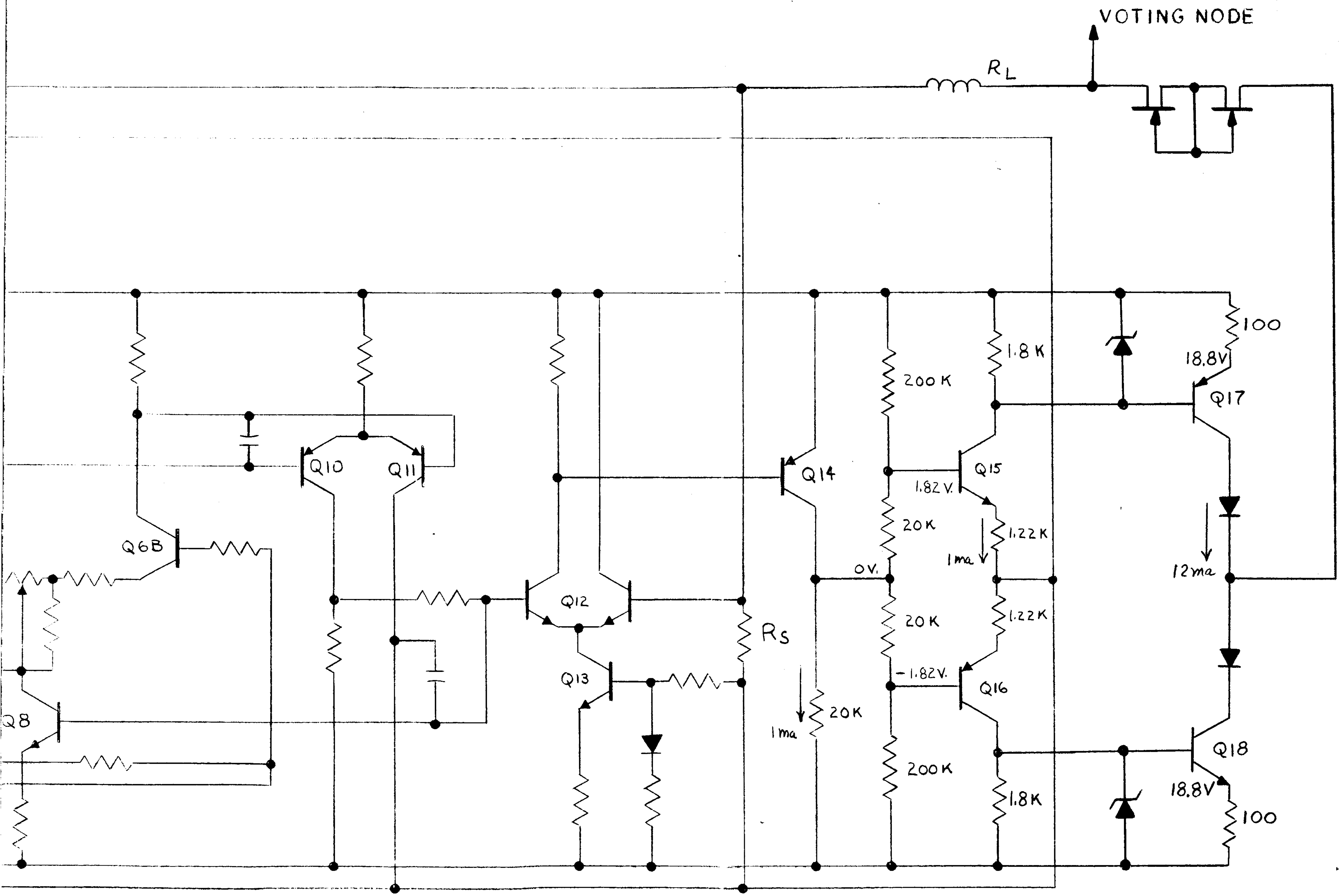
c. Case III is the autopilot with analog majority voting of the 50 ma servo amplifier and of the D.C. amplifier (see Figure 4). The 50 MA Servo Amplifier is the same as that used in Case II. The D.C. Amplifier has fourteen parts added for Majority Voting purposes. This includes four transistors, eight diodes, and two resistors. (See Figure 6).

d. Case IV is the same as Case II except that no parts have been added for majority voting. This case is to get a better comparison between the reliabilities of pair and spare redundancy and analog majority voting.


R_f
Q6A

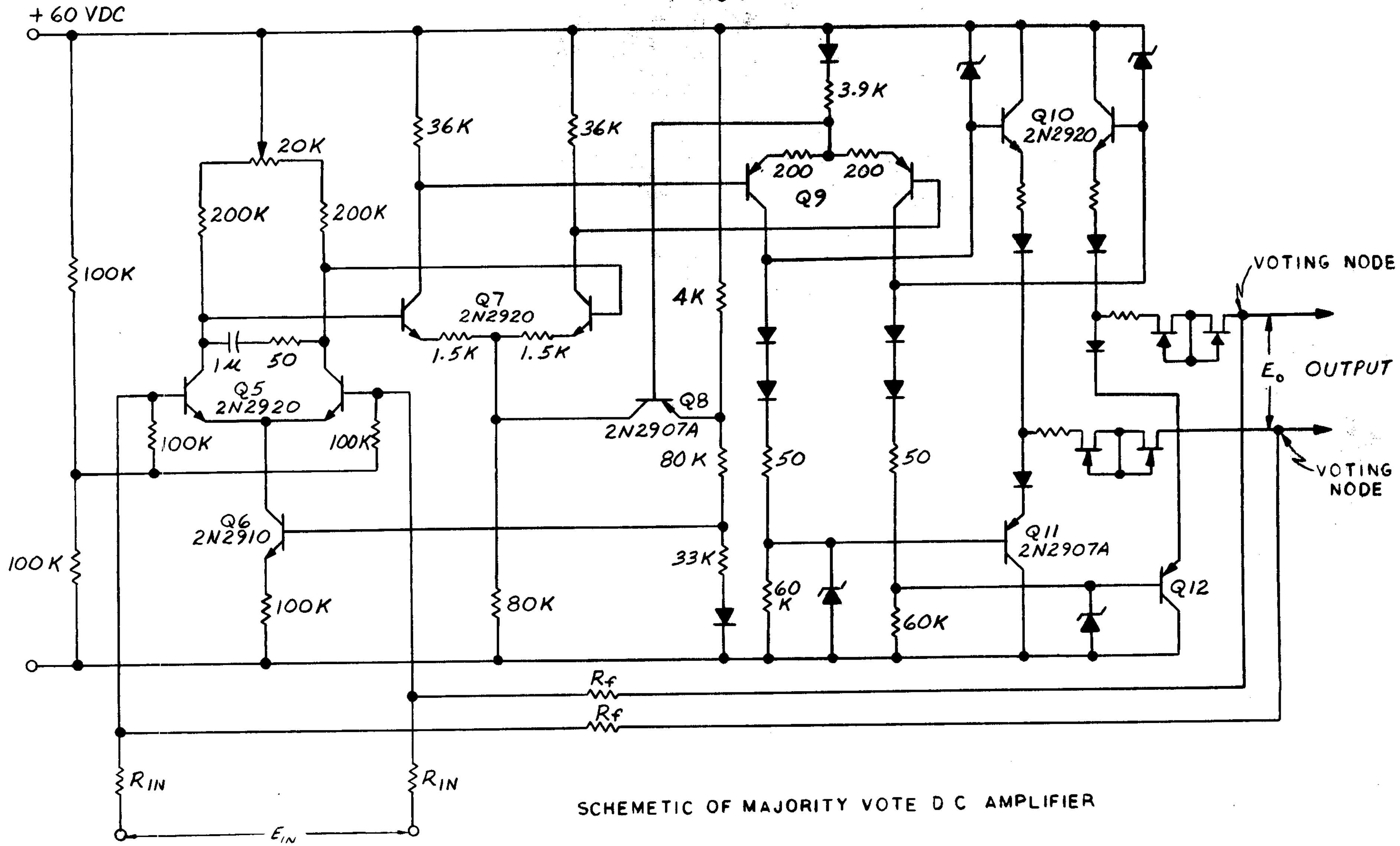
FOLDOUT FRAME 2

FOLDOUT FRAME 3



SCHEMATIC DIAGRAM
MAJORITY VOTE SERVO AMPLIFIER
(FINAL FORM)

FIGURE 5



SCHEMETIC OF MAJORITY VOTE D C AMPLIFIER

FIGURE 6

1.1 Examination of Existing Autopilot

The Saturn S-IVB Autopilot was examined so that it could be modified for Majority Voting.

The familiarization of the circuitry by analysis has taken the logical steps of 1) DC Analysis, 2) AC Analysis, 3) Transfer Function Analysis, and 4) Output Impedance, open loop, which is of special significance when Majority Voting is being considered.

The analysis is covered in detail in Appendix A.

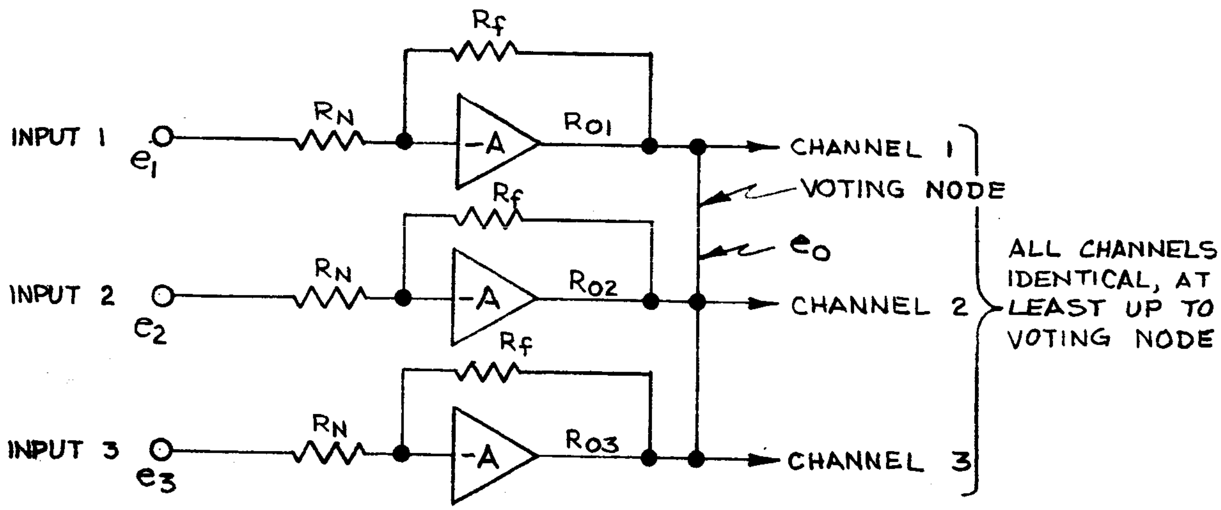
1.2 Majority Voting Autopilot

A number of ways are suggested for the use of Majority Voting on the Apollo Autopilot. First, however, some theory is presented for Analog Majority Voting. The way Majority Voting is mechanized in the Titan III MOL Autopilot is also presented as a working example.

1.2.1 Requirements for Majority Voting

Analog Majority Voting is a scheme for cancelling out failures in the channel circuitry that precedes the voting stage or "Voting Node". This is done without the use of complicated sensing and switching circuitry, whose high parts count could compromise the reliability it is attempting to improve. Analog Majority Voting is automatic. It is immune to transient effects that might cause a switching system to actuate. Transient malfunctions occuring in any channel are voted out as readily as a constant malfunction and the Majority Vote circuitry is ready to take on another malfunction as soon as the transient one has gone away.

The "Voting Node" is the common output (all outputs attached) of the identical feedback amplifiers, each of which is in a separate, identical channel.



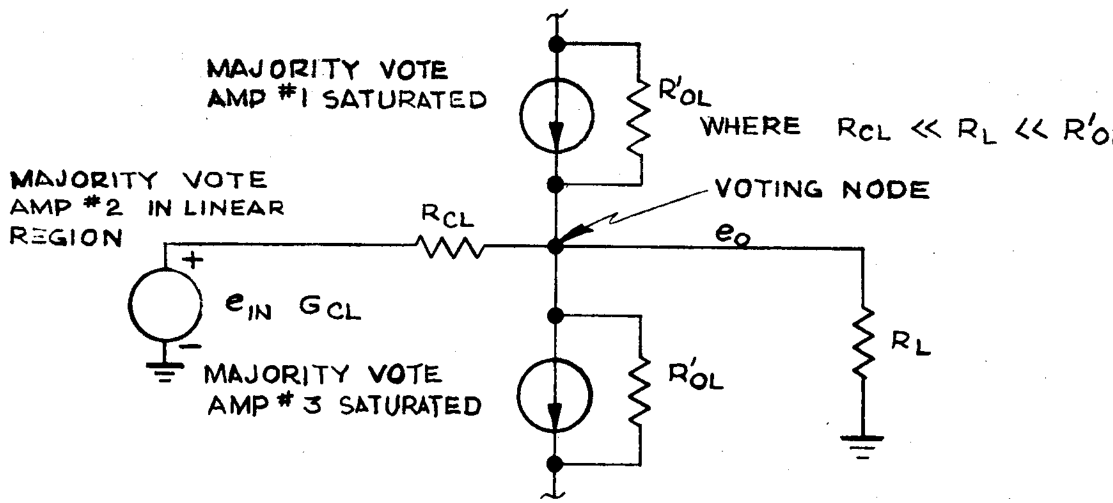
NOTE: AMPLIFIERS HAVE HIGH OPEN LOOP OUTPUT IMPEDEDANCES: R_{O1}, R_{O2} & R_{O3}

The theory of how Majority Voting works can be seen from its operation under normal conditions, that is with no failures in any channel and all inputs the same, $e_1 = e_2 = e_3$. Associated with the input voltage is an output voltage:

$e_O = \frac{-R_f}{R_n} e_{in}$, which is common to all three

Majority Vote Amplifier outputs. However, all three of the loop gains are not exactly equal. Thus the output voltage will give rise to a feedback voltage, which will satisfy only one of the Amplifiers - the one with the middle loop gain. The highest gain amplifier will have too much feedback for linear operation and will saturate with the polarity of the output voltage. This is due to the fact that the amplifiers have high Loop gains and a very small signal (one or two millivolts) at the summing junction will cause saturation. The lowest gain Amplifier will go towards saturation in the opposite direction and supply or accept the saturation current of the saturated Amplifier.

Sometimes this is done with the help of the Amplifier that stays in its linear operation. That is the middle gain amplifier is helping to meet the demands of the saturated Amplifier as well as drive the load. This can be done because the Majority Vote Feedback Amplifiers have high Open Loop output impedances, even when saturated. Thus the output picture is as follows:



NOTE: CL = CLOSED LOOP
OL = OPEN LOOP

In the Titan III Autopilot Majority Vote Amplifier (See Appendix A, Figure A-6) the Open Loop output impedance is made high by taking the output off of the collectors of Q2 and Q3. The impedance is kept high, even during Amplifier saturation by the zener diodes CR1 and CR2, which never allow Q2 and Q3 to become saturated. Thus the output transistors always remain in their linear region of operation and their collector output impedances are high.

The Titan III Autopilot Majority Vote Amplifier shown is immune to single part failures, when it is being voted. This means that the channel up to the Voting Node is not dependent upon the operation of any one piece part. The graph of Figure A-7 in Appendix A shows the voting operation of three Majority Vote Amplifiers with three different inputs. When there is a great difference between one signal and the other two, the middle signal is chosen. The output will be

$e_o = \frac{-R_f}{R_n} e_{in}$ (middle). This same situation will exist when there is a failure upstream of the Voting Node that causes one Majority Vote Amplifier to go hardover. The middle signal of the remaining two will be the one that determines the output voltage. However, when all three signals are very close together an averaging will take place:

$$e_o = \frac{-R_f}{R_n} \frac{(e_1 + e_2 + e_3)}{3}$$

The amount of dispersion of the input signals before averaging ends is a function of the loop gain. The higher the loop gain, the smaller the region of input signal dispersion will be, when averaging takes place.

1.2.2 Conceptual Design

The conceptual design started by devising different schemes for using Majority Voting in the Autopilot. This consisted of voting at the Servo Amplifier, voting at the DC Amplifier, and a combination of both (see Appendix A).

Several schemes were also considered for modifying the 50 MA Servo Amplifier and the DC Amplifier to allow them to Majority Vote.

From technical meetings with NASA, the most promising schemes for autopilot modification were chosen with the following considerations:

1. Least number of changes to the existing circuitry
2. Emphasis to be placed on Majority Voting the 50 MA Servo Amplifier
3. Other methods to be considered if time permitted

1.2.3 Majority Voting Autopilot Configurations

1.2.3.1 Majority Voting the 50 MA Servo Amplifier

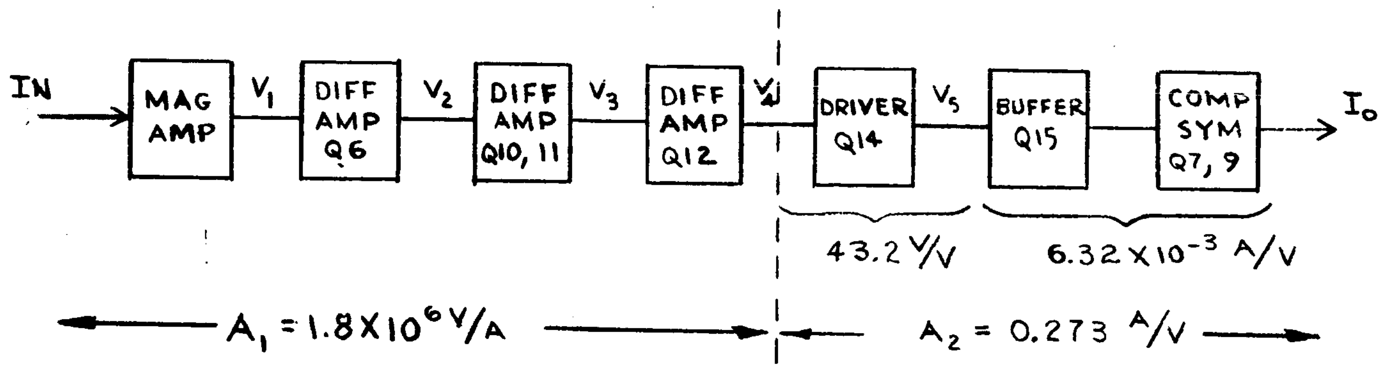
Since the Majority Voting technique, which involves the fewest changes to the existing circuitry is of special interest, this scheme was developed further. (See Figure A-8, Schematic Diagram Majority Vote Servo Amplifier No. 1). The biasing and gain (open loop) were worked out for this case. The open loop gain has been improved by almost an order of magnitude. This would make it possible to do away with the feedback trim pot. If some adjustment was still desired, fixed resistors could be used.

To accomplish this and achieve the design goals, specifically those of high open loop output impedance and Voting Node protection, thirty-three parts will have to be added when compared to voting at the actuator only. When compared to the present redundant configuration (pair and a spare), this scheme would save 76 parts and allow voting at two places - the actuator and the Servo Actuator.

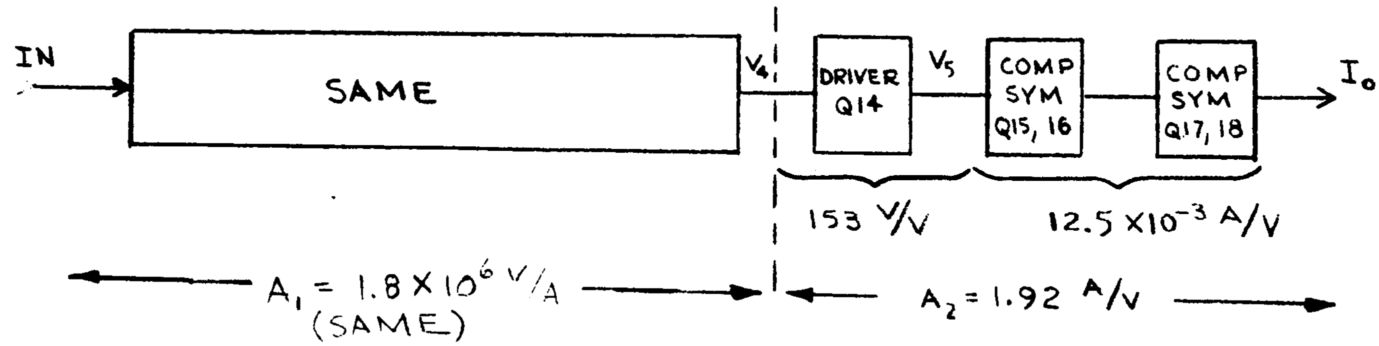
1.2.3.1.1 Biasing - The biasing for the Servo Amplifier remains the same as the present configuration up to Q14. (See Figure A-3, Present Schematic Diagram 50 MA Servo Amplifier). The collector of Q14 will have 0 volts steady state instead of 1.2 volts. The DC levels are recorded on the schematic. (See Figure 5, final form schematic diagram, 50 MA Majority Vote Servo Amplifier)

1.2.3.1.2 Open Loop Gain (Nominal) - Present configuration vs. new configuration:

Present Configuration:



New Configuration:



The open loop gain A_1 remains the same. A_2, however, increases by almost an order of magnitude. The calculation of the new gain for A_2 follows:

$$\frac{V_5}{V_4} = \frac{R_L//(R_{in}\ \text{Comp Sym Q15, 16})}{r_e + \frac{R_B}{B+1}}$$

$$= \frac{20K//65.5K}{100}$$

$$\frac{V_5}{V_4} = 153$$

Letting Q15,16
B = 200

$$\frac{I_0}{V_5} = \frac{V_6}{V_5} \frac{I_0}{V_6}$$

where $\frac{V_6}{V_5} = \frac{R_L}{R_e + r_e + \frac{R_B}{B+1}}$

and $\frac{I_0}{V_6} = \frac{R_L}{R_e + r_e + \frac{R_B}{B+1}} \quad \frac{1}{R_L}$

thus $\frac{I_0}{V_5} = \frac{1.8K//20.5K}{1.22K + 26 + 91} \quad \frac{1}{100 + 2 + 9}$ $\quad B = 200$

$$\frac{I_0}{V_5} = 12.5 \times 10^{-3} \quad A/V$$

The open loop gain (nominal) for the present configuration is $\underline{491 \times 10^3}$ A/A

The closed loop gain expression derived in Appendix A:

$$A_I = \frac{N_c/N_g \quad A_1A_2}{N_f/N_g \quad \frac{R_s}{R_f} \quad A_1A_2 + A_2R_s + 1}$$

which if $\frac{N_f}{N_g} \frac{R_s}{R_f} \quad A_1A_2 >> R_sA_2 + 1$

was approximately

$$A_I \cong \frac{N_c}{N_f} \frac{R_f}{R_s}$$

It is apparent that the approximation is better as the values of A_1 and A_2 become larger. Furthermore, since the closed loop gain is 1.667×10^3 A/A and the new open loop gain is 3450×10^3 A/A, this gives an accuracy of 0.5% from:

$$A_{CL} = \frac{A}{1 + AB}$$

$$= \frac{1}{B} \frac{AB}{1 + AB}$$

Assuming a worst case open loop gain of 1/10 that at nominal or 345×10^3 A/A

$$A_{CL} = 1.667 \times 10^3 \quad \frac{(345 \times 10^3)\left(\frac{1}{1.667 \times 10^3}\right)}{1 + (345 \times 10^3)\left(\frac{1}{1.667 \times 10^3}\right)}$$

$$A_{CL} = 1.667 \times 10^3 \quad \frac{206}{1 + 206}$$

$$A_{CL} = (0.995)\ 1.667 \times 10^3 \text{ A/A}$$

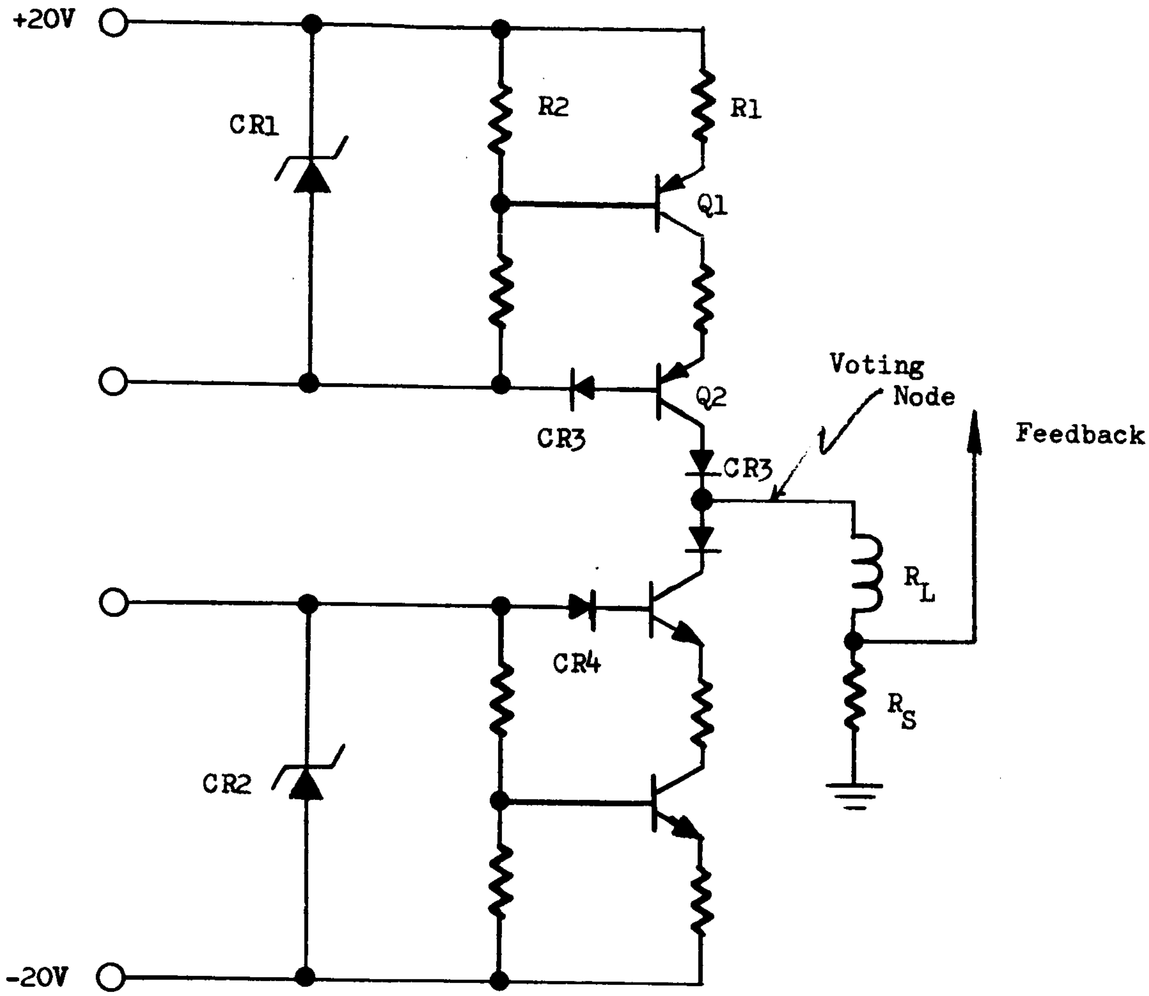
Thus with an accuracy calculated for the Amplifier of 0.5% and an accuracy specification of 2%, it is feasible to eliminate the feedback pot.

1.2.3.1.3 Voting Node Protection, 50 ma Servo Amplifier -

The first scheme for voting node protection presented, Appendix A, took twelve (12) extra parts. (See Figure 7 Voting Node Protection). Another method will now be presented which affords the same protection against single piece part failures, but requires only six extra parts. In Figure 7, Q1 along with R1 and R2 furnished a redundant output transistor which took over the drive if Q2 happened to short out. This prevented the voting node from being loaded excessively. This requirement can be met with a savings of six parts by using two FET's in series with the output. (See Figure 8, Voting Node Protection, Revised). Here the I_{DSS} characteristic of the FET's are used to restrict the load closer to what it would be during normal operation. Thus, for our application I_{DSS} (min) would have to be greater than 50 ma and I_{DSS} (max) kept as low as practical, perhaps 10 to 15 ma above I_{DSS} (min).

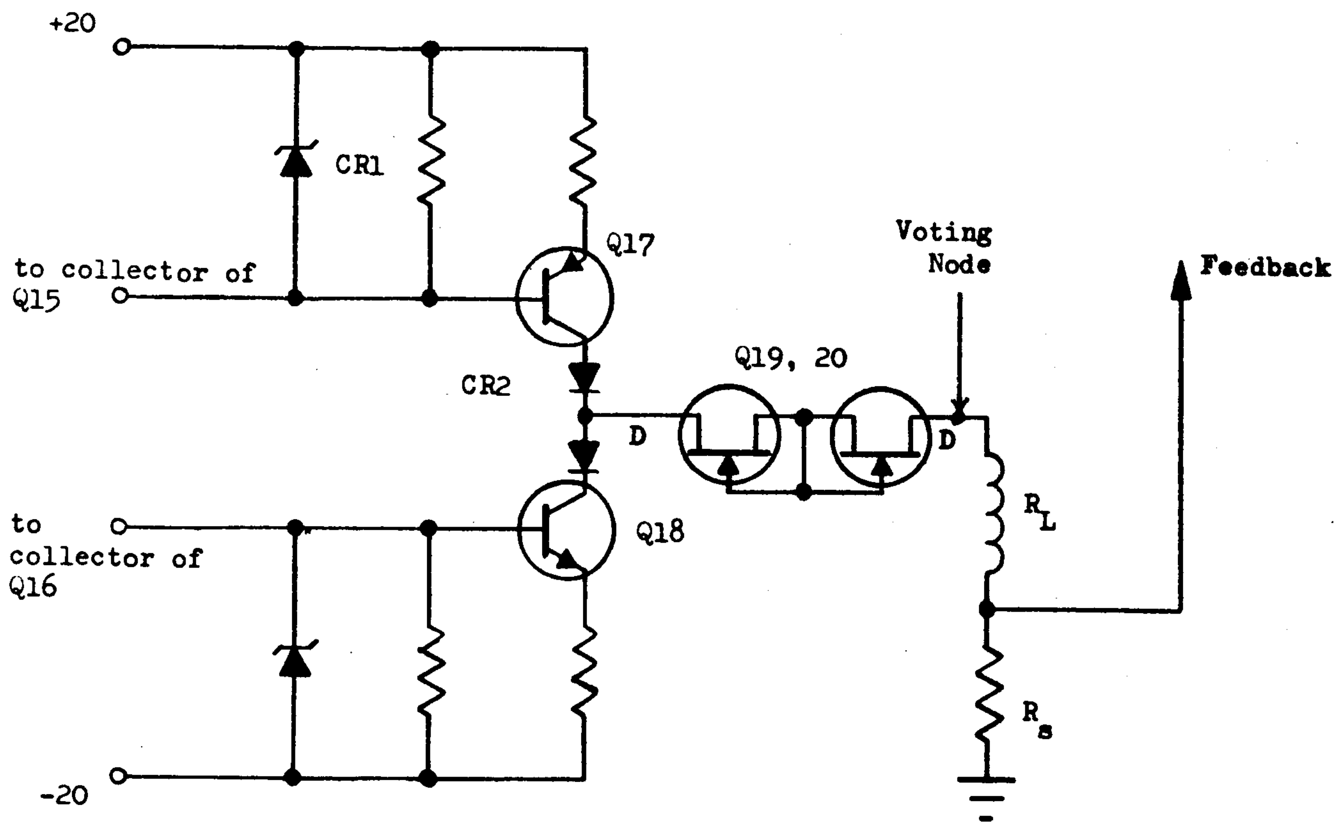
This method also allows us to eliminate CR2 as excessive loading, if Q2 fails (collector to base), is prevented by the FET's.

The final form of the 50 MA Servo Amplifier with saturation and Voting Node protection is shown in Figure 5.



Voting Node Protection

Figure 7

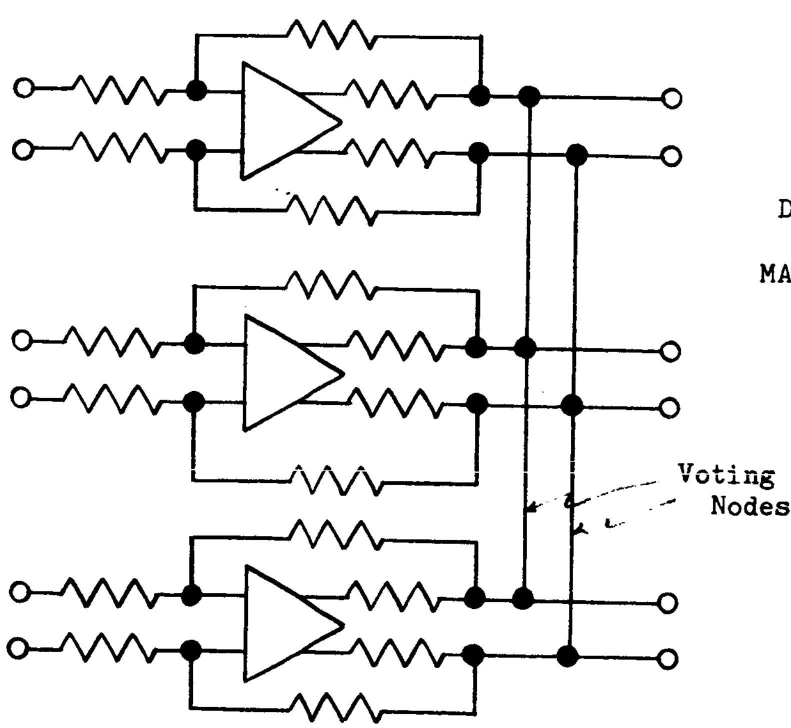


Voting Node Protection, Revised

Figure 8

1.2.3.2 Majority Vote DC Amplifier

Majority Voting the DC Amplifier was given last priority in the study. Majority Voting the DC Amplifier does not have the importance that Majority Voting the Servo Amplifier has. When voting the DC Amplifier, only that unit is protected. (See Figure A-1). This makes it all the more important for the voting mechanization to be as simple as possible, for any advantage to be gained by voting. Added to this consideration was the fact that if the same majority voting technique first used on the Servo Amplifier was used on the DC Amplifier, quite a few parts would have had to be added. (See Appendix A for first method of Voting the Servo Amplifier). This would have amounted to 38 parts per Amplifier or 114 parts added in all. Thus a new method of majority voting was looked for. One method discovered would be very simple - requiring only slight modification to the present DC Amplifier. This involves the addition of two resistors per Amplifier. A resistor would be placed between each Amplifier differential output and the voting node, which is also the point that feedback is taken off. This method would probably not work for the Servo Amplifier because the added resistor would be too large for the desired output current.



DIFFERENTIAL
AMPLIFIERS
MAJORITY VOTING

A thorough investigation of this method was not made due to the lack of time. However, it was felt that there might be problems (such as output stage saturation) so a conservative approach was taken. The Majority Vote DC Amplifier final form uses the same techniques as the Majority Vote Servo Amplifier (see Figure 5). The one exception is the use of resistors before the Voting Node to increase the open loop output impedance, instead of taking the output off collectors. The parts added were not as numerous as first considered necessary, (14 additional parts instead of 38 per amplifier).

The Majority Vote DC Amplifier of Figure 6 was the configuration used in the reliability study.

1.3.0 Reliability Study of Autopilot

1.3.1 Reliability of Existing Autopilot (Case I)

Case I - The probability of failures equation was derived for the existing pair and spare Autopilot from a truth table of failures and successes. The questionable cases were considered failures so the derived equation is conservative. The symbols used in the truth table have the following meanings:

Q = probability of failure (0) of the Autopilot channels exclusive of the comparator circuit. This stands for failure of the drive, reference, or spare channel. Also referred to as the unreliability of the autopilot channels.

Q_c = probability of failure of the comparator curciut (or unreliability).

Also, R, probability of success (1) of autopilot channels = $1-Q$.

And R_C, probability of success (1) of comparator circuit = $1-Q_c$.

The truth table shown in Table II was used in deriving the reliability equations.

TABLE II

PAIR AND SPARE TRUTH TABLE

Drive	Reference	Spare	Comparator	Failures	Terms for Probability of Failure Equation
0	0	0	0	F	$Q^3 Q_C$
0	0	0	1	F	$Q^3 (1-Q_C)$
0	0	1	0	F	$Q^2 Q_C (1-Q)$
0	0	1	1		
0	1	0	0	F	$Q^2 Q_C (1-Q)$
0	1	0	1	F	$Q^2 (1-Q)(1-Q_C)$
0	1	1	0	?(F)	$Q Q_C (1-Q)^2$
0	1	1	1		
1	0	0	0	F	$Q^2 Q_C (1-Q)$
1	0	0	1	F	$Q^2 (1-Q) (1-QC)$
1	0	1	0		
1	0	1	1		
1	1	0	0	?(F)	$Q Q_C (1-Q)^2$
1	1	0	1		
1	1	1	0		
1	1	1	1		

Combining the failure terms from the truth table the probability of failure equation for the pair and spare is:

$$Q_{channel} = Q^3Q_C + Q^3(1 - Q_C) + 3Q^2Q_C(1 - Q) + 2Q^2(1 - Q)(1 - Q_C)$$

$$+ Q\,Q_C(1 - Q)^2$$

$$= 2Q^2 + 2Q\,Q_C - Q^3 - 3Q^2Q_C + Q^3Q_C$$

$$Q_{channel} = 2(Q^2 + Q\,Q_C) - (Q^3 + 3Q^2Q_C) + Q^3Q_C$$

For actual calculations the last term was dropped because of being negligible, giving:

$$Q_{channel} = 2(Q^2 + Q\,Q_C) - (Q^3 + 3Q^2Q_C)$$

This equation is used to determine the reliability for Case I by summing the probabilities of failure for the three phases of flight. The probability of failure for each phase of flight is calculated from failure rates furnished from IBM. Electrical failure rates (λ_e) were multiplied by an environment modifier (K_e) and then multiplied by the time of the phase of flight (T). This gives an unreliability $\lambda_e K_e T$, which is summed with an unreliability for mechanical failures $\lambda_m K_m T$, giving an unreliability for the phase of flight which is $Q \times 10^{-6}$. The same operation is used for calculating Q_C, the comparator circuit probability of failure. The equation for $Q_{channel}$ is then used to determine the probability of failure for the pitch or yaw channel for the existing pair and spare redundancy.

1.3.2 Reliability of Autopilot with Majority Vote Servo Amplifier (Case II)

Case II - The general equation for majority vote probability of failure can be derived from the following truth table of failures and successes. This equation was used for Case II (as well as Case III and Case IV), where the pitch or yaw channel has three identical channels, any two of which need to be good for a success.

TABLE III Truth Table, Majority Vote

Channel 1	Channel 2	Channel 3	Failures	Terms for Probability of Failure Equation
0	0	0	F	Q^3
0	0	1	F	$Q^2(1 - Q)$
0	1	0	F	$Q^2(1 - Q)$
0	1	1		$Q^2(1 - Q)$
1	0	0	F	
1	0	1		
1	1	0		
1	1	1		

Combining the failure terms from the truth table, the probability of failure equation for majority voting is:

$$Q_T = Q^3 + 3Q^2(1 - Q)$$
$$= 3Q^2 - 2Q^3$$

1.3.2 Case II - (Continued)

For Case II (see Figure 3), this equation is used to determine the total channel probability of failure. The channel unreliability Q differs numerically from that used in Case I by the addition of the unreliabilities of the nine parts added to enable the 50 MA Servo Amplifier to majority vote. Otherwise, the Q's are determined in the same way as that used in Case I.

1.3.3 Reliability Analysis of Majority Voting at the Servo Amplifier and D.C. Amplifier (Case III)

Case III - The same basic majority vote equation for probability of failure is used in Case III as in Case II. Case III, however, is voted on twice, at the DC Amplifiers and at the 50 ma Servo Amplifiers (see Figure 4). The total channel unreliability is therefore a summation of the two unreliabilities for the two parts of the channel. The Q for the DC Amplifier has the additional unreliabilities of the fourteen parts added to majority vote that stage (see Figure 6, Schematic of Majority Vote DC Amplifier).

1.3.4 Reliability Analysis of Autopilot with Majority Voting at the 50 ma Servo Amplifier - Alternate Configuration

Case IV - This case is the same as Case II except that the parts count is the same as that for Case I. That is Q for the channel is numerically the same as Case I. The channel probability of failure, however, is determined by the majority vote equation

$$Q_T = 3\,Q^2 - 2\,Q^3$$

This case was calculated primarily for purposes of comparison. It is not unrealistic. Circuits have been proposed (See Appendix A) that could vote the Servo Amplifier with an actual reduction of the parts count over that of the present Amplifier. This though, would entail more changes to the Servo Amplifier than that shown in Figure 5.

1.4 Autopilot Configurations Reliability Results

Table IV shows the reliability and probability of failures for the four cases investigated for the first burn, coast, second burn, and total flight phases of the Saturn S-IVB stage operation. Comparing the different cases to Case I, the existing Autopilot configuration (pair and spare), there is a four per cent decrease in failures by using the Case II scheme of majority voting at the 50 MA Servo Amplifier. By looking at Cases I and IV a better comparison can be made of the reliabilities between the two techniques of redundancy, pair and spare and majority voting.

Case IV uses a 50 MA Servo Amplifier with the same parts count as the one used in Case I. The majority vote system shows a 12 per cent decrease in failures over the pair and spare redundancy.

Case III, which uses majority voting both at the Servo Amplifier and at the DC Amplifiers, has the same Servo Amplifier circuitry as Case I. To vote the DC Amplifier an additional fourteen parts are needed. Along with these parts are the nine added to majority vote the Servo Amplifier. Despite these added parts, Case III showed a 40 per cent decrease in failures over the existing pair and spare redundancy.

TABLE IV - AUTOPILOT RELIABILITY

AUTOPILOT CONFIGURATION	RELIABILITY 1st Burn	Coast	2nd Burn	Total Flight
Case I Existing A/P (Pair and Spare)				
Q	3716.872×10^{-12}	29925.12×10^{-12}	1578.162×10^{-12}	$49607.144 \times 10^{-12}$
R				.9999999504
Case II Majority Vote at 50 MA Servo Amplifier				
Q	3259.112×10^{-12}	$15624.692 \times 10^{-12}$	$28484.846 \times 10^{-12}$	$47368.650 \times 10^{-12}$
R				.9999999526
Case III Majority Vote at Servo Amplifier and at DC Amplifier				
Q	3891.352×10^{-12}	9137.422×10^{-12}	$16530.796 \times 10^{-12}$	$29559.570 \times 10^{-12}$
R				.9999999704
Case IV Majority Vote at 50 MA Servo Amplifier (with same parts count as Amplifier in existing A/P)				
Q	2404.002×10^{-12}	$14809.614 \times 10^{-12}$	$27120.926 \times 10^{-12}$	$44334.542 \times 10^{-12}$
R				.9999999557

2.0 HYDRAULIC SYSTEM FOR THRUST VECTOR CONTROL

In the previous study program (Reference 1) the hydraulic system components and various redundant actuators were analyzed at the piece part level. Equations were derived describing the generic failure rate of each component. These equations were further classified into separate catagories depending on the type of failures and their effect upon various redundancy schemes. The component Generic Failure Rate equations were derived for various phases of the launch vehicle mission including:

Ground check-out
Countdown
Engine Start
Flight

A computer program was developed to perform the necessary computations which determined the weight, cost, and probability of failures during ground check-out, engine start, and flight for the following hydraulic system configurations.

Single System, Standard Actuator
Single System, Majority Vote Actuator
Dual System, Standard Actuator
Dual System, Majority Vote Actuator
Dual System, Tandem Actuator

The computer program performed the above calculations for various ranges of hydraulic system pressures, engine gimballing torques and actuator moment arms. A sample calculation was performed using the hydraulic system design parameters for the Saturn S-IV B thrust vector control system. The results were presented in Reference 1.

In order to arrive at the reliability of the hydraulic thrust vector control system, the approach was to determine the reliability or probability of failure of the previous system configurations for various time phases depending on the system operating mode during the coast or on-orbit phase of the S-IV B operation. This approach required the modification and use of the computer program developed during the previous study.

The computer program of the previous study was written in Fortran II-D language to be used primarily on an IBM 1620, Mark II Computer augmented with an IBM 1311 Disk Storage Drive. Due to the size of the program and the limited storage capacity of the IBM 1620 Computer it was decided to convert the computer program for the GE 1130 Computer using Fortran IV language while incorporating the necessary modifications.

In modifying the computer program, it was necessary to change the reliability equations stored in the computer which were included in reference 1. In the previous study, the conversion of failure rates to probability of failure were accomplished through the following approximation:

$$Q = 1 - R$$
$$Q = 1 - e^{-t/\bar{t}}$$
$$Q = 1 - \frac{t}{\bar{t}} \quad (\text{for } \frac{t}{\bar{t}} < .01)$$
$$Q = 1 - \frac{(GF_R)(K_{OP})(K_F)(K_A)\ t}{10^{-6}}$$

where R = Reliability
Q = The probability of failure
t = Operating time during various mission phases
$\bar{t}$ = Mean-time-to-failure
GF_R = Generic failure rate
K_A = The application factor which takes into account the application of the piece part with respect to the component during component operation.
K_F = The system function modifiers which adjusts the failure rate taking into account the function of the component with respect to the launch vehicle during periods of operation being considered
K_{OP} = The operating mode factor which adjusts the generic failure rate to the various external environmental conditions.

For any hydraulic system thrust vector control operation during the coast phase of the launch vehicle the generic failure rate (GF_R) and the application factor (K_A) do not change from those during powered flight. The remaining problem therefore was to determine the environmental operating mode factor (K_{OP}), the system function modifier K_F, and the time (t) in seconds of the various mission phases where a significant change in external environments occurs. The analysis and values derived for these factors for the Saturn S-IVB Stage operation are discussed in Appendix B of this report.

Using the new values of K_{OP}, K_F, and t, the component reliability equations F and the unreliability equations Q were rewritten and reprogrammed into the computer.

Since the probability of failure is a function of the K_{OP} factor, there is a difference between the two study results of approximately a factor of 4.

Another significant difference is between the probability of failure during ground testing phase of the two study programs. During the conversion of the computer program the G.E. 1130 computer picked up an error in the original computer program equations. The nature of the error was an "undefined variable" in one of the ground test probability of failure equations. It is suspected that the IBM 1620 computer failed to pick up the error and instead picked an arbitrary number for the undefined variable and continued with the computations.

In the previous study program the external leak failure modes of the majority vote servo valves were considered catastrophic in nature, however in actuality the present design of the majority vote actuator ports the servo valve housing cavity and the piston rod leakage to the return portion of the hydraulic system. In the present study program the equations of the majority vote actuator were modified such that the servo valve and piston rod leakage were not considered catastrophic. The result is a significant improvement over the standard actuator than was predicted in the previous study program.

After the checkout of the new computer program was completed, the new environmental factors were programmed into the computer along with the design parameters of the Saturn S-IVB hydraulic system. The results of a sample calculation for the S-IVB Stage hydraulic system is summarized in Table V. This table shows the probability of failures during ground test, countdown, engine start, first burn, coast, and second burn phases of the S-IVB operation in addition to the total probability of failure from first ignition thru the end of the second burn flight phase. The total probability of failure includes the first engine ignition, first burn, coast, second engine ignition and the second burn phases and was determined by the summation of the probability of failures during each phase of flight. It was assumed that the environmental conditions during the second engine ignition were not significantly different from those during first ignition so that the probability of failures during both engine ignitions were considered to be the same.

The results of the S-IVB operation obtained from the previous study program are presented in Table VI in order to compare the results of the two study programs.

In comparing the results of the computer programs for the Saturn S-IVB Stage hydraulic system there is a significant difference between the probability of failures during engine start and first burn calculated in the previous program and those calculated in this program. This difference is attributed to the fact that the K_{OP} factor used in the previous study was 1000 for all hydraulic components which is typical for the Titan III upper stage vehicles whereas the K_{OP} factors derived for this study were as high as 4292

TABLE V - HYDRAULIC SYSTEM PROBABILITY OF FAILURE

	Probability of Failure						
	Ground Test	Count-down	Engine Start	1st Burn	Coast	2nd Burn	Engine Start Thru 2nd Burn
I. Thrust Vector Control System							
A. Single System, Standard Actuator	.197297	.000954	.000882	.000409	.000035	.001219	.003427
B. Single System, Majority Vote Actuator	.265873	.001068	.000622	.000235	.000022	.000699	.002200
C. Dual System, Standard Actuator	.241189	.004348	.000672	.000353	.000028	.001052	.002777
D. Dual System, Majority Vote Actuator	.306016	.004461	.000412	.000179	.000015	.000533	.001551
E. Dual System, Tandem Actuator	.314660	.005747	.000047	.000012	.000002	.000034	.000142
II. Actuator							
A. Standard	.068930	.000064	.000334	.000176	.000013	.000525	.001382
B. Majority Vote	.10959	.000121	.000204	.000089	.000007	.000265	.000769
C. Tandem	.115781	.001413	.000021	.000005	.0000004	.000016	.000063

TABLE VI - REDUNDANCY COMPARISON FOR SATURN S-IVB PARAMETERS (PREVIOUS STUDY)

	Weight (lbs)	System Cost (20 Vehicle Dollars)	Probabilities of Failure			
			Ground	Countdown	Engine Start	Flight
I. System						
A. Single System, Standard Actuator	230.5	8,931,195	.326546	.00095	.000200	.000115
B. Single System, Majority Vote Actuator	235.1	9,273,478	.383874	.00106	.000181	.000095
C. Dual System, Standard Actuator	300.2	9,635,129	.363448	.00434	.000143	.000094
D. Dual System, Majority Vote Actuator	304.8	9,976,865	.417610	.00445	.000124	.000074
E. Dual System, Tandem Actuator	368.4	10,367,720	.428380	.00574	.000005	.000001
II. Actuator						
A. Standard	42.31	---	.06619	.0000622	.0000693	.000046
B. Majority Vote	44.62	---	.10680	.0001190	.0000599	.000036
C. Tandem	70.40	---	.11573	.0014119	.0000049	.000001

On April 20, 1967, a meeting was held at the George C. Marshall Space Flight Center National Aeronautics and Space Administration, Huntsville, Alabama, between Martin and NASA personnel to review the program schedule and the technical performance of the study program to date. At this time the Martin Marietta Corporation was asked to investigate the possibility of including the following additional effort in the study:

a. Determine the reliability of the Saturn S-IV Stage hydraulic system utilizing a single hydraulic system and majority vote actuators with the existing engine driven pump and the motor pump operating in parallel during the first and second burn phase of flight. The reliability of this system would then be compared with hydraulic system configurations already investigated.

b. Determine the reliability of hydraulic systems already under investigation for the S-IVB operation using a system pressure of 2500 psi and the same actuator piston area.

The reason for this request is that there is a strong possibility that the Saturn S-IVB Stage hydraulic system will use the three torque motor majority vote actuators in place of the present Standard actuators. Consideration is also being given to operating the existing engine driven pump and the motor pump in parallel during all powered phases of the S-IVB Stage operation as an added improvement in reliability. Use of the three torque motor majority vote actuators will result in an increase in system internal leakage since three valve first stages per actuator are required instead of only one for the present actuators. In order to compensate for this, consideration is being given to lower the system pressure from 3650 psi to 2500 psi.

The technical approach to accomplish the additional effort was to rerun the computer program and change the input data cards such that the operating pressure is 2500 psi. Since the actuator moment arm and piston area are to remain the same it will be necessary to reduce the engine torque proportionally with the reduction of system operating pressure. Under this approach the results of the computer program is conservative since the computer program was derived assuming that the hydraulic system components are designed for the particular operating pressures derived. In the case of the proposed change in the hydraulic system the existing components which were designed for an operating pressure of 3650 psi would be operated at 2500 psi which, from a reliability standpoint, is an improvement since the components would be operated at a much lower stress level than originally designed. The computer program output does not reflect the reliability improvement resulting from lower stress levels. However, for purposes of comparative evaluation, it is believed that the existing computer program is adequate.

In order to evaluate the effects on system reliability of reducing the hydraulic system pressure from 3500 to 2500 psi and operating the motor pump and engine driven pump in parallel, a comparison was made of the following hydraulic system configurations.

1. Existing Saturn S-IVB stage hydraulic system operating at 3500 psi with the primary hydraulic power derived from the engine driven pump.

2. Existing Saturn S-IVB stage hydraulic system operating at 3500 psi with the engine driven pump and motor pump operating in parallel.

In order to accomplish this investigation the computer program was modified to take into account the motor pump and engine pump operating in parallel. In the third configuration the engine torque input data to the computer program was reduced proportionally to the reduction of system pressure such that the actuator piston area and system flow would be the same as in the other two configurations.

Table VII shows the reliability and probability of failures of the three hydraulic system configurations investigated. It should be noted that the reliability and probability of failures for the configuration in which the system pressure was reduced to 2500 psi is conservative since the computer program results are for a system which was specifically designed of a 2500 psi system. In case of the Saturn S-IVB proposed change the hydraulic system was specifically designed for 3500 psi operation and would operate at 2500 psi. The results shown in this case does not show the reliability improvement as a result of operating at a lower stress level than the designed level.

TABLE VII - HYDRAULIC SYSTEM RELIABILITY

HYDRAULIC SYSTEM CONFIGURATION	Probability of Failure						Flight Reliability
	Ground	Countdown	Engine Start	1st Burn	Coast	2nd Burn	
Single System-Standard Actuator							
A. 3500 psi - Single Pump	.198004	.000955	.000882	.000409	.000035	.001219	.003427 .996573
B. 3500 psi - Dual Pump	.198004	.000955	.000759	.000378	.000033	.001127	.003056 .996944
C. 2500 psi - Dual Pump	.190693	.000841	.000734	.000372	.000032	.001106	.002978 .997022

IV. CONCLUSIONS

Based on the analysis and results of this study, it was concluded that:

1. The probability of failure of the existing S-IVB autopilot could be reduced by 44% by modifications which would allow majority voting of the three existing channels at the output of the D.C. amplifier and the 50 ma servo amplifier.

2. The probability of failure of the existing autopilot and hydraulic system could be reduced by 49% by replacing the existing actuators with Majority Voting actuators, and operating the hydraulic system at 2500 psi with the motor pump and engine driven pump in parallel operation. This reliability improvement is essentially independent of the autopilot configuration investigated.

3. When considering the reliability of the combined autopilot and hydraulic system the contribution of the autopilot improvement is not apparent due to the large difference in the reliability of the two basic sub-systems.

4. The autopilot configuration, which would cause the least impact and cost to the total system, is the one which deletes the comparator and switch circuits of the existing autopilot and connecting the three autopilot output pitch and yaw channels to the three servo valves of the Majority Voting actuator.

5. The weight and cost of the hydraulic system did not change as a result of the expansion of the scope of work in this study; therefore, the weight and cost figures of the previous study are still applicable.

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APPENDIX A

Autopilot Electronics Analysis

Autopilot Electronics Analysis

1.0 ANALYSIS OF EXISTING SATURN S-IVB AUTOPILOT

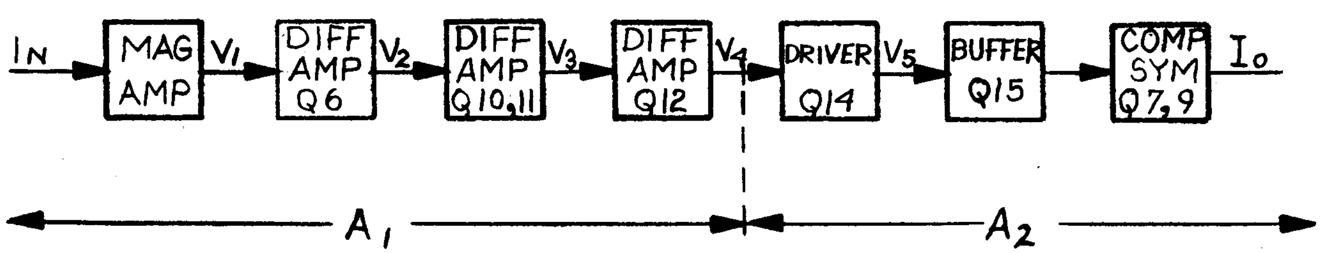
The examination part of the study was to become aware of features peculiar to the system as well as detailed analyses of circuitry. Some of the more salient features of the channels studied are: 1) The use of Balanced Differential input lines for rate and attitude signals from the A/P inputs through half of the 50 MA Servo Amplifiers. This takes the attitude signals on Balanced Lines through the DC Amplifiers, the Filters and into the Servo Amplifier. The rate signals come into the A/P on Balanced Lines and go through filters where the attenuation is changed in the second S-IV B burn mode (Sequence S-IV B: First Burn Mode, Coast Mode, Second Burn Mode). 2) The use of separate power supplies in each Amplifier to achieve the desired isolation and reliability. The power supplies have ± 28 VDC inputs for the Servo Amplifier and a + 28 VDC input for the DC Amplifier. The DC supplies consist of inverters, rectifiers, and regulators. The output voltages are ± 20 VDC for the transistor circuits of the Servo Amplifier and 60 VDC for the DC Amplifier. A square wave voltage of 1 K HZ is supplied for the Magnetic Amplifier in the Servo Amplifier. 3) The use of Push-Pull, Full Wave Magnetic Amplifiers for isolation of the many inputs for low drift, and most important, for differential summing. 4) The use of sensor redundancy - "Pair and a Spare" - at the channel output. A Servo Amplifier, which drives the actuator, is compared to another Servo Amplifier. If a malfunction occurs in the two Amplifiers being compared, a third Amplifier is switched into the channel to drive the actuator. 5) The use of quad redundant relays at the critical point in the front end of the channel, before it is broken out into three redundant paths.

Figure A-1 shows the block diagram of that part of the Apollo Autopilot which the study covers, which is the S-IV B Gimballed Engine Actuator channels.

1.1 50 MA Servo Amplifier - The 50 MA Servo Amplifier is used to drive the Gimballed Engine Actuators. It has a balanced differential input and a single ended output, which is voted on in the comparator circuit ("pair and a spare"). The Servo Amplifier features magnetic summing of attitude and rate signals into a push-pull magnetic amplifier front end. The rest of the amplifier is made up of differential transistors and driver stages. Each Servo Amplifier has its own power supply, furnishing 1 K HZ to the magnetic amplifier gate windings and ± 20 V to the transistors. (See Block Diagram, Figure A-2)

1.1.1 DC Analysis - The DC Analysis was accomplished by starting with Q12, since the base on the right is approximately 0 V. This establishes the DC volts on the base of Q8 as approximately 0 V and determines the collector currents of Q6A and Q6B. (See Schematic, Figure A-3)

1.1.2 AC Analysis - The forward loop gain, I_o/I_{in} will be determined by solving for the gains (nominal) for the following stages:



BLOCK DIAGRAM OF S-IV-B GIMBALLED ENGINE ACTUATOR CHANNELS

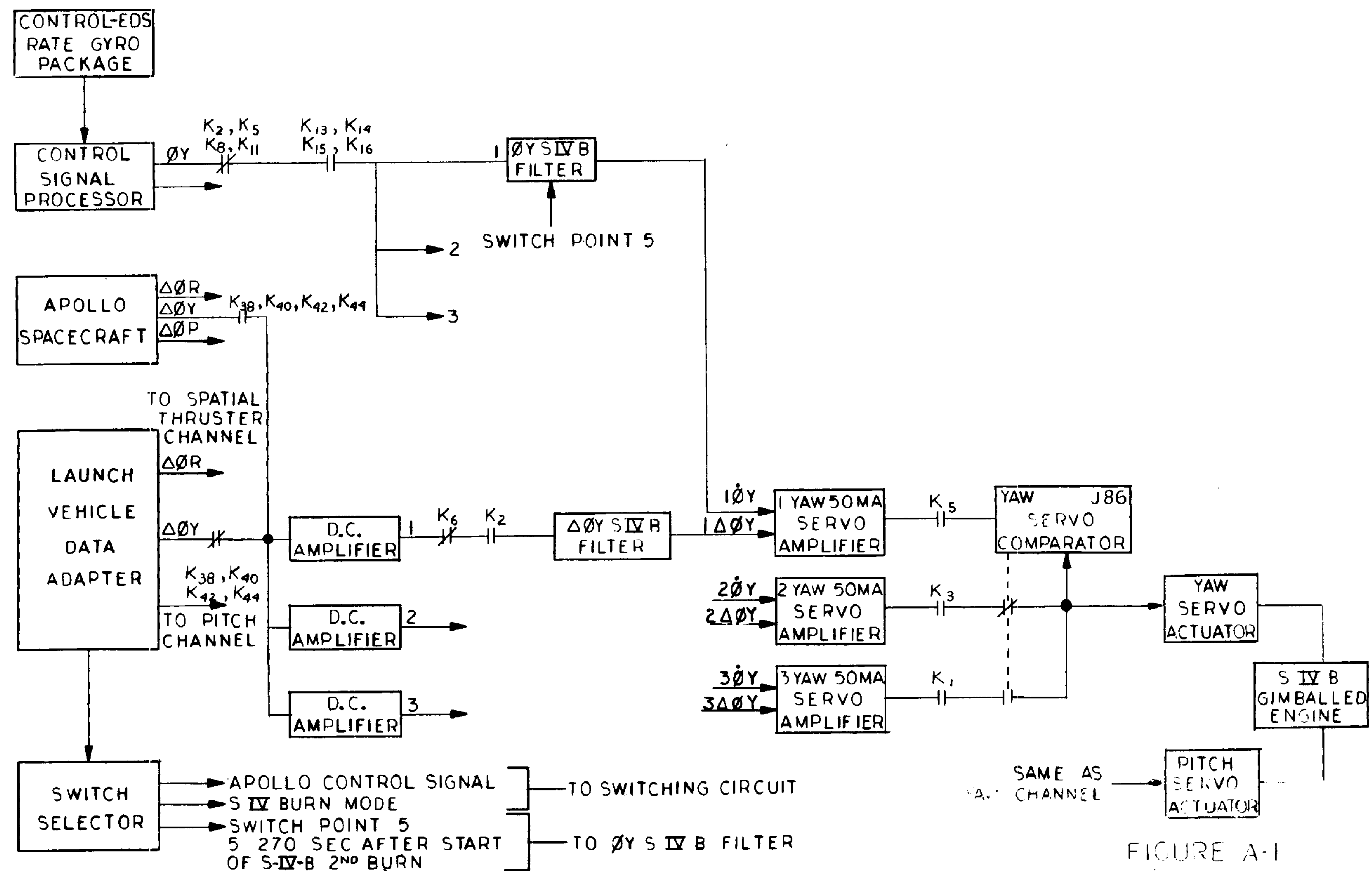
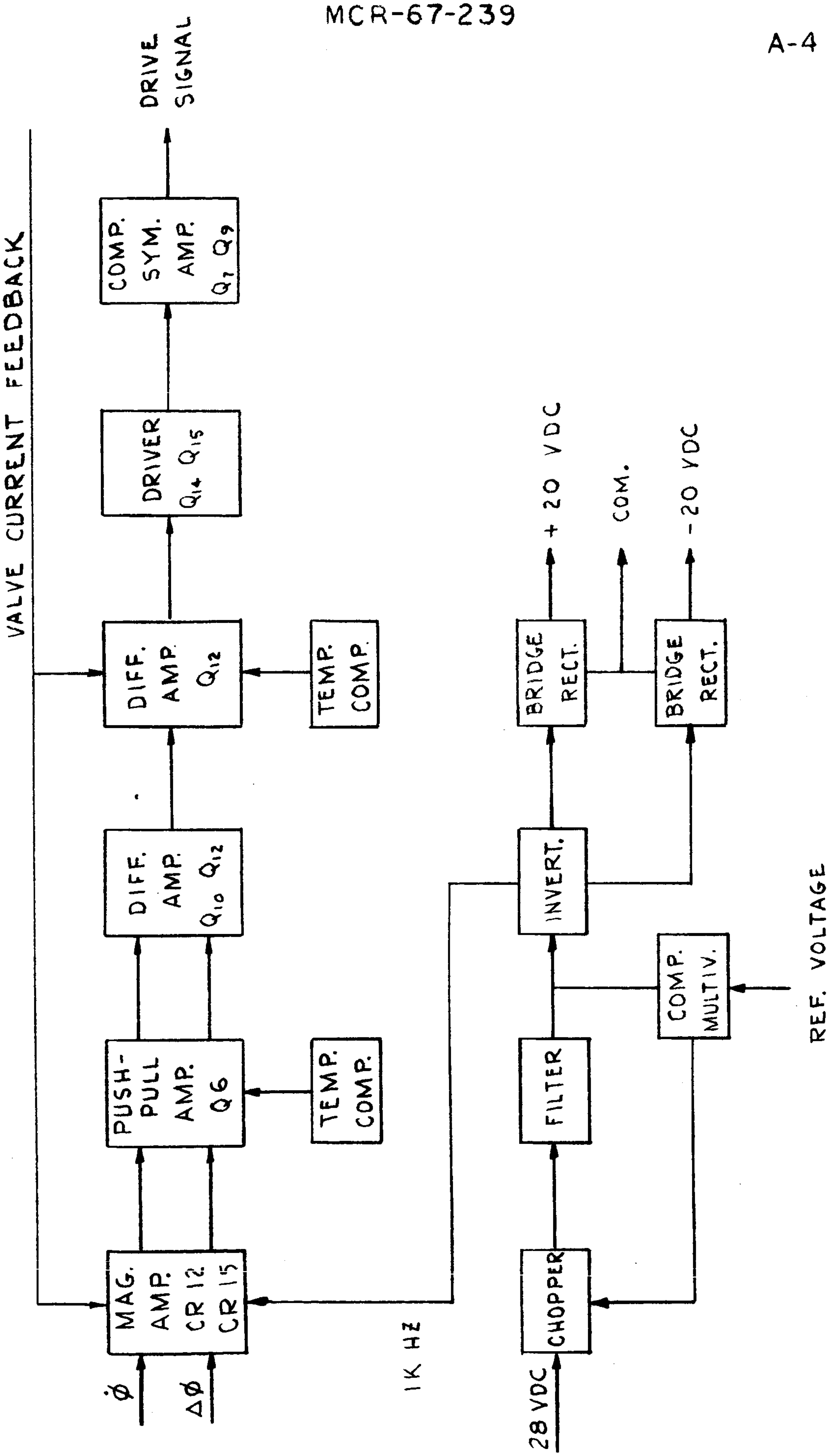


FIGURE A-1



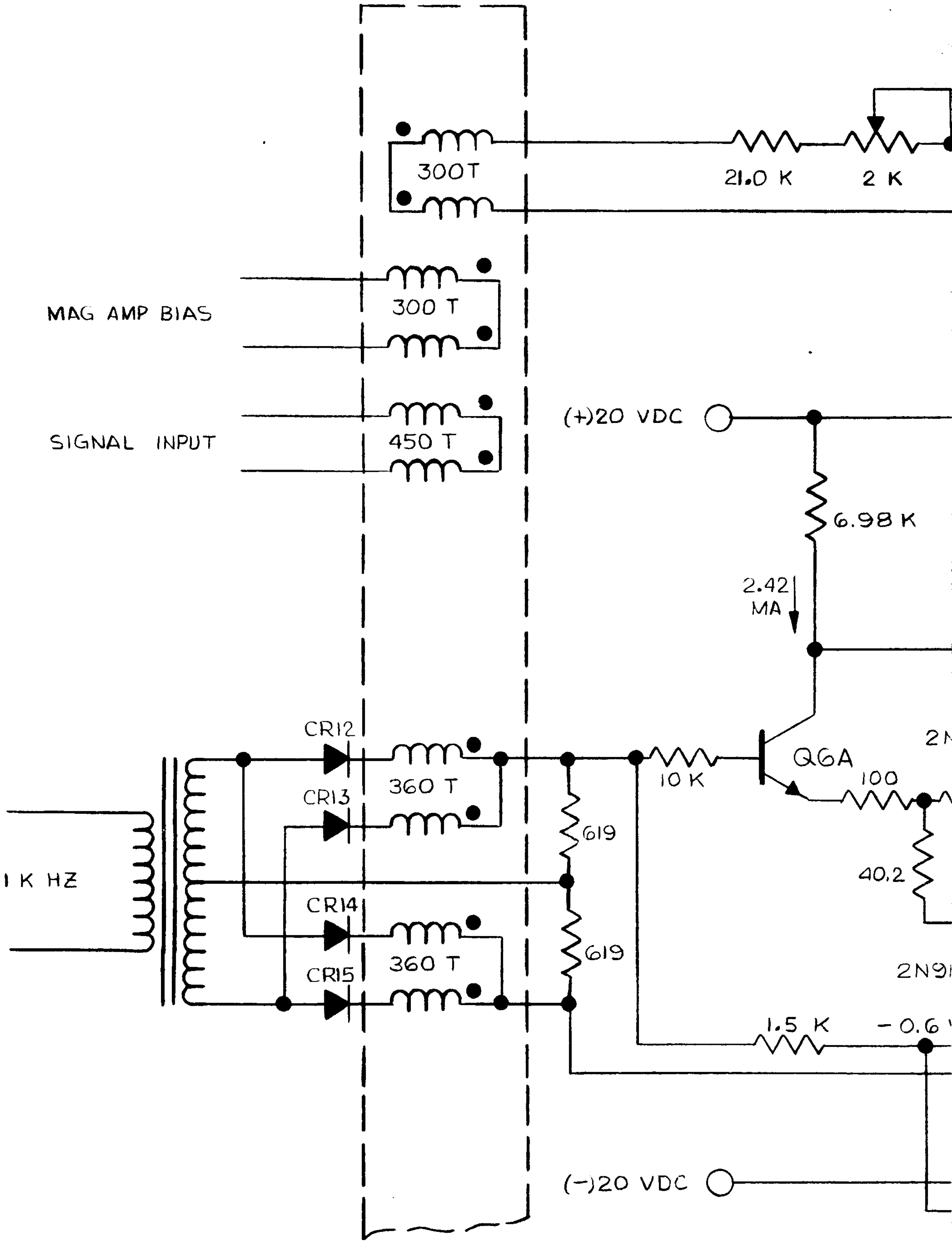
BLOCK DIAGRAM - 50 MA. SERVO AMPLIFIER

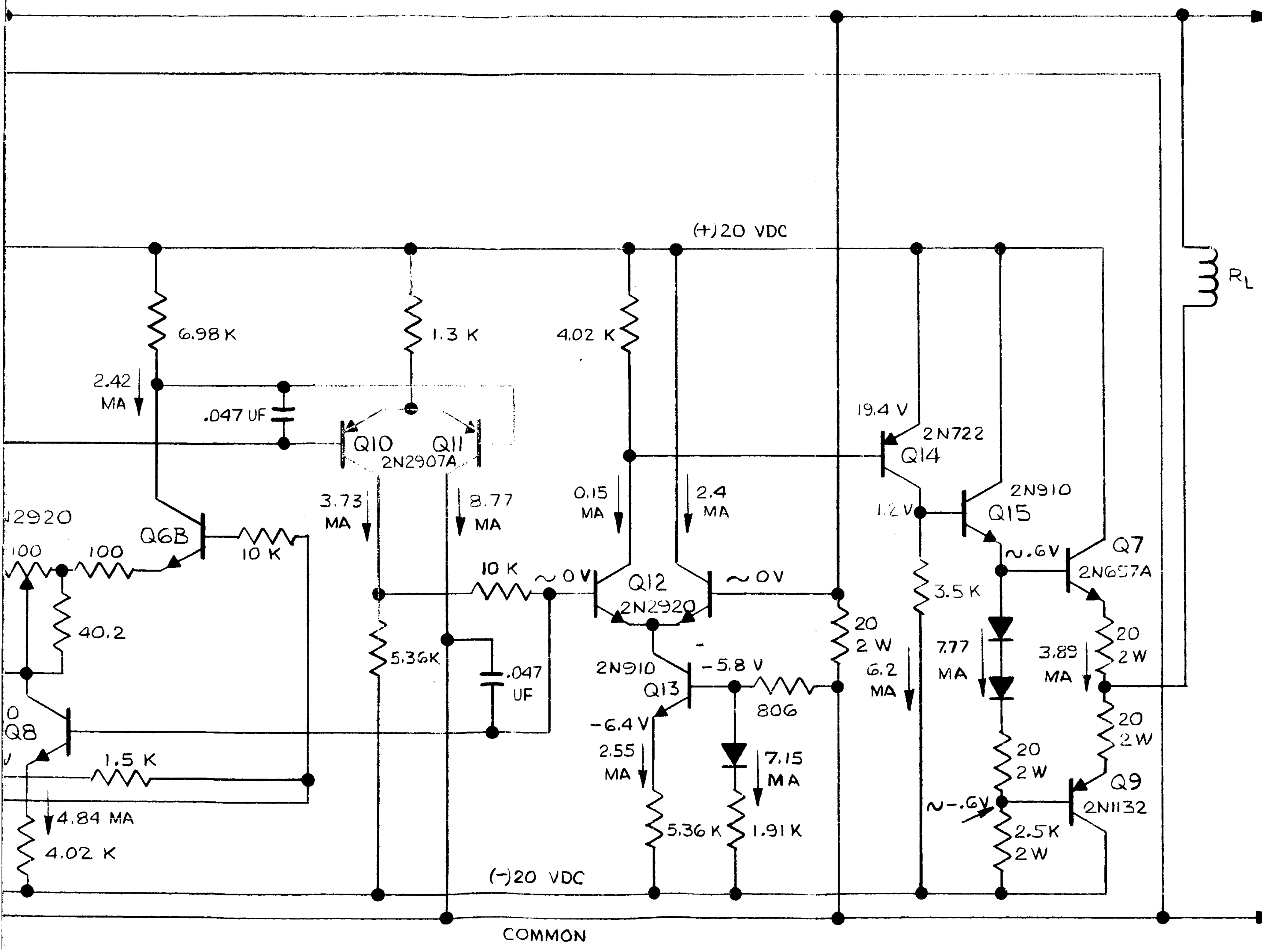
FIGURE A-2

50 MA SERVO AMPLIFIER

Input Power	22 to 32 Vdc, 2.9 watts maximum (28 volts nominal)
Electrical Characteristics:	
Input Signal	
$\dot{\phi}$ Y or $\dot{\phi}$ P	33.6 or 48.4 Vdc, positive or negative
$\Delta\dot{\phi}$ Y or $\Delta\dot{\phi}$ P	7.4 Vdc, positive and negative
Current Gain	1.1 milliamperes per turn ($\pm$2%)
Input Current	Not more than 0 $\pm$ 30 microamperes into 450 turns per stack for full output signal
Output Impedance	Greater than 40,000 ohms from 0 to 20 Hz
Output Current	A full output swing between 0 and 50 milliamperes, positive and negative, as developed across a 100-ohm valve load
Dynamic Response	The 3 db down frequency is 55 ($\pm$5) Hz
Null Offset	With no input signal applied, null offset is less than 0 $\pm$ 20 mV referred to input
Source Impedance	Not less than 20,000 ohms and isolated by at least 150,000 ohms from the 28 Vdc supply voltage

FOLDOUT FRAME 1





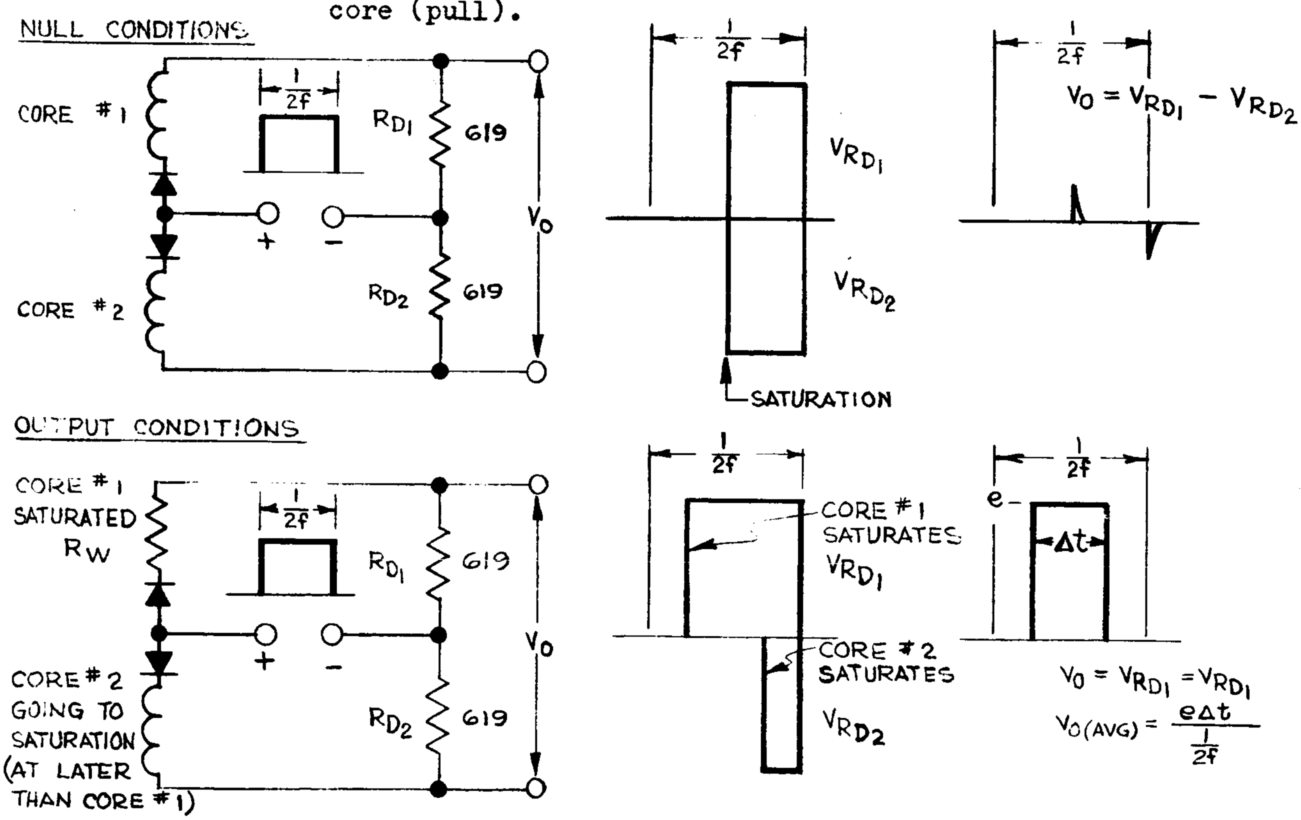
NOTE:

1. RESISTANCE VALUES IN OHMS UNLESS NOTED OTHERWISE

SCHEMATIC DIAGRAM — 50 MA. SERVO AMPLIFIER

FIGURE A-3

1.1.2.1 Magnetic Amplifier Open Loop Gain - The Magnetic Amplifier is used in the front end of the 50 ma Servo Amplifier (see schematic, Figure A-3). It is of the full-wave, push-pull variety which has good drift characteristics with variations in temperature and supply voltage. The supply voltage is 1K Hz Square Wave . The cores are biased to saturate (fire) at approximately 90°. With no signal in , the two cores saturate at the same time and the resulting output voltage across each dummy resistor (619Ω) is of the same magnitude, but of opposite polarity. Thus there is no output. When there is an input signal, one core is aided by the flux due to the input and will saturate earlier. The other core is opposed by the flux due to the input and will saturate later. The sum total of the outputs across the dummy resistors will now be a voltage pulse of the polarity corresponding to the core which saturated first. The change from null was brought about by an earlier saturation of a core (push) and a later saturation of an opposing core (pull).



1.1.2.1.1 Derivation of Open Loop Gain:

The transfer function for the Magnetic Amplifier will be derived for a change of average voltage out for a change of average current in

$$G = \frac{\Delta V_o \text{ avg}}{\Delta I_C \text{ avg}}$$

The change of voltage out can be expressed in terms of a change of flux in the core

$$\int e\,dt = N_{gate} \Delta \phi$$

$$\text{or } e \Delta t = N_g \Delta \phi_g$$

$$V_{avg} = \frac{e \Delta t}{1/2\ f}$$

The change of flux can also be expressed in terms of a change of mmf

$$\Delta \phi_g = K\, N_g \Delta I_g$$

$$= K\, N_g \frac{N_c}{N_g} \Delta I_c$$

$$\frac{\Delta \phi_g}{N_c \Delta I_c} = K$$

$$\frac{e \Delta t}{N_g N_c \Delta I_c} = K$$

$$e \Delta t = K\, N_g N_c\, \Delta I_c$$

$$V_{avg} = \frac{e \Delta t}{1/2\ f} = N_c K\ 2f N_g\ \Delta I_c$$

Thus $G = \frac{\Delta V_{avg}}{\Delta I_{C_{avg}}} = N_c K \, 2fN_g$

1.1.2.1.2 Calculation of the Open Loop Gain:

The cores used in the 50 ma Servo Amplifier are Magnetic Metals 47A8702. The core gain K, since it is push-pull, is twice that for the single ended case derived above.

$$K = \frac{2\Delta\varphi}{N_c A I_c} = \frac{2\Delta B}{\Delta H} \frac{A}{l}$$

$\frac{\Delta B}{\Delta H}$ can be obtained from the Constant Current Flux Reset Data (CCFR) and is:

$$\frac{\Delta B}{\Delta H} = \frac{\Delta B_2 - \Delta B_1}{\Delta H_2 - \Delta H_1} = \frac{1/3 \, B_{max}}{\Delta H_2 - \Delta H_1}$$

$$\frac{\Delta B}{\Delta H} = \frac{8100}{(3)0.0095} \frac{\text{Gauss}}{\text{Oersteds}} \text{ nominally}$$

$$K = \left(\frac{(2)(8100)}{(3)(0.0095)} \frac{\text{Gauss}}{\text{Oersteds}}\right)\left(\frac{10^{-6}}{79.6} \frac{\text{Webers/CM}^2}{\text{Ampere-Turns/CM}}\right)\left(\frac{0.0428}{4.49} \frac{\text{CM}^2}{\text{CM}}\right)$$

$$= 6.82 \times 10^{-5} \frac{\text{Webers}}{\text{Ampere-Turn}}$$

And the Transfer Function is

$$\frac{\Delta V_o}{\Delta I_c} = N_c \, K2f \, N_g$$

$$= (450)(6.82 \times 10^{-5})(2 \times 10^3)(360)$$

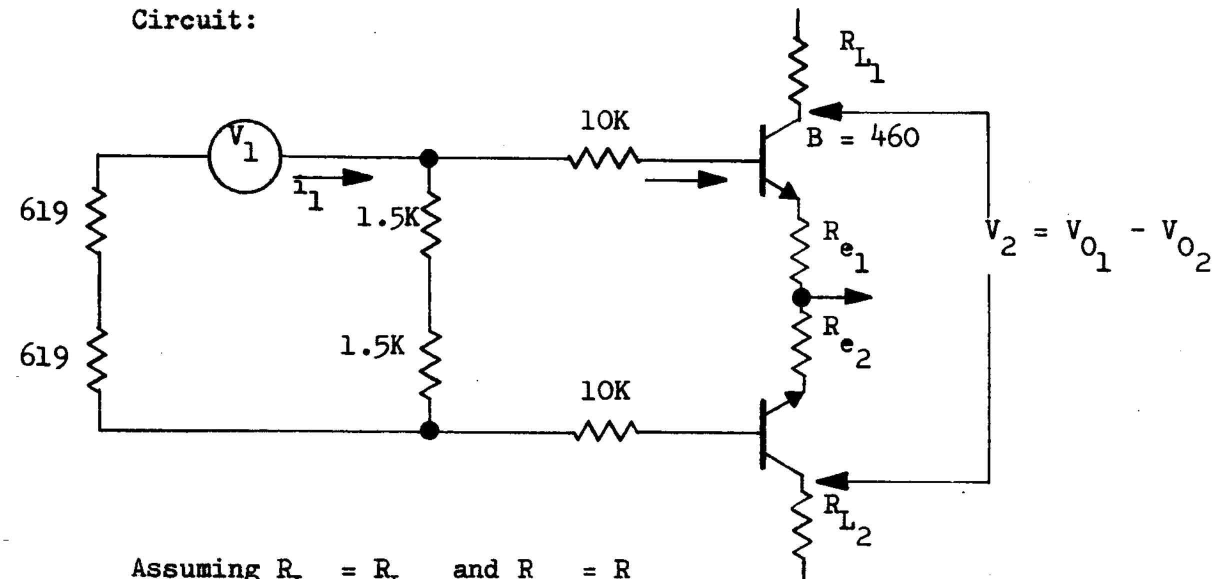
$$\frac{\Delta V_o}{\Delta I_c} = 22.1 \times 10^3 \frac{\text{Volts}}{\text{Ampere}}$$

1.1.2.1.3 Magnetic Amplifier - There is some disagreement with the NASA approach in determining the open loop gain V_{in}/I_{in}. For the time being the NASA Value will be used. (It is the smaller)

$$\frac{V_{in}}{I_{in}} = 1645 \quad \frac{\text{Volts}}{\text{Amp}}$$

1.1.2.2 Gain (V_2/V_1) of Differential Stage Q6 - Equivalent Input

Circuit:



Assuming $R_{L_1} = R_{L_2}$ and $R_{e_1} = R_{e_2}$

$$V_2 = Bi_b 2R_1$$

$$i_b = i_1 \frac{3K}{3K + 20K + 2(h_{ie} + R_e)}$$

$$= i_1 \frac{3K}{3K + 20K + 2\,(11.4K + 460(245))}$$

$$i_b = \frac{3}{290}\, i_1$$

$$i_1 = \frac{V_1}{(1.24K + 3K) \,//\, (20K + 2\,(11.4K + 460(245))}$$

$$i_1 = \frac{V_1}{4.01K}$$

$$\frac{V_2}{V_1} = (460)\left(\frac{3}{290}\right)\left(\frac{1}{4.01K}\right)(2)\,(4.03K)$$

$$= 9.03$$

1.1.2.3 Gain V_3/V_2) of Differential Stage Q10, Q11

$$\frac{V_3}{V_2} = \frac{R_L \,//\, 10K + (hie(Q12) + BR_E) \,//\, (hie(Q8) + BR_E)}{r_{e_1} + r_{e_2} + \frac{2R_B}{B + 1}}$$

$$= \frac{5.02K}{79.8}$$

$$\frac{V_3}{V_2} = 63.2$$

1.1.2.4 Gain V_4/V_3) of Differential Stage Q12

$$\frac{V_4}{V_3} = \frac{R_L \,//\, hie\ (Q14)}{r_{e_1} + r_{e_2} + \frac{R_B}{B + 1}}$$

$$= \frac{429}{224}$$

$$\frac{V_4}{V_3} = 1.91$$

1.1.2.5 Gain V_5/V_4) of Driver Stage Q14

$$\frac{V_5}{V_4} = \frac{R_L \,//\, (hie(Q15) + BR_E)}{r_e + \frac{R_B}{B + 1}}$$

$$= \frac{3.40K}{78.7}$$

$$\frac{V_5}{V_4} = 43.2$$

1.1.2.6 Gain I_O/V_5) of Q15, Q7, and Q9

$$\frac{I_O}{V_5} = \frac{V_6}{V_5} \frac{V_7}{V_6} \frac{1}{R_L}$$

where $$\frac{V_6}{V_5} = \frac{R_L}{R_L + R_E + \frac{R_B}{B + 1}}$$

and $\frac{V_O}{V_6}$ the output transfer function has a similar formula

then $$\frac{I_O}{V_5} = \frac{1.99}{2.03} \frac{140}{155} \frac{1}{140}$$

$$= 6.32 \times 10^{-3}$$

1.1.2.7 The forward loop gain (I_O/I_N) for the nominal case:

$$\frac{I_O}{I_N} = A_1 A_2$$

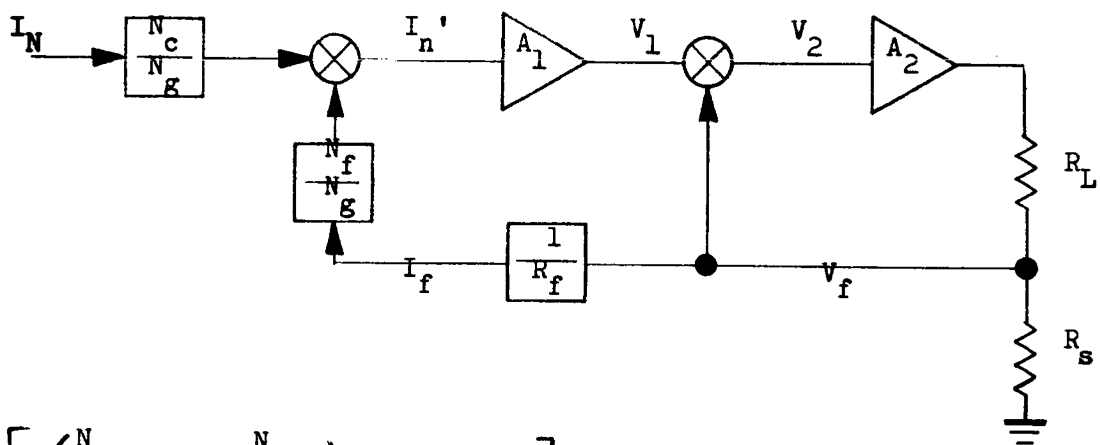
$$= \frac{V_4}{I_N} \frac{I_O}{V_4}$$

$$\Big((1654)(9.03)(63.2)(1.91)\Big) \Big((43.2)(6.32) \times 10^{-3}\Big)$$

$$= \Big(1.8 \times 10^6\Big) \Big(0.273\Big)$$

$$\frac{I_O}{I_N} = 491 \times 10^3$$

1.1.3 Transfer Function of Servo Amplifier ($A_I = I_O/I_N$)



$$\left[\left(\frac{N_c}{N_g} I_N - \frac{N_f}{N_g} I_f\right) A_1 - V_f\right] A_2 = I_O$$

$$\left[\left(\frac{N_c}{N_g} I_N - \frac{N_f}{N_g} I_O \frac{R_S}{R_f}\right) A_1 - I_O R_S\right] A_2 = I_O \qquad I_f = I_O \frac{R_S}{R_f}$$

$$V_f = I_O R_s$$

$$\frac{N_c}{N_g} A_1 A_2 I_N - \frac{N_f}{N_g} \frac{R_S}{R_f} A_1 A_2 I_O - R_S A_2 I_O = I_O$$

$$I_O\left(\frac{N_f}{N_g} \frac{R_S}{R_f} A_1 A_2 + R_S A_2 + 1\right) = \frac{N_c}{N_g} A_1 A_2 I_N$$

$$\frac{I_O}{I_N} = \frac{N_c/N_g \quad A_1 A_2}{N_f/N_g \; \frac{R_S}{R_f} \; A_1 A_2 + A_2 R_S + 1}$$

$$A_I = \frac{I_O}{I_N} \cong \frac{N_C}{N_f} \frac{R_f}{R_S} \qquad \text{if } \frac{N_f}{N_g} \frac{R_S}{R_f} A_1 A_2 >> R_S A_2 + 1$$

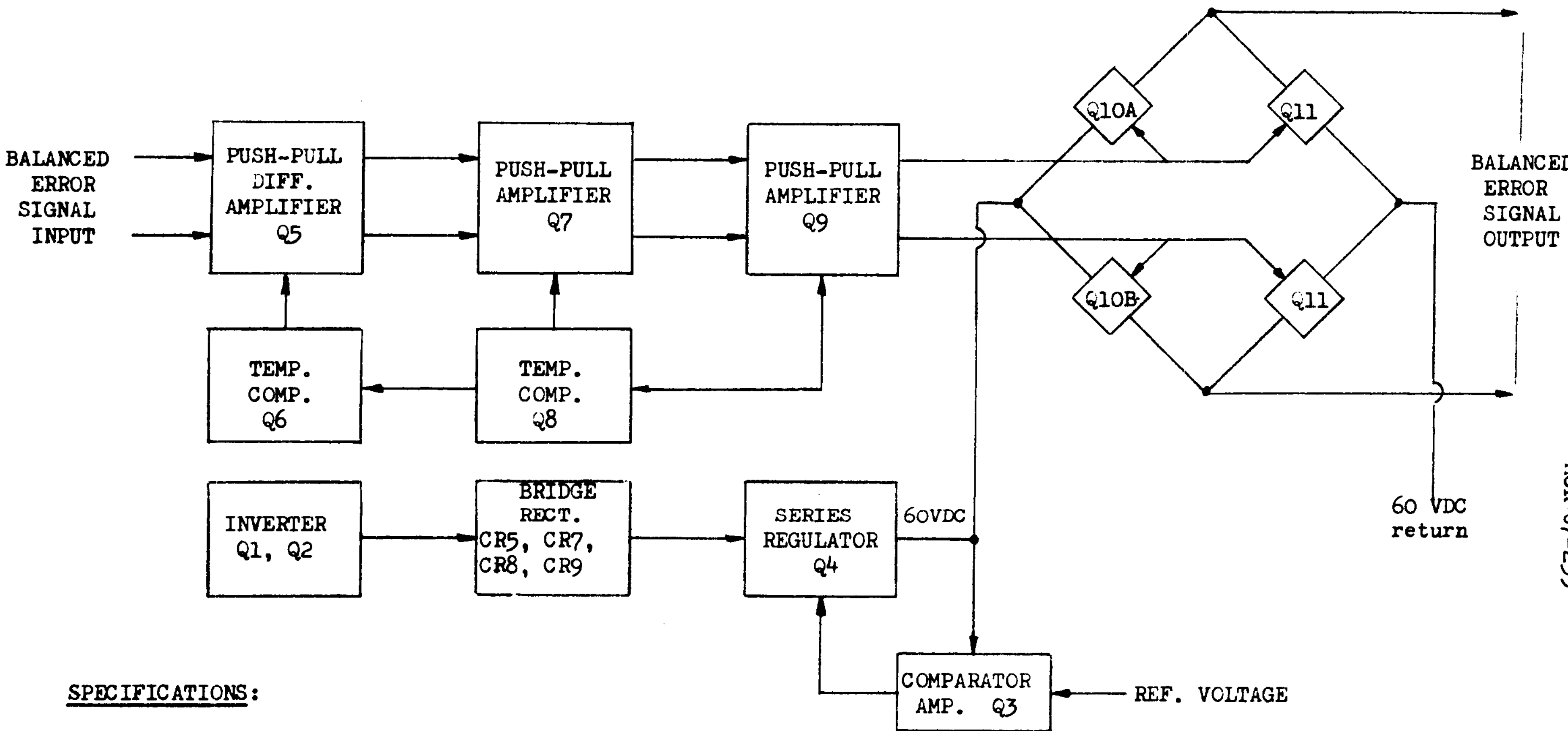
Using the approximation with the range of feedback resistance of 21K + 0 to 2K, the gain range is:

$$A_1 = \frac{450}{300} \; \frac{21K \text{ to } 23K}{20} = 1.575 \times 10^3 \text{ to } 1.725 \times 10^3$$

This agrees with the spec which requires 50 MA out for 30 μa into the 450 turns. That is:

$$\frac{I_0}{I_N} = \frac{50 \times 10^{-3}}{30 \times 10^{-6}} = 1.667 \times 10^3$$

1.2 DC Amplifier - The DC Amplifier is used in the front end of the Gimballed Engine Actuator Channels to amplify the Pitch and Yaw Attitude Error Signals (See Figure A-1). The attitude signals are carried on isolated balanced lines (double ended) both into and out of the Amplifier. Each Amplifier has its own power supply with ± 28 VDC inputs and a 60 VDC output for the Amplifier Circuits, which are all transistors. Feedback and input resistors are used to set the voltage gain at a predetermined value from 0.5 to 25.0 (See Figure A-4 for open loop block diagram and Figure A-5 for the schematic).



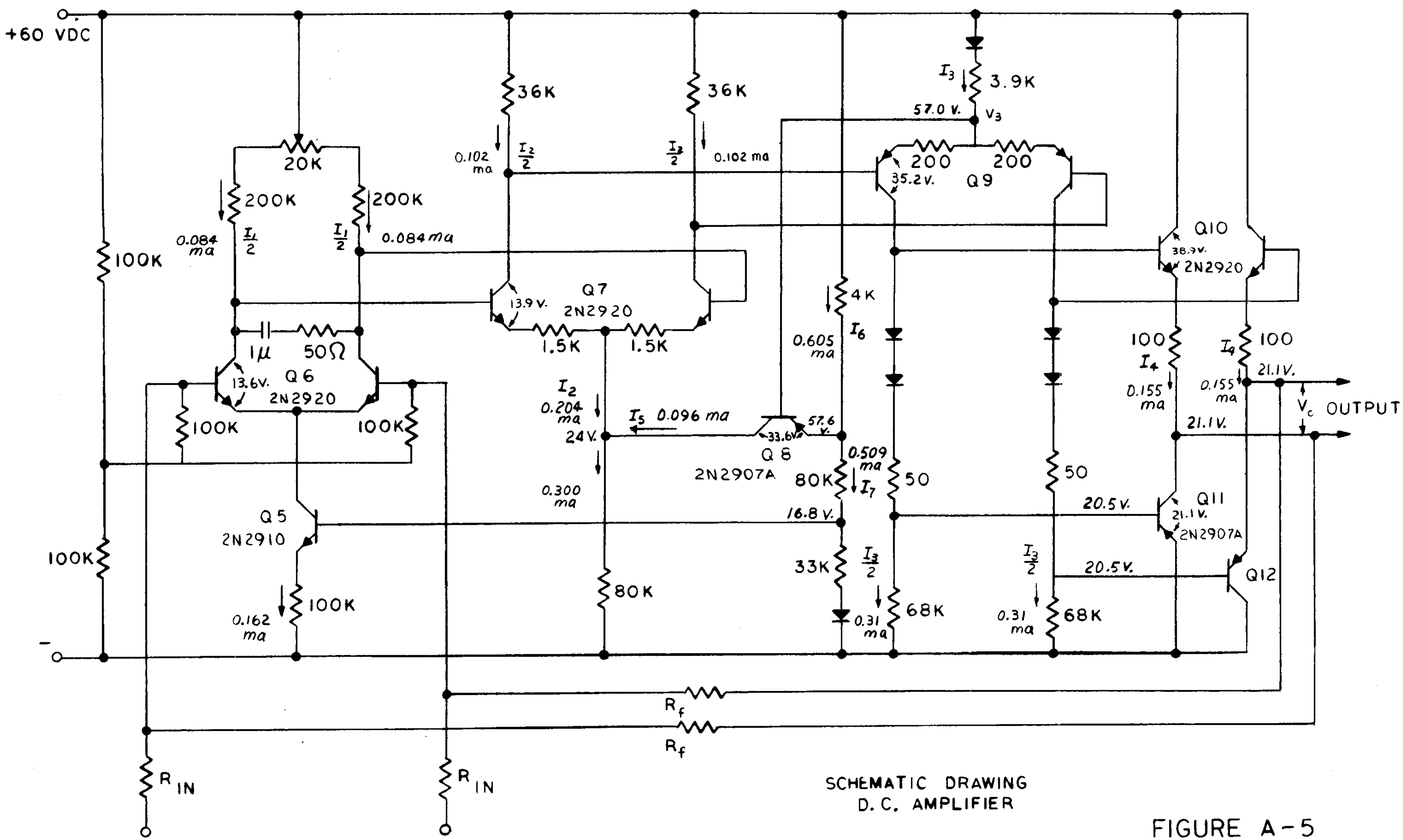
SPECIFICATIONS:

Dual Input 45 v. Diff. Ampl.
Input Power: 22 to 32 vdc 1.96 watts max. (28vdc nom.)
Gain: 0.5 to 25.0 according to feedback resistor.
Input Impedance: 20K at gain of 0.5, 2 megohms at gain of 25.0
Output Impedance: 100 ohms.
Load Limit: 5K.
Output Signal: a differential value between 0 & 45 v. positive or negative as developed across a 5 K. load.
Non-linearity: Not more than 2%
Dynamic Response: Not more than 5° phase shift with 10 HZ. or lower frequency input signal.
Null Offset: 0 $\pm$ 10 mv.

FUNCTIONAL BLOCK DIAGRAM OF D. C. AMPLIFIER

FIGURE A-4

MCR-67-239



SCHEMATIC DRAWING
D. C. AMPLIFIER

FIGURE A-5

1.2.1 <u>DC Analysis of DC Amplifier</u> - The DC Analysis of the DC Amplifier (see schematic, Figure A-5) will be accomplished by writing the DC equations in terms of the collector current of Q6 (I_1) and the emitter current of Q9 (I_3). This will yield two equations in two unknowns and all currents and voltages of the Amplifier can then be solved.

Starting with I_3 and the voltage (V_3) due to it, at the junction of the 200 Ω emitter resistors of Q9 and going to I_1 by way of the current source Q5:

1.2.1 DC Analysis of DC Amplifier - (Continued)

a. DC Analysis of DC Amplifier - (Continued)

$$V_3 = 60 - I_3\,(3.9K) - 0.6$$

$$I_7 = \frac{1}{113K}\;(V_3 + 0.6)$$

and $I_1 = \frac{1}{100K}\quad I_7\,(33K) + 0.6 - 0.6$

or $I_1 = \frac{1}{100K}\;\frac{1}{113K}\;(V_3 + .6)(33K)$

$$= \frac{1}{100K}\;\frac{1}{113K}\left[60 - I_3(3.9K) - 0.6 + 0.6\right](33K)$$

Thus $I_1 = 0.175 \times 10^{-3} - 0.0114\; I_3$ (1)

Now starting with I_1 and finding it in terms of I_3 by using the collector currents of the following stages:

$$I_1 = 60 - \frac{(I_2 + I_5)\;80K + I_2/2\;(1.5K) + 0.6}{210K} \qquad (2)$$

Solving for I_2 in terms of I_3:

$$\frac{I_2}{2} = \frac{I_3\,(3.9K) + 0.6 + I_3/2\;(200) + 0.6}{36K}$$

$$I_2 = \frac{4}{18}\;I_3 + \frac{1.2}{18K}$$

Solving for I_5 in terms of I_3

$$I_5 = I_3\;\frac{3.9K}{4K} - \frac{(60 - I_3(3.9K) - 0.6)}{113K}$$

$$I_5 = 3.9\;I_3\left(\frac{1}{4} + \frac{1}{113}\right) - \frac{59.4}{113K}$$

Thus $I_2 + I_5 = I_3 \; 3.9 \left(\frac{1}{4} + \frac{1}{113} \right) + \frac{4}{18} \quad + \frac{1.2}{18K} - \frac{59.4}{113K}$

$$= 1.23\, I_3 - 0.460 \times 10^{-3}$$

And $\frac{I_2}{2} = 0.111\, I_3 + 0.0333 \times 10^{-3}$

Substituting back into equation (2)

$$I_1 = \frac{96.3}{210K} - \frac{98.7}{210}\, I_3$$

$$I_1 = 0.459 \times 10^{-3} - 0.470\, I_3 \quad (3)$$

This gives two equations in two unknowns (1) and (3)

$$I_1 = 0.175 \times 10^{-3} - 0.0114\, I_3 \quad (1)$$
$$I_1 = 0.459 \times 10^{-3} - 0.470\, I_3 \quad (3)$$

which solved simultaneously yield:

$$I_3 = 0.62 \text{ ma}$$
$$I_1 = 0.168 \text{ ma}$$

Now the other currents can be solved:

$$\frac{I_2}{2} = 0.102 \text{ ma}$$

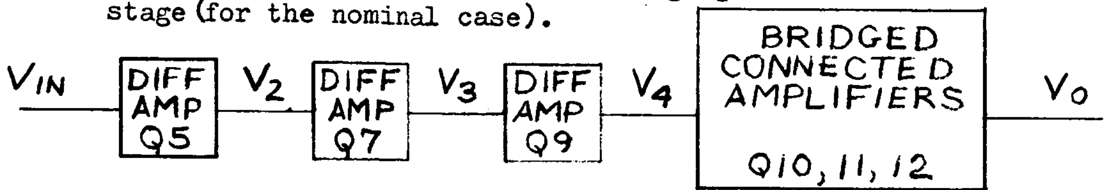
$$I_4 = \frac{I_3}{4} = 0.155 \text{ ma}$$

$$I_6 = 0.605 \text{ ma}$$

$$I_7 = 0.509 \text{ ma}$$

With these currents, the transistor collector to emitter voltages were calculated and recorded on Figure A-5.

1.2.2 AC Analysis - The forward loop gain (V_0/V_{in}) will be determined by solving for the voltage gains of each stage (for the nominal case).



where R_B and R_E = total base and emitter resistance, including intrinsic resistance when appropriate

$$\frac{V_2}{V_{in}} = \frac{R_L // (h_{ie} + BR_E)}{\frac{R_B}{B+1} + R_E}$$

$$= \frac{(200K)//400(1.7K)}{\frac{100K}{375} + 350}$$

$$= 252$$

$$\frac{V_3}{V_2} = \frac{R_L // (h_{ie} + BR_E)}{\frac{R_B}{B+1} + R_E}$$

$$= \frac{36K // 200(260)}{\frac{5K}{400} + 1.7K}$$

$$= 12.5$$

$$\frac{V_4}{V_3} = \frac{R_L // (h_{ie}(Q10) + BR_E) // (h_{ie}(Q11, Q12) + BR_E)}{\frac{R_B}{B+1} + R_E}$$

$$= \frac{60K // 400(312) // 200\ (312)}{\frac{5K}{200} + 260}$$

$$= 86.3$$

$$\frac{V_5}{V_4} = \frac{R_L}{\frac{r_b}{B+1} + R_L + r_e}$$

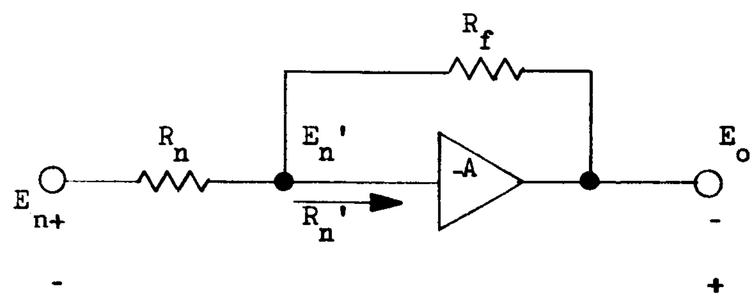
$$= 0.661$$

Thus the Open Loop gain is:

$$\frac{V_O}{V_{in}} = (252)(12.5)(86.3)(0.661)$$

$$= 180 \times 10^3$$

1.2.3 Transfer Function Analysis



if $E_n' \neq 0$ and $I_n' \neq 0$

$$\frac{E_n - E_n'}{R_n} - \frac{(E_n' - E_O)}{R_f} = I_n' = \frac{E_n'}{R_n'}$$

Now E'A = EO

So $$\frac{E_O/A}{R_n'} + \frac{E_O/A}{R_n} + \frac{E_O}{R_f} + \frac{E_O/A}{R_f} = \frac{-E_n}{R_n}$$

$$E_O\left(\frac{1}{AR_n'} + \frac{1}{AR_n} + \frac{1}{R_f} + \frac{1}{AR_f}\right) = \frac{-E_n}{R_n}$$

Thus $$\frac{E_O}{E_n} = -\frac{1}{R_n} \quad \frac{1}{\frac{1}{R_f} + \frac{1}{A}\left(\frac{1}{R_n'} + \frac{1}{R_n} + \frac{1}{R_f}\right)}$$

and $\frac{E_0}{E_n} = -\frac{R_f}{R_n}$ if $\frac{1}{R_f} \gg \frac{1}{A}\left(\frac{1}{R_n'} + \frac{1}{R_n} - \frac{1}{R_f}\right)$

For the differential case where

$E_n = V_1 - V_2$ and $E_0 = V_{10} - V_{20}$

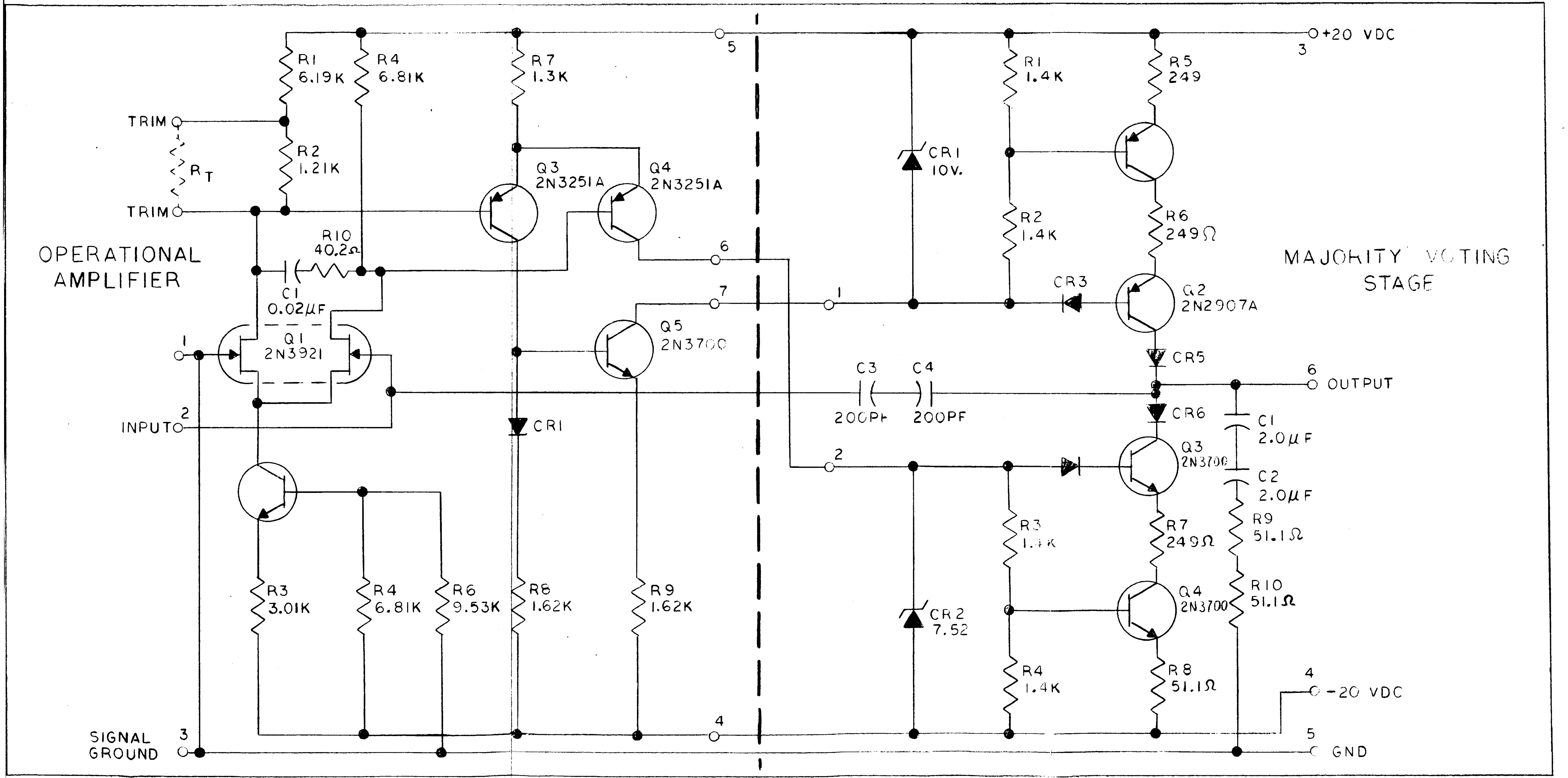
$V_{10} = -\frac{R_f}{R_n} V_1, \quad V_{20} = -\frac{R_f}{R_n} V_2$

$$V_{10} - V_{20} = -\frac{R_f}{R_n} V_1 + \frac{R_f}{R_n} V_2$$

$$= \frac{-R_f}{R_n}(V_1 - V_2)$$

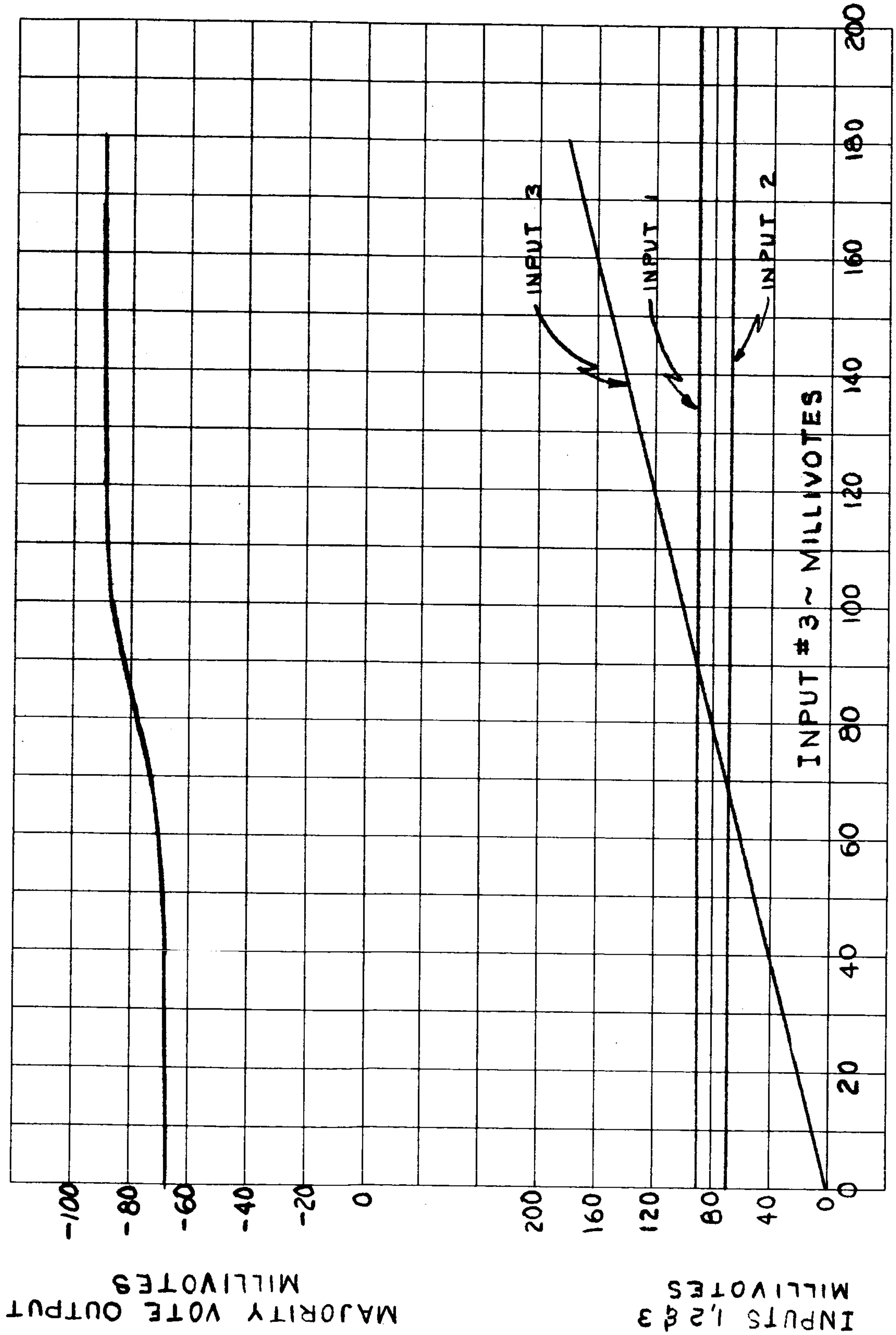
Thus $\frac{V_{10} - V_{20}}{V_1 - V_2} = \frac{-R_f}{R_n}$

2.0 T III MOL MAJORITY VOTE AMPLIFIER - The T III MOL majority vote amplifier is shown schematically in Figure A-6. Figure A-7 shows that variation of the majority voted output as a function of two input signals close together with a varying third signal. The curves shown were obtained from laboratory tests of the Titan III MOL majority vote amplifier.



TITAN III MOL MAJORITY VOTING AMPLIFIER

FIGURE A-6



MAJORITY VOTE OUTPUT vs INPUT

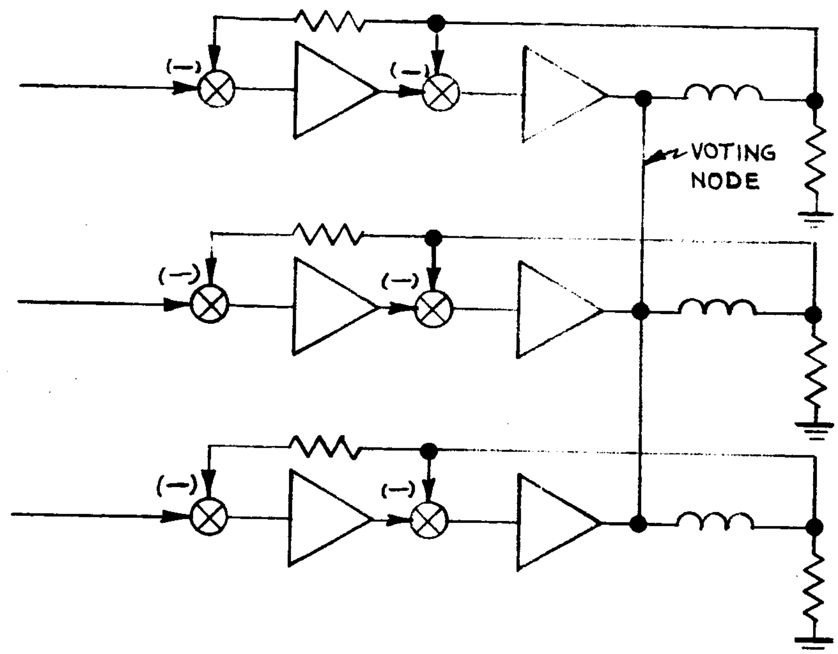
FIGURE A-7

3.0 MAJORITY VOTE CONFIGURATIONS FOR APOLLO AUTOPILOT

Suggestions for Majority Voting the Apollo Autopilot will be made, which could affect both the guidance and the Rate Signals (see Block Diagram, Figure A-1).

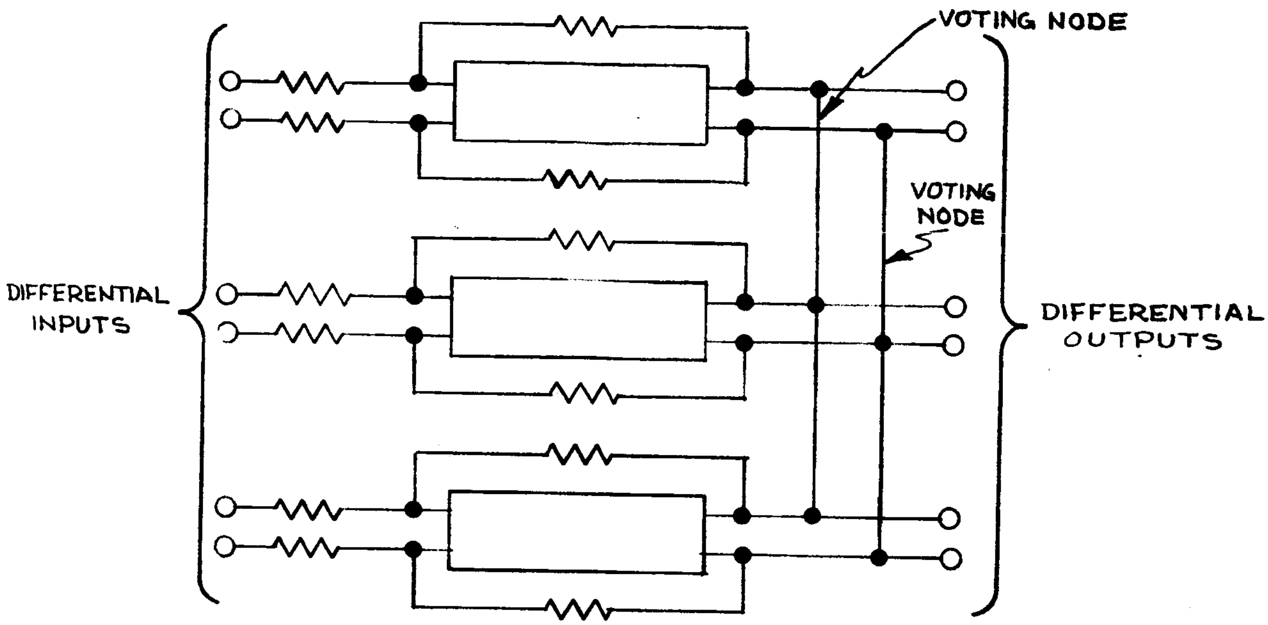
An obvious first choice for Majority Voting, when using the Majority Vote Actuator, is to eliminate the Servo Amplifier Circuitry and send all three signals from the Servo Amplifiers to the Actuator. This would handle all single failures in the Autopilot.

If more reliability is desired, then Majority Voting can be done inside the Autopilot. One choice could be the 50 MA Servo Amplifiers.



A different arrangement of feedback would not solve our problem as it is the Open Loop impedance that has to be high. This is due to the fact that when the Amplifiers saturate, they are operating virtually without feedback. As the Servo Amplifiers exist now, feedback is arranged to boost the Closed Loop output impedance, but this does not help Majority Voting.

Another choice for Majority Voting could be the DC Amplifiers. This would not vote out any failures in the Rate channel, but would protect the DC Amplifiers. The system could then tolerate a failure of a DC Amplifier and another failure downstream up to the actuator Voting Node. The same comments made before about boosting the Open Loop output impedance would apply to the DC Amplifier.

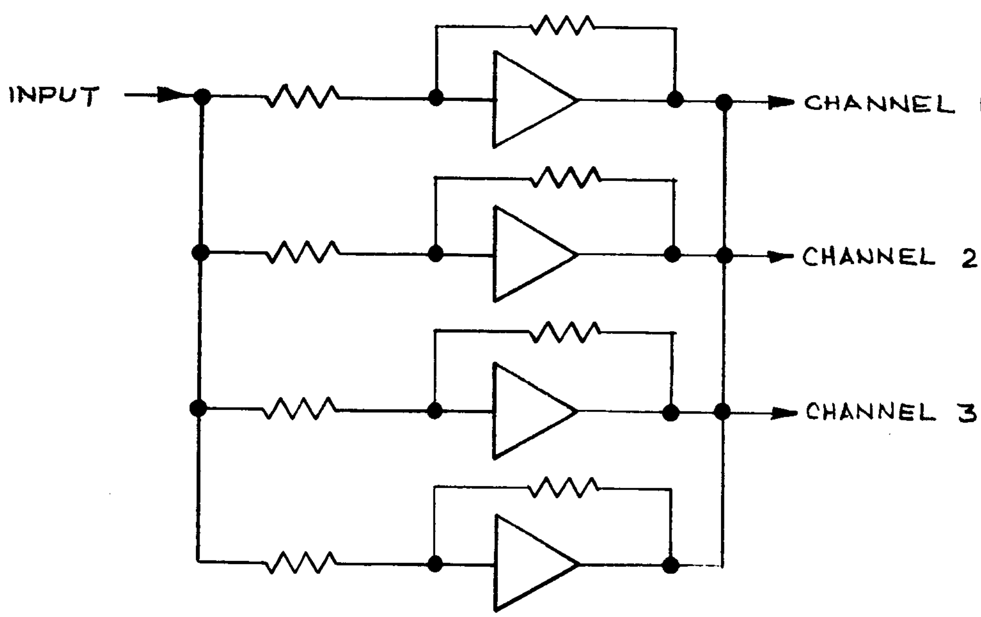


If Voting took place at the DC Amplifier and the Servo Amplifier (as well as at the Actuator), then the failures that could be tolerated would be a DC Amplifier plus a Relay or Filter or Servo Amplifier, plus an Actuator. The reliability figures for that configuration will probably not show much improvement over the configurations mentioned previously.

Somewhat outside the scope of this Study, but another place that voting could occur, would be inside the Control Signal Processor. The Amplifiers in this unit that are voted on with a Comparator Circuit, could probably be Analog Majority voted, or the signals could be sent to the Autopilot and amplified and voted on there. This would eliminate the quad redundant relays as well as the Comparator Circuit in the Control Signal Processor - all of which are in the Spatial

Thruster channels. Majority Voting could probably be used to advantage, however, these areas are not to be considered in this study.

A possibility of improving the number of piece part failures that the system could tolerate, would be to increase the number of Amplifiers voted. Such as:



It is doubtful if four Majority Vote Amplifiers of the Titan III variety would operate properly under normal conditions. Five Amplifiers probably would, but then you would have the peculiar situation of being capable of withstanding one or three Amplifier failures but not two Amplifier failures. These problems could probably be designed around, but very little work has been done in this area so far.

4.0 MAJORITY VOTE CONFIGURATIONS FOR THE 50 MA SERVO AMPLIFIER

This section of the Appendix will cover the conceptual design configurations of the Majority Vote 50 MA Servo Amplifier. Two general configurations will be considered for Analog Majority Voting the 50 MA Servo Amplifier. The first keeps the two feedback loops of the present Servo Amplifier and the second has only one feedback loop. Two output circuits are also presented as being able to meet the design goals in a number of circuit configurations. These are discussed and compared with considerations of Open Loop Output Impedance, Open Loop Gain, and Piece Parts Count. The more promising circuits are presented in conceptual schematic form for the full Majority Vote Servo Amplifier. The protection of the "voting node" is then discussed, this being applicable to any of the various circuits for Majority Voting. The voting node is the common output point of the three voting amplifiers, that is where the three outputs are physically attached to one another.

The three choices for a Majority Vote Servo Amplifier boil down to this: the more changes made, the more piece parts saved.

4.1 Goals for Design of Majority Vote Servo Amplifier -

a. Increase Open Loop Output impedance, even when the amplifier is saturated.

b. Protect voting node from single piece part failure or power supply failure.

c. Maintain present performance levels of Open Loop Gain, Current Drive, Null Offset, and Dynamics Response.

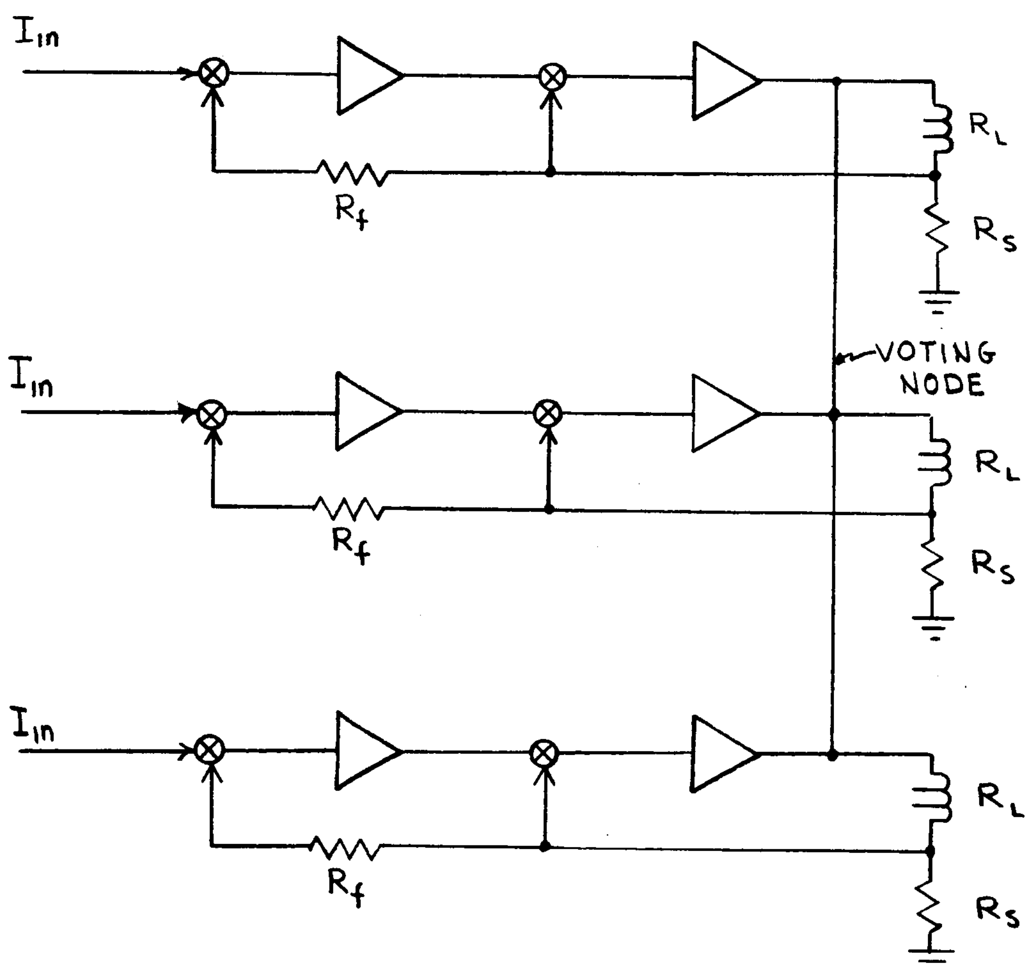
d. Low piece parts count - Design Goal of keeping the piece part count the same on the Servo Amplifier.

This would eliminate the entire Comparator Circuit (109 parts) when the Servo Amplifier is Majority Voted.

e. At least one alternate way of Majority Voting to be developed as study progresses.

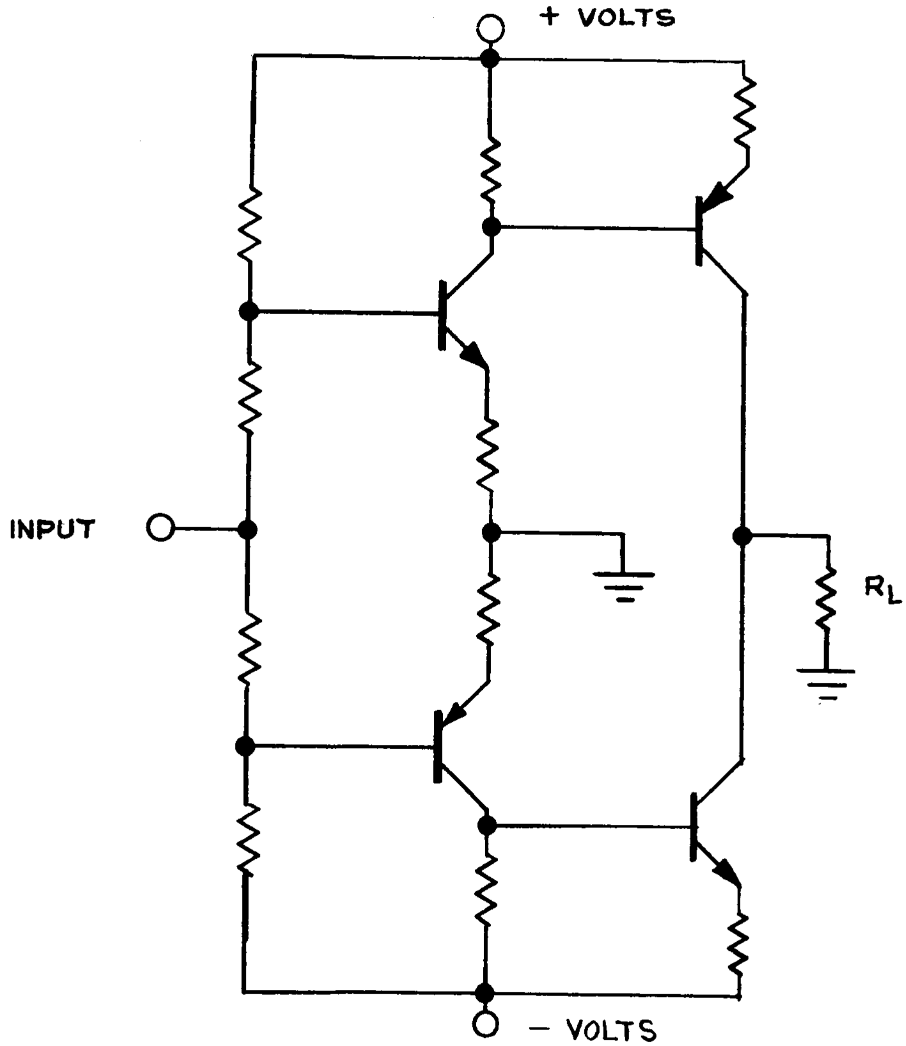
4.2 Two Feedback Loop

The first general configuration to be considered for Majority Voting the Servo Amplifier is the following:



Here the two feedback loops are kept and the voting is done at the power amplifier output. The differences between this method and the method normally used for Majority Voting are: 1) there are two feedback loops while normally there is only one, 2) the load is much greater for the Servo Amplifier, that is much more drive capability will be needed, and 3) current feedback is used instead of the usual voltage feedback. This means that the place where feedback is taken is not the same as the voting node. The voting node and the point feedback is sensed are separated by the load impedance (the actuator coil).

A good way to increase the output impedance is to drive the load from the collectors and the complimentary symmetry arrangement lends itself nicely to the job. The first output circuit considered is a single-ended to single-ended arrangement.



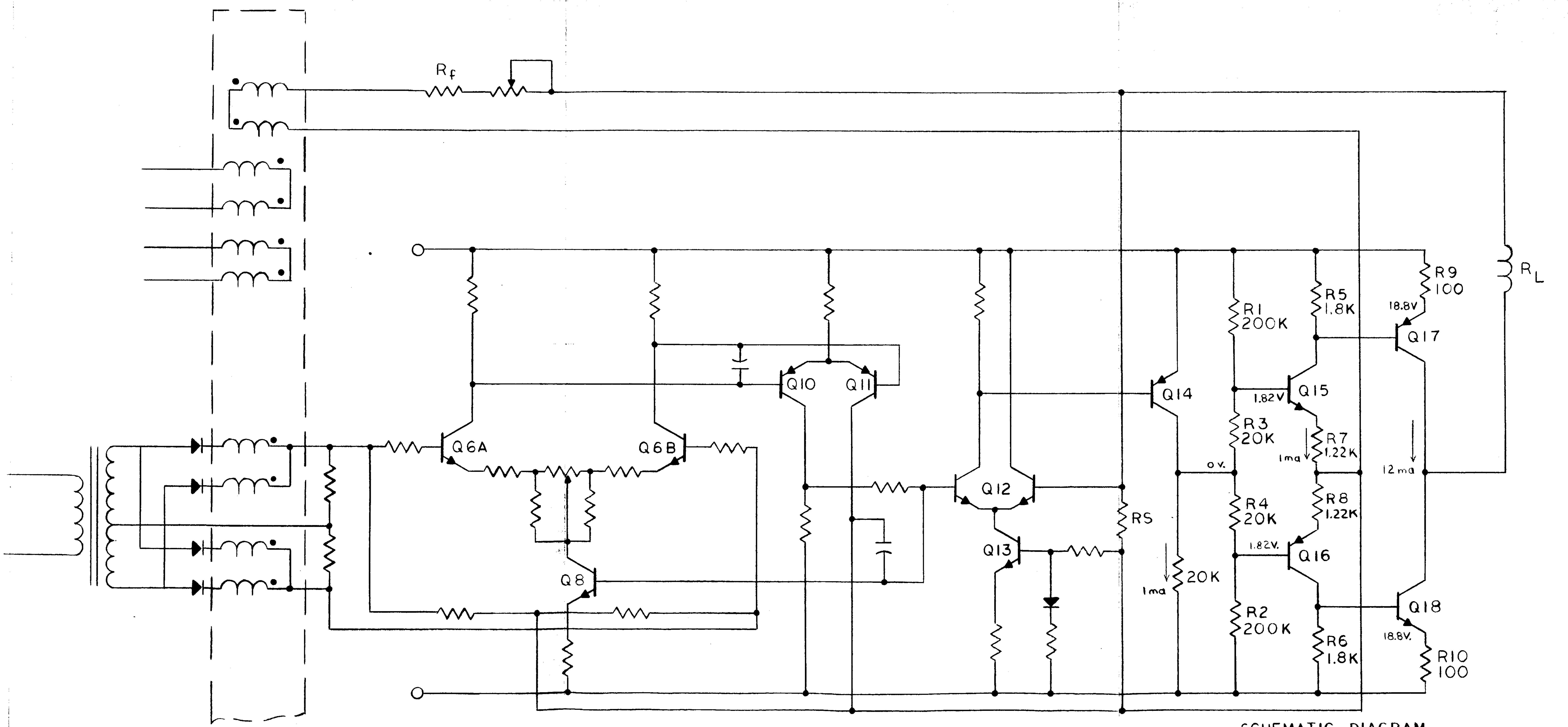
Using representative values for the components, a gain of from 10 x 10^{-3} to 20 x 10^{-3} $\frac{ma}{V}$ could be expected from this circuit.

This circuit could be placed at the output of the Servo Amplifier (see Figure A-3, 50 ma Servo Amplifier). This, however, would be a waste of parts as well as more difficult to stabilize. A better place to use the circuit would be at the collector of Q14 and eliminate Q15, Q7, and Q9. (See Figure A-8, Majority Vote 50 ma Servo Amplifier). This would eliminate nine parts and add fourteen parts so that for the three Majority Vote Amplifiers there would be a net of fifteen parts added. However, since the entire comparator circuit was eliminated (109 parts), there would be a net elimination of 94 piece parts.

Other considerations of this circuit change are:

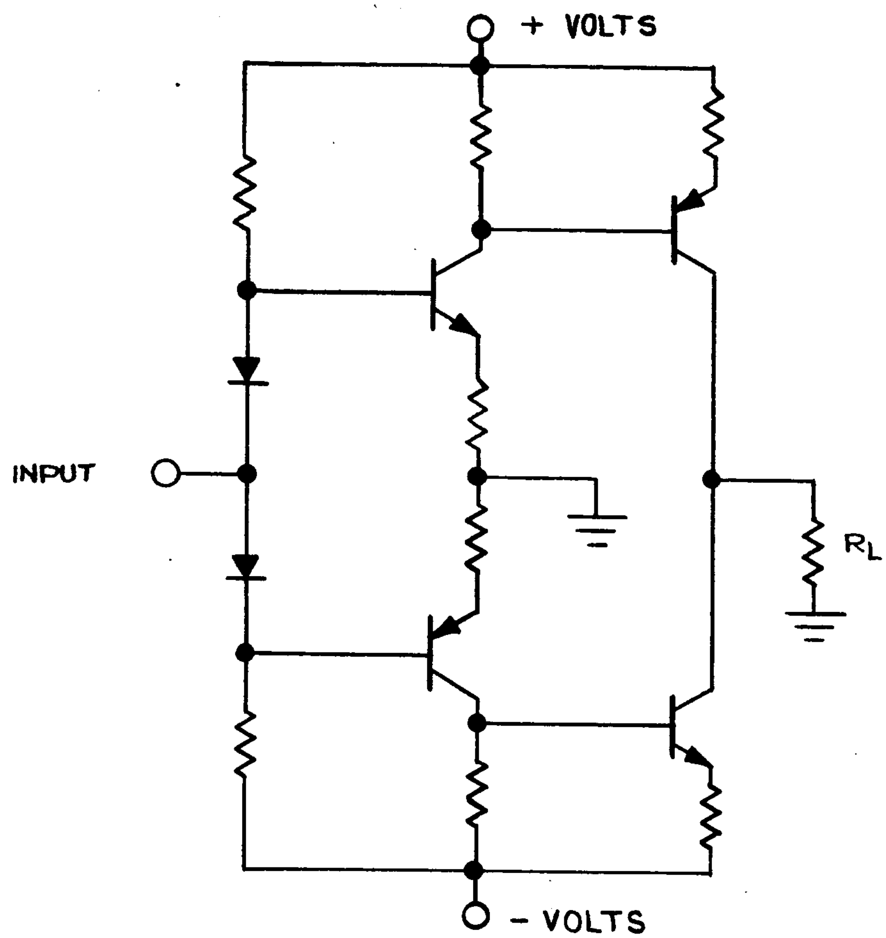
a. Open Loop Gain - This will be increased some, perhaps as much as two to three times. This will probably necessitate adjustment of the stabilizing circuitry. It could also mean higher reliability by the elimination of the 2K feedback adjustment resistor, which is used to set the closed loop gain. If some closed loop gain adjustment was still desired, a higher open loop gain would make the use of fixed resistors more practical.

b. Drift or Null Offset - Should not be affected very much since there is at least a gain of 10^5 preceding the output circuit. However, since the closed loop gain <u>is</u> high (1667 ma/ma), any contribution to offset of the output circuit could be minimized by using input diodes in place of resistors.



SCHEMATIC DIAGRAM
MAJORITY VOTE SERVO AMPLIFIER
NO. 1

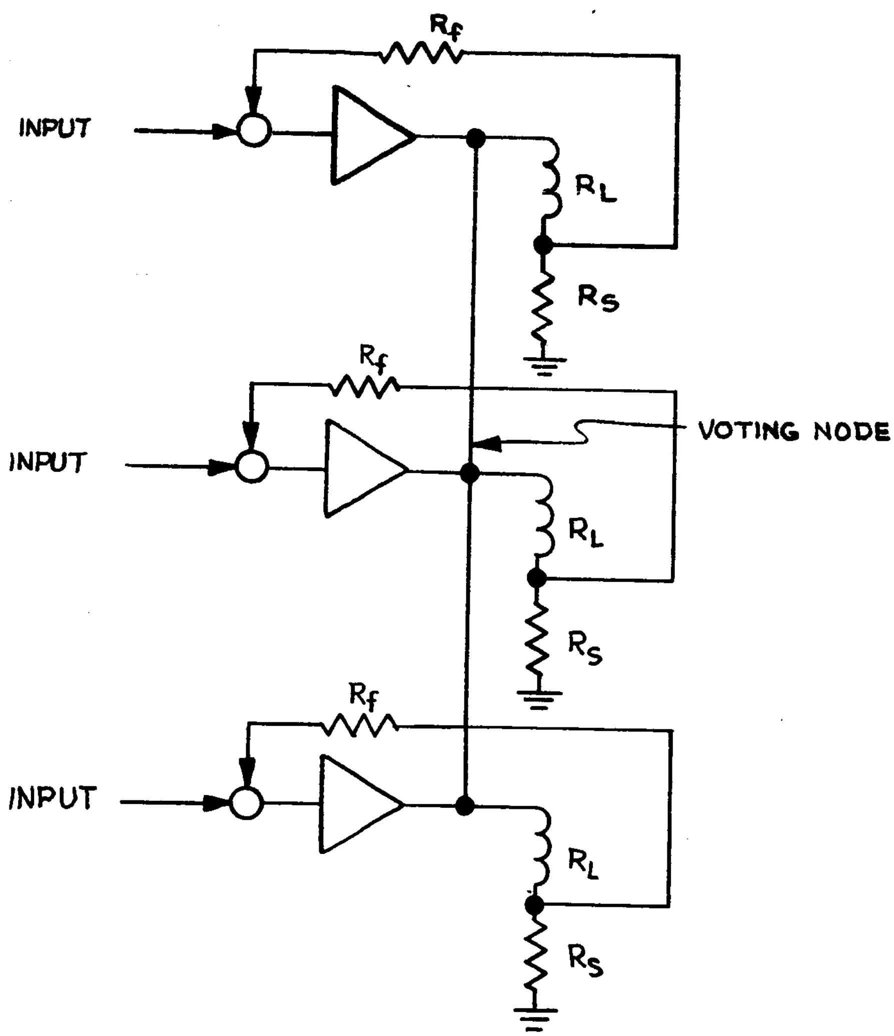
FIGURE A-8



c. Drive Characteristics - Since the closed loop output impedance will be increased considerably (about 10^3 x the former closed loop output impedance), the output characteristics of the Servo Amplifier will be much less affected by impedance variations in the actuator.

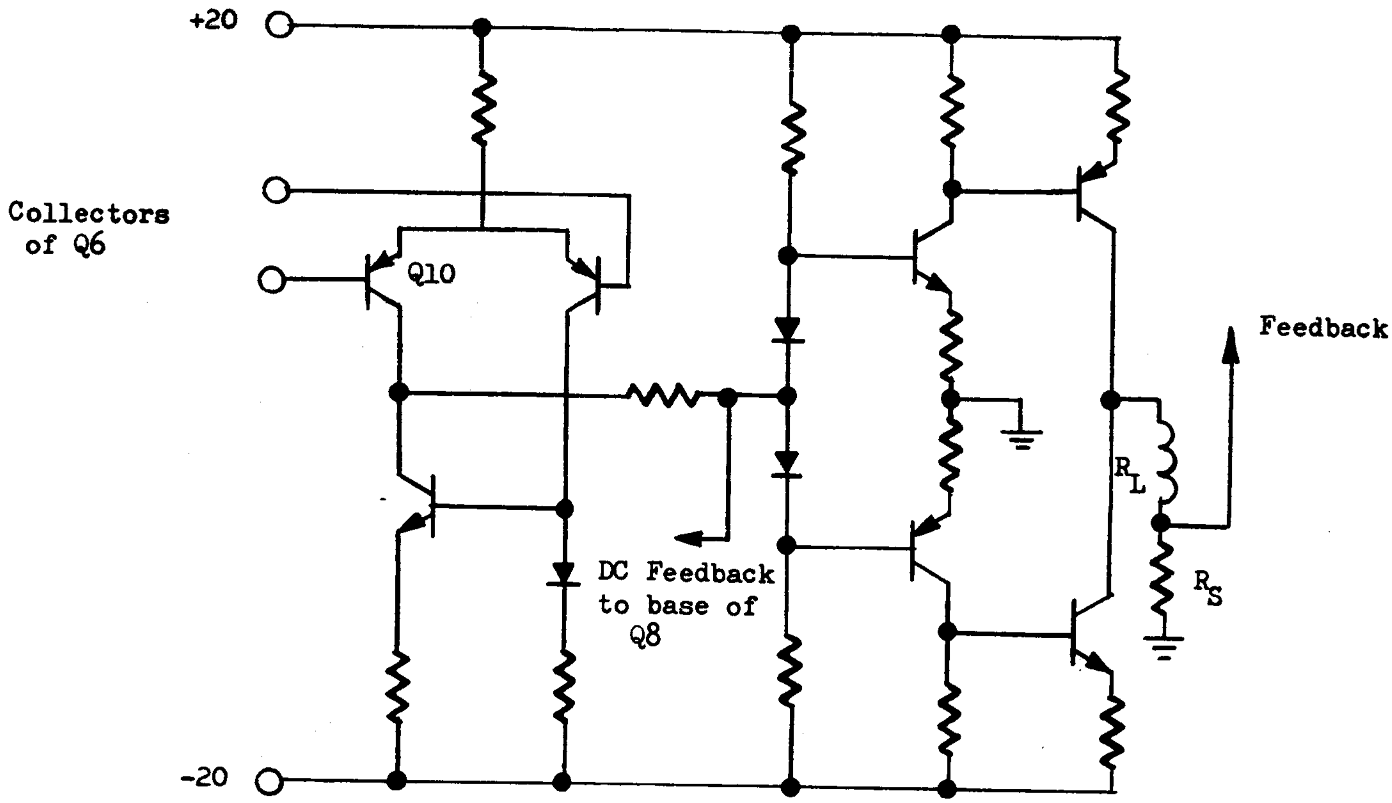
4.3 Single Feedback Loop

a) Another way the output circuit could be used is to connect it to the collector of Q10. This introduces us to the second general configuration for majority voting the Servo Amplifiers, which has one feedback loop.



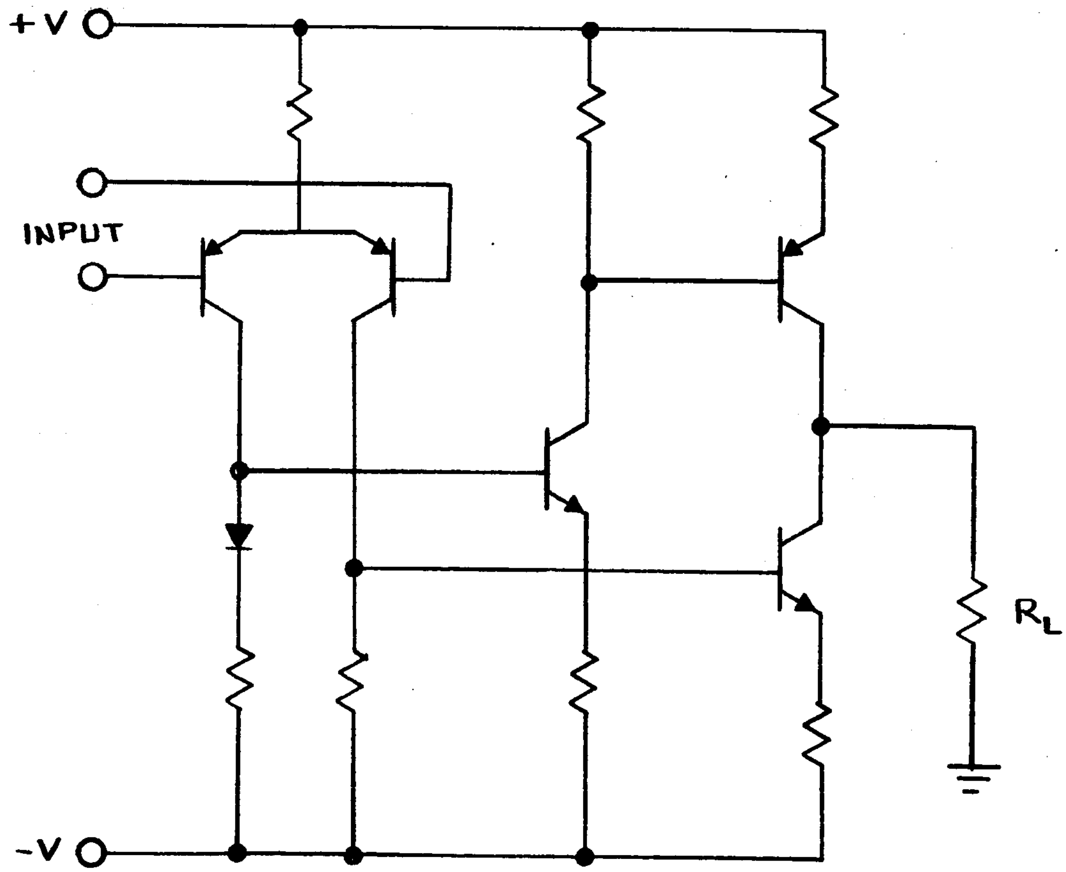
This would eliminate Q12, Q14, Q15, Q7, and Q9. In all, nineteen parts would be eliminated and fourteen added, giving a net elimination of fifteen parts for the three Servo Amplifiers (plus 109 parts for the comparator).

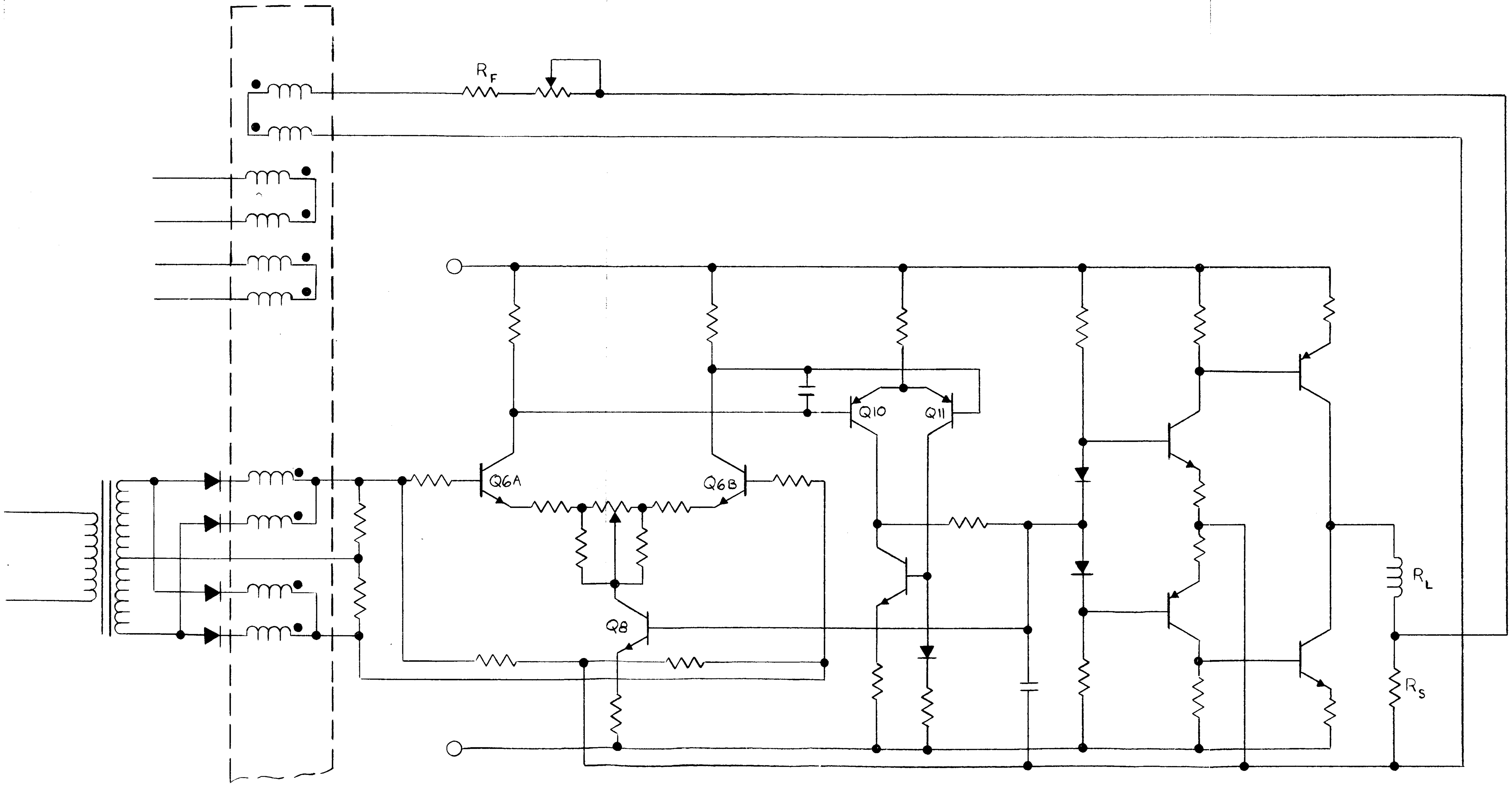
This scheme would also do away with the second feedback loop and with six stages to stabilize, could be a problem. To make up for the open loop gain lost by eliminating Q12 and Q14, the gain of Q10 could be boosted considerably by feeding the collector into another collector as shown:



This gain (open loop) boost plus that already obtained from the output circuit should just about make up for that lost by the parts elimination. If more gain is required or desired (to do away with the feedback pot) a good place to get it would be in the transistor circuit first stage, Q6. (See Figure A-3). It is a good place because any increase of gain in the first stage or two, when their gains are low, would greatly help the offset drift problem. Since the nominal gain of Q6 is about 9, it could be expected to be quite low under worst case conditions, say 1 or 2. If it was desired to eliminate the DC feedback to the base of Q8, in order to increase the open loop gain, a boost of the gain of Q6 would then surely be required. (See Figure A-9 for Complete Circuit, Majority Vote Servo Amplifier No. 2).

b) The second output circuit considered is a differential input to single-ended output.





SCHEMATIC DIAGRAM
MAJORITY VOTE SERVO AMPLIFIER
No. 2

FIGURE A-9

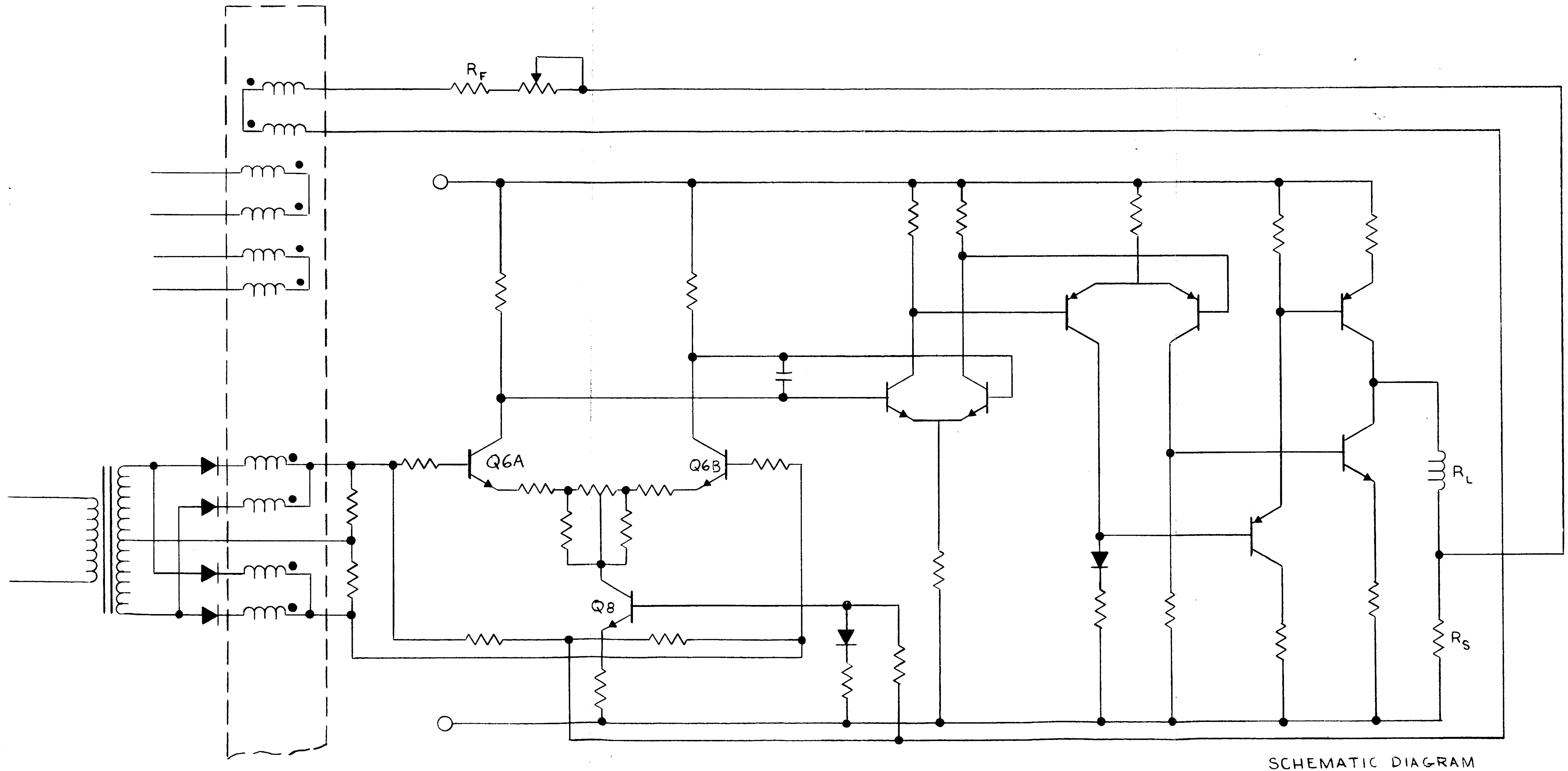
Here again the output is taken off the collectors of a complementary symmetry stage to give a high open loop output impedance. This circuit has good gain and drift characteristics. By changing Q10 and Q11 from PNP to NPN, it can be used in a simple circuit (see Figure A-10, Majority Vote Servo Amplifier No. 3). This arrangement offers the most savings in piece parts, 24 for the three amplifiers plus 109 for the Comparator Circuit. The Open Loop gain obtainable could probably enable the feedback pot to be eliminated, at least with fixed resistors. With more balance in its stages, the drift characteristics of Amplifier No. 3 will probably allow dispensing with the DC feedback to Q8. A boost in the gain of Q6 would also help. The elimination of DC feedback increases the open loop gain, but DC feedback could be employed if needed.

4.4 Conceptual Design Conclusion

Majority Vote Servo Amplifier No. 1 involves the fewest changes with a good boost in gain. Majority Vote Servo Amplifier No. 2 and No. 3 offer the biggest savings in piece parts, but are the most drastic in change. Amplifier No. 3 retains only the Magnetic Amplifier and the differential stage (Q6) that it feeds into. The Magnetic Amplifier is a very handy device for differential summing and should probably be retained. The first transistor stage could be made a lot simpler with a differential Field Effect Transistor. The gates of a FET are not as sensitive to unbalanced impedances as the differentail transistor bases. Also, a simple trim resistor arrangement in the drain circuit would not only eliminate the Pot now used but would eliminate four resistors. Altogether eight resistors including a Pot could probably be eliminated by using a differential FET instead of a differential bipolar transistor.

4.5 Protection of the Voting Node

Protection of the voting node is necessary to keep failures of the Majority Vote Amplifier and the power supply from causing excessive loading of the voting node.



SCHEMATIC DIAGRAM
MAJORITY VOTING SERVO AMPLIFIER
No. 3

FIGURE A-10

Voting node protection is applicable to any of the output circuits covered in this report. Twelve parts for each Majority Vote Amplifier would have to be added to the parts count previously discussed. The following schematic shows the circuitry that would have to be added. An explanation for each addition will be given to only the top half of the circuit, since there is symmetry.

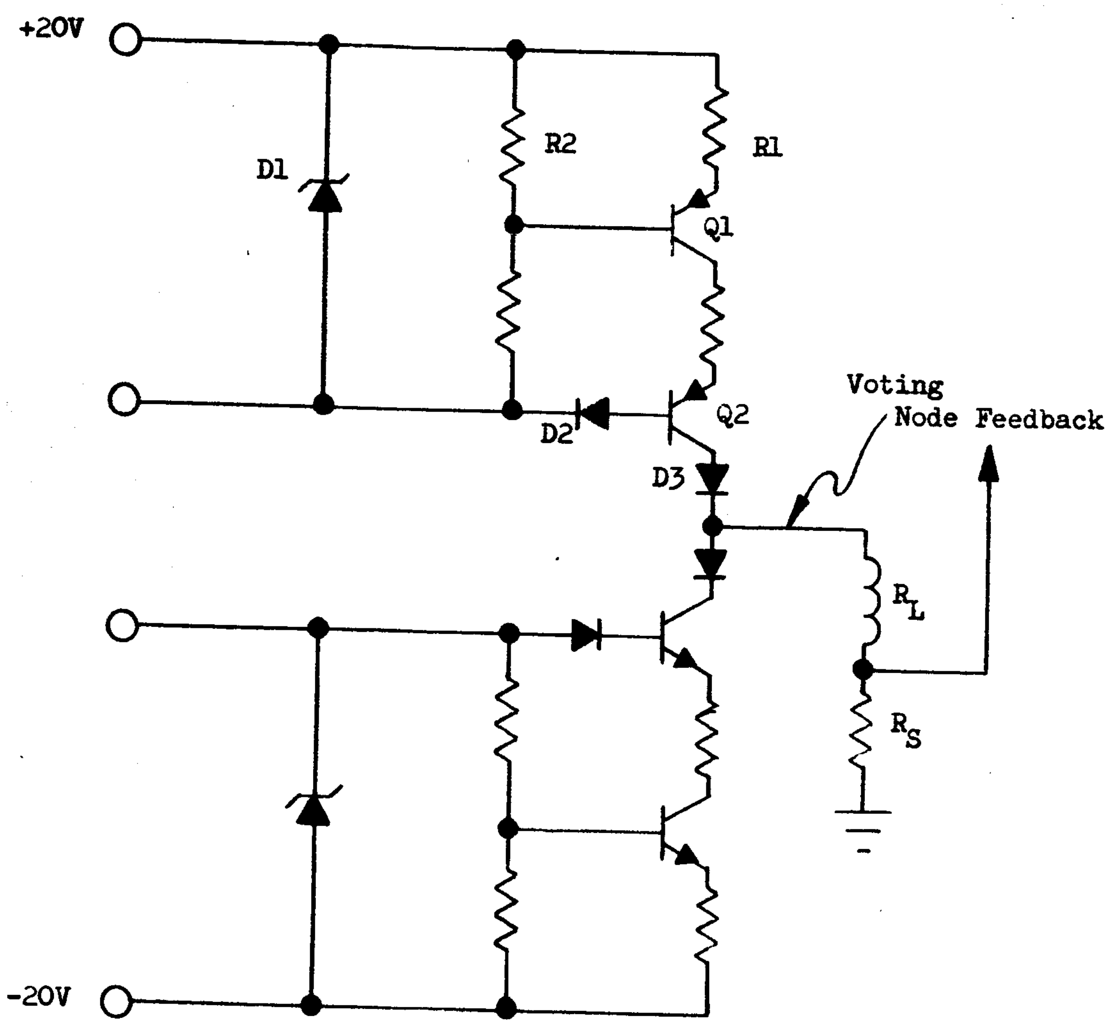
Q_1 - Redundant drive transistor, normally in saturation but takes over the drive if Q2 shorts out. Without Q_1 the voting node would be heavily loaded if Q_2 shorted.

R_1, R_2 - Biasing resistors for Q_1

D_1 - Zener Diode, prevents Drive Transistor from saturating, thus keeping the open loop output impedance high.

D_2, D_3 - Diodes prevent excessive loading of voting node if Q_2 has short from collector to base. Also prevent excessive loading through the collector to base diode of Q_2 and D_1 if power supply fails.

See Figure A-11.



Voting Node Protection
Figure A- 11

APPENDIX B

Hydraulic System Thrust Vector Control Analysis

MCR-67-239

Appendix B

Hydraulic System Thrust Vector Control Analysis

1.0 RELIABILITY ANALYSIS

In the previous study the conversion of failure rates to probability of failures were accomplished through the following approximation.

$$Q = 1 - R$$

$$Q = 1 - e^{-t/\bar{t}}$$

$$Q = 1 - \frac{t}{\bar{t}} \quad \left(\text{for } \frac{t}{\bar{t}} < .01\right)$$

$$Q = 1 - \frac{(GF_R)(K_{OP})(K_F)(K_A)(t)}{10^6}$$

where:

- R = Reliability
- Q = The probability of failure
- t = Operating time during various mission phases
- $\bar{t}$ = Mean-time-to-failure
- GF_R = Generic failure rate
- K_A = The application factor which takes into account the application of the piece part with respect to the component during component operation.
- K_F = The system function modifiers which adjust the failure rate taking into account the function of the component with respect to the launch vehicle during periods of operation being considered.
- K_{OP} = The operating mode factor which adjusts the generic failure rate to the various external environmental conditions.

During the previous study the Generic Failure Rate (GF_R) and the Application Factor (K_A) were derived for ground, countdown, engine start and flight. Since these factors do not change during the coast or on-orbit phase of the mission, the remaining factors that needed to be determined for this study were the System Function Modifier (K_F), the Operating Mode Factor (K_{OP}) and the time (t) of the different operating modes.

Since $$K_{OP} = \int (K_t, K_p, K_v, K_s)$$

where

$$K_t = \int (\text{temperature})$$

$$K_p = \int (\text{atmospheric pressure})$$

$$K_v = \int (\text{vibration})$$

$$K_s = \int (\text{shock})$$

The anticipated environmental conditions and flight plan of the S-IV B stages during the coast or on-orbit phase of flight were reviewed. With this information and data from the Titan III C transtage program, the required K_{OP}, t, and K_F factors were derived. These factors were then incorporated into the previous computer program in order to determine the probability of failures during the coast or on-orbit phase of the S-IV B stage operating for the previous system configurations.

1.1 Analysis of Time Phases (t) of the Saturn S-IV B Stage Operation - The Saturn flight AS-204 and AS-504 flight trajectory data in Reference 2 and 3 were reviewed in order to determine the "worst case" trajectory with respect to orbit and engine reignition time. It was concluded that the AS-504 flight trajectory would impose the most severe requirement on the thrust vector control system. The mission of the AS-504 flight is to insert the S-IV B and payload into a circular parking orbit with a mean altitude (at the equator) of 185.2 KM (100 N Mi) and remain in a parking orbit for approximately 1.5 revolutions if translunar injection occurs at the first opportunity and approximately 2.5 revolutions if translunar injection occurs at the second opportunity. Boost to translunar injection is accomplished by a second burn of the S-IV B stage. A tabulated summary of the parking orbit and engine burn times for five launch azimuths are shown in Table B-1.

It was concluded that the reliability of the thrust vector control system should be determined for the following three major times phases:

S-IV B First Burn - .0362 hours
S-IV B Parking Orbit - .3.944 hours
S-IV B Second Burn - .108 hours

TABLE B-I

S-IV B OPERATION	OPERATION TIME FOR VARIOUS LAUNCH AZMUTHS				
	72° HR:MIN:SEC	79° HR:MIN:SEC	85° HR:MIN:SEC	91° HR:MIN:SEC	98° HR:MIN:SEC
1st Opportunity					
S-IV B 1st Burn	2:10.457	2:07.217	2:07.117	2:06.777	2:07.357
S-IV B Parking Orbit	2:28:34.762	2:25:31.462	2:22:42.845	2:19:58.736	2:17:09.470
S-IV B 2nd Burn	6:28.598	5:29.444	5:29.956	5:30.264	5:30.483
2nd Opportunity					
S-IV B 1st Burn	2:10.457	2:09.217	2:07.111	2:07.777	2:07.357
S-IV B Parking Orbit	3:56:36.807	3:53:33.506	3:50:44.891	3:48:00.782	3:45:12.516
S-IV B 2nd Burn	5:26.786	5:21.071	5:28.637	5:28.754	5:28.042

1.2 Analysis of Environmental Factors (K_{OP}) - In the previous study reference (1) and previous reliability studies for the Transtage, it was established that:

$$K_{OP} = K_t + K_v + K_s + K_p$$

where K_t is a factor related to temperature

K_v is a factor related to vibration

K_s is a factor related to shock

K_p is a factor related to atmospheric pressure

Since the Titan III C transtage mission requirements and the thrust vector control system hydraulic components are similar to those of the Saturn S-IV B stage the same technique in determining the K_{OP} for the Titan III C transtage was applied in this study.

1.2.1 Temperature Factor (K_t) - From the Titan III C Transtage analysis it was also determined that

$$K_t = 2 \left(\frac{T_1 - T_2}{X}\right)^2$$

where T_2 is the nominal laboratory test temperature and T_1 is the predicted environmental temperature.

For a Type II hydraulic system the temperature range is -65°F to 275°F.

For a Type II hydraulic system components $K_t = 1000$ at temperatures of -65°F. Assuming the nominal component laboratory operating temperature is 100°F.

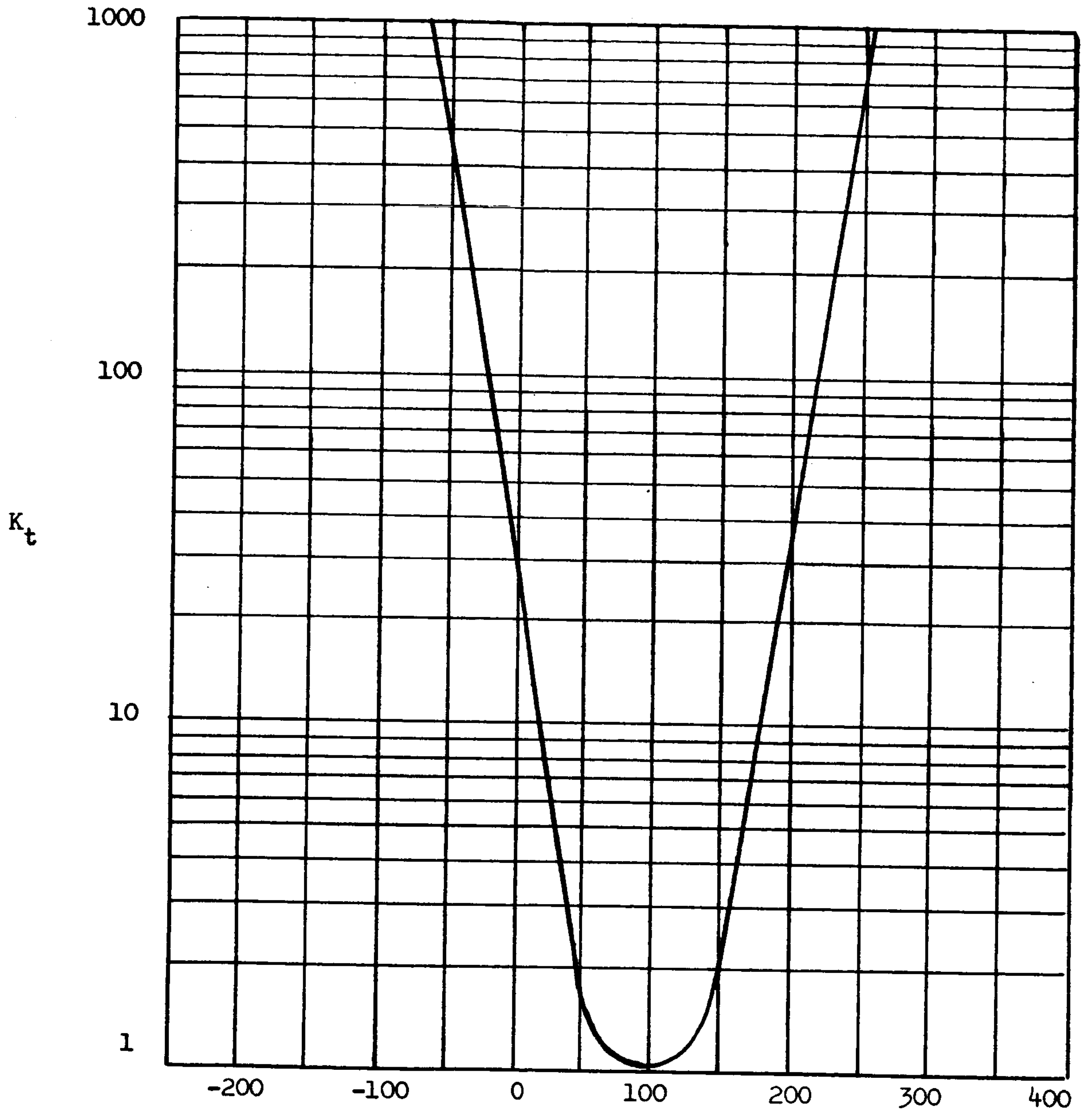
$$K_t = 2\left(\frac{T_1 - 100°F}{X}\right)^2$$

At $T_1 = -65°F$, $K_t = 1000$ and solving for X

$$K_t = 2\left(\frac{T_1 - 100}{52.2}\right)^2$$

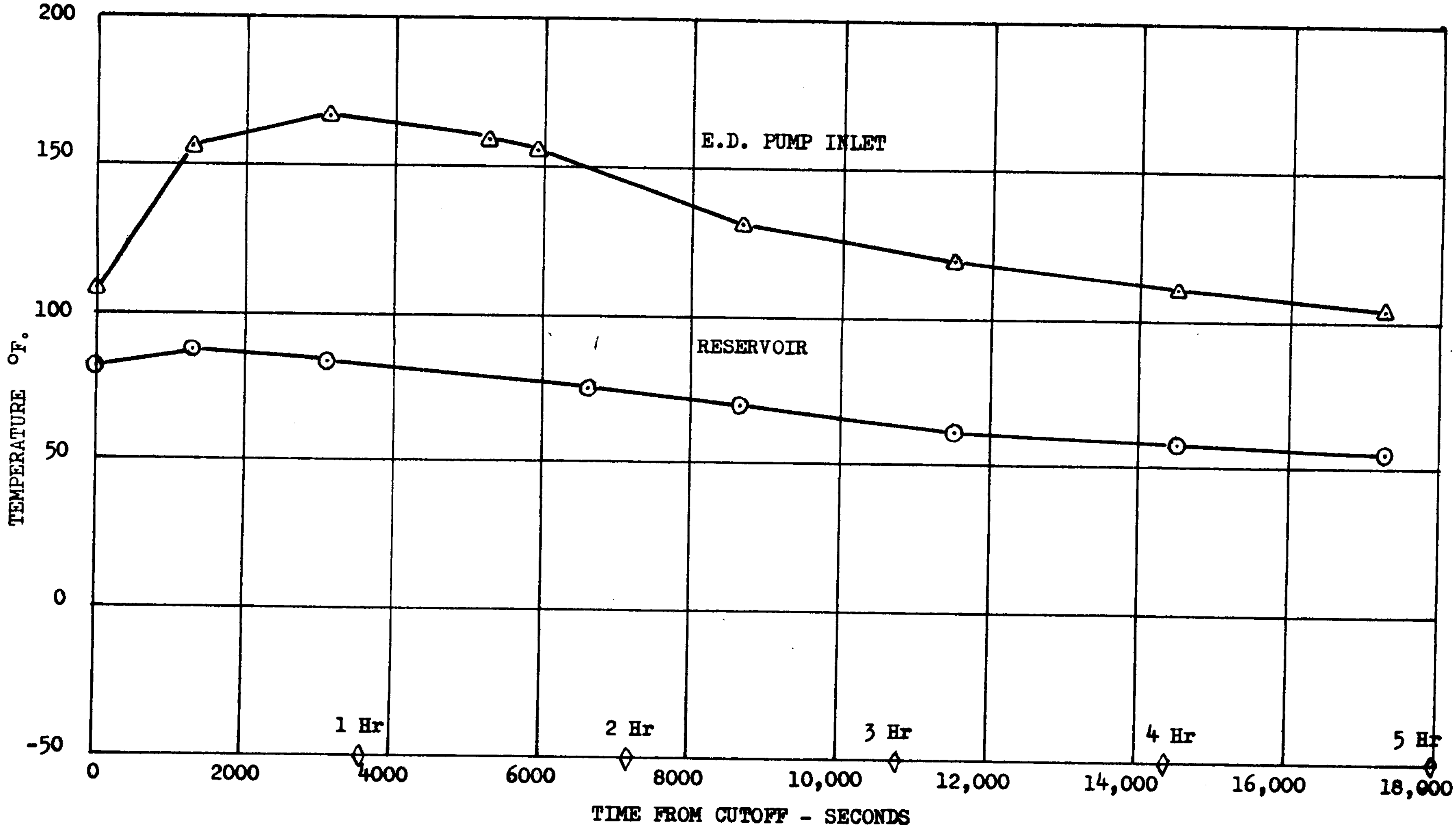
This function is plotted in Figure B-1.

Examination of the actual hydraulic system temperature obtained during the S-IV B-203 (reference 5) orbital flight (see Figure B-2) does not indicate adverse thermal condition of the hydraulic TVC system during the parking orbit phase.



$$K_t = 2\left(\frac{T - 100}{52.2}\right)^2$$

FIGURE B-1- K_t vs TEMPERATURE



HYDRAULIC SYSTEM FLUID TEMPERATURES IN ORBITAL COAST

DATA SOURCE: S-IVB-203 FLIGHT 7/66

Figure B-2

1.2.2 Vibration Factor (K_v) - From the Titan III C Transtage reliability analysis it was determined that

$$K_v = a\,(G_{rms})^2$$

where a = constant

G_{rms} = anticipated vibration level in g rms.

For mechanical and hydraulic equipment (reference 1)

$$K_v = 1000 \text{ for } G_{rms} = 22 \text{ g rms}$$

Solving for a

$$a = 2.07$$

Therefore

$$K_v = 2.07\,(G_{rms})^2$$

This relationship is plotted Figure B-3.

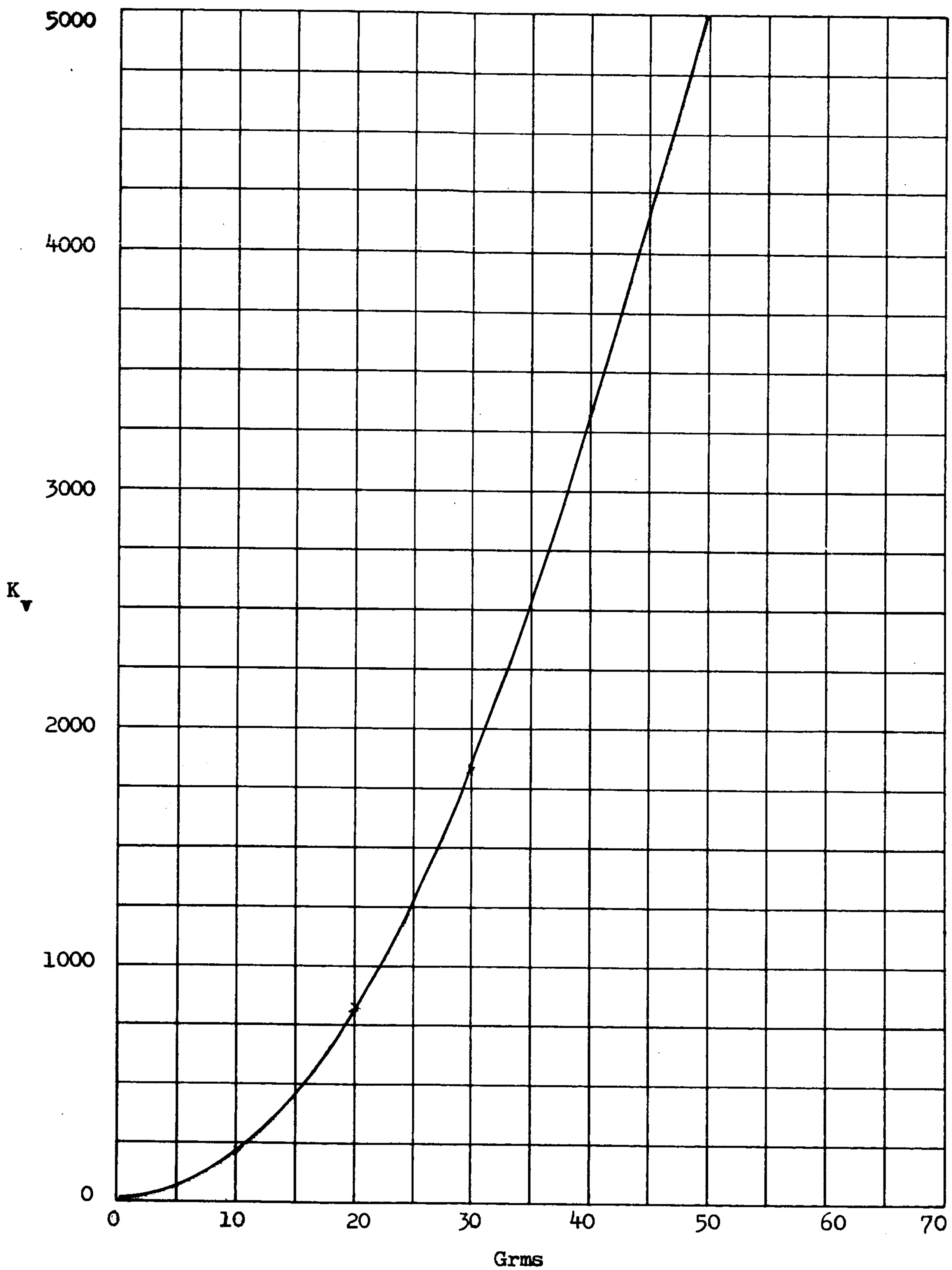


FIGURE B-3 - K_v vs. G_{rms}

1.2.3 Shock Factor (K_s) - From the Titan III C Transtage reliability analysis it was established that the K_s term is

$$K_s = .1105 \, (g \, t)$$

where

g = Shock in g's

t = Time duration of shock loads

This function is plotted in Figure B-4.

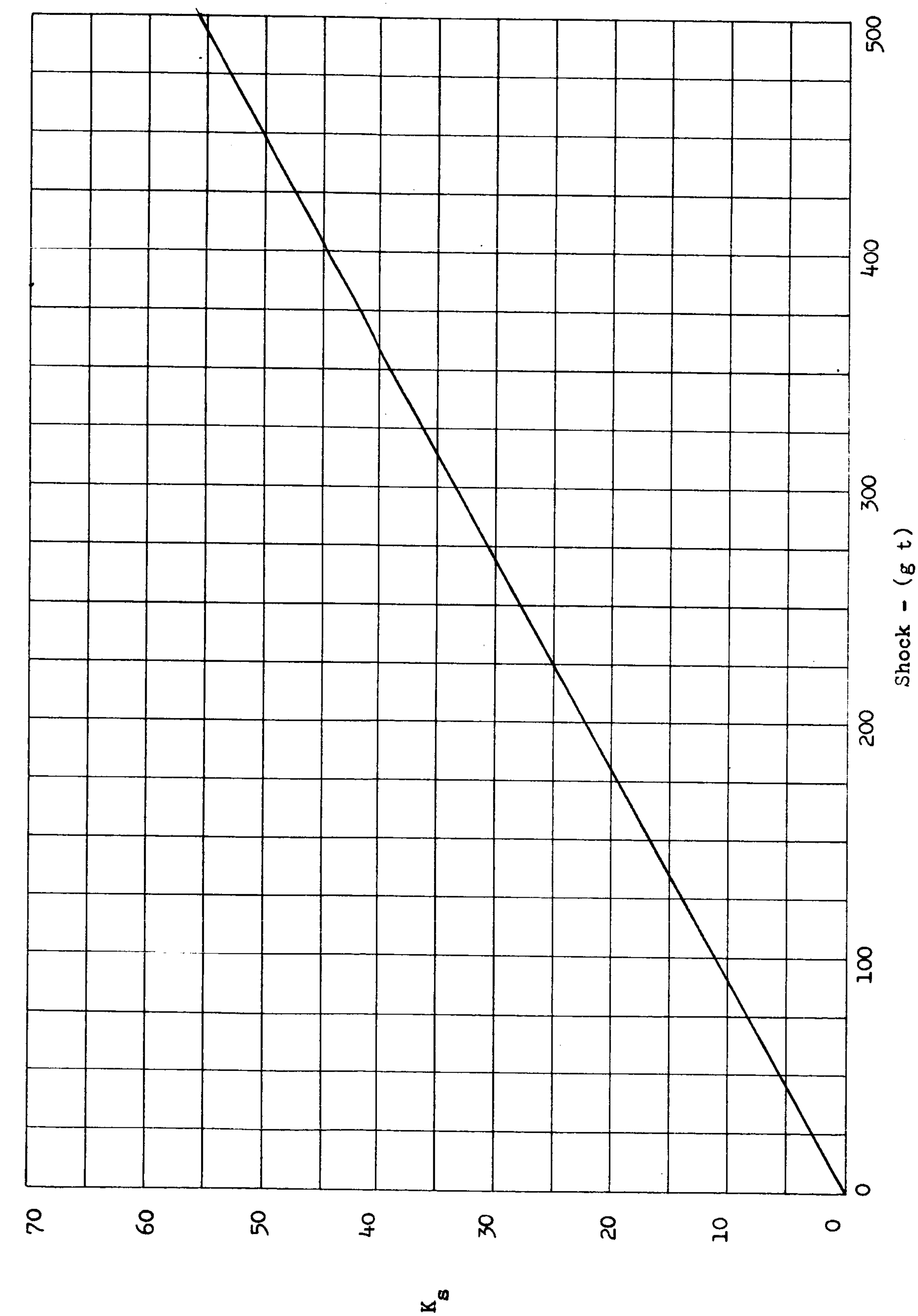


FIGURE B-4 — K_s vs SHOCK

1.2.4 Ambient Pressure Factor (K_p) - Review of the Titan III C Transtage orbital flight and the environmental tests performed on the hydraulic system components does not show any failure that was attributed to high altitude or the absence of atmospheric pressure particularly for short orbiting periods. The term K_p was, therefore, considered to be negligible.

1.3 Analysis of Function Modifier (K_f) - The system function modifier adjusts the component generic failure rate and takes into account the function of the component with respect to the launch vehicle during periods of operation under consideration. The value of K_f varies for 0 when the hydraulic system is not pressurized to 1 for system operation. For this study the K_f factor was considered to be 1 during all phases of the S-IV B stage operation including the coast phase since the hydraulic components would be pressurized by the motorpump operation during the thermal conditioning of the hydraulic system.

1.4 Analysis of Generic Failure Rate Modifiers for the Saturn S-IV B Stage Operation - After determining the relationship between the K_v, K_t, K_s, and K_p terms and their respective environmental parameters and next step was to determine the values of these terms for each hydraulic system component based upon predicted or actual Saturn S-IV B stage flight data.

Table B-2 lists the shock and random vibration levels predicted for the various hydraulic system components of the Saturn S-IV B stage obtained from reference 6. The maximum root-mean-square vibration level was derived from the random vibration requirement for each component by the following relationship:

$$G_{rms} = \left[\int_{f_1}^{f_2} G\ (f)\ df \right]^{1/2}$$

where G (f) = vibration acceleration density

f_2 = maximum vibration frequency

f_1 = minimum vibration frequency

The hydraulic fluid temperatures during the S-IV B boost and coast phase to be used for this study was determined from references 5 and 7. It was assumed that the hydraulic fluid temperature at the end of the boost phase was approximately 40 °F less than predicted which would then correlate with the temperature obtained at the beginning of the coast phase during actual flight. Table B-3 shows the temperature ranges and the average temperature for the S-IV B boost and coast phase.

The values of the K_v, K_t, K_s, and the resulting K_{OP} factors for the hydraulic components of the Saturn S-IV B stage during S-IV B ignition, boost phase, coast phase, and translunar injection phase are shown in Table B-4.

TABLE B-II - VIBRATION AND SHOCK REQUIREMENTS

COMPONENT AND LOCATION	VIBRATION REQUIREMENTS			SHOCK g
	FREQUENCY - CPS	G^2/CPS	GRMS	
Zone: 12-2, 12-3 Actuator Truss Engine Driven Pump Intensifier	20-2000	1.04	45.5	100 g
Zone: 12-2-C Auxiliary Pump Quick Disconnect Transfer Valve	20-100 100-750 750-2000	3 db/oct $0.15g^2$/cps -6.0 db/oct	9.9	--
Zone: 12-2-D Accumulator-Reservoir Filter	20-100 100-650 650-2000	3 db/oct $.1g^2$/cps -6 db/oct	7.3	--

TABLE B-III - TEMPERATURE RANGES FOR SATURN S-IVB TVC HYDRAULIC SYSTEM

SYSTEM - COMPONENT	TEMPERATURE RANGE °F			AVG. TEMPERATURE °F		
	BOOST	COAST	2nd BURN	BOOST	COAST	2nd BURN
System	94-107	--	--	100	--	--
E.D. Pump Inlet	94-107	107-166	107-141	100	141.5	126
Reservoir	94-107	81-86	--	100	72.3	126

TABLE B-IV - OPERATIONAL MODE AND ENVIRONMENTAL FACTORS FOR SATURN S-IVB TVC HYDRAULIC SYSTEM COMPONENTS

COMPONENT AND LOCATION	MISSION PHASE	K_v	K_t	K_s	K_{OP}	K_f	t HRS
Zone 12-2, 13-3	*Start	--	--	--	21,460	10.0	.0005
Actuator, Truss	1st Burn	4280	1	11	4,292	1.0	.0362
E.D. Pump	Coast	1	1.3	1	3.3	1.0	3.944
	2nd Burn	4280	1.1	11	4,292	1.0	.108
Zone 12-2-C	*Start	--	--	--	1,020	10.0	.0005
Aux. Pump	1st Burn	202	1	1	204	1.0	.0362
Quick Disconnect	Coast	1	1.3	1	3	1.0	3.944
Transfer Valve	2nd Burn	202	1	1	204	1.0	.108
Zone 12-2-D	*Start	--	--	--	560	10.0	.0005
Accum-Reservoir	1st Burn	110	1	1	112	1.0	.0362
Filter	Coast	1	1	1	3	1.0	3.944
	2nd Burn	110	1	1	112	1.0	.108
**Tubing	Start	--	--	--	7,680	10.0	.0005
	1st Burn	--	--	--	1,536	1.0	.0362
	Coast	--	--	--	3	1.0	3.944
	2nd Burn	--	--	--	1,536	1.0	.108

* During engine start the K_{OP} was assumed to be five (5) times that during flight and K_f ten (10) times that during flight

** K_{OP} was assumed to be equal to the average of all components

APPENDIX C

Computer Program

Appendix C

Computer Program

1.0 GENERAL PROGRAM DISCUSSION

The computer program derived for the previous study was designed around an IBM 1620, Mark II computer utilizing Fortran II-D language for communicating with the machine. After the completion of the previous study the Martin Marietta Corporation replaced the IBM 1620 computers with the GE 1130 computer. Since for this study it was necessary to modify the previous computer program the entire computer program was converted to Fortran IV language for communicating with the IBM 1130 computer. In converting the computer program, improvements were made such that the punching and transferring output data on IBM cards between component decks were eliminated. The computer program for this study has the capability of storing all output data within the computator such that the transfer of output data from the component subprograms is accomplished automatically. Once the program is loaded into the computer it is only necessary to read the input data into the machine.

Included in this appendix is a description of the input data cards and a listing of the computer program.

The individual component programs are listed in Table C-I.

TABLE C-I

INDIVIDUAL COMPONENT PROGRAMS

PROGRAM	CALL CODE	OLD PROGRAM IDENTIFICATION
STORED SUBROUTINE	ØSUB	O-RING SUBROUTINE
STORED PROGRAM 1	ACT 12	ACTUATOR - PART I AND PART II
STORED PROGRAM 2	ACT 34	ACTUATOR - PART III AND PART IV
STORED PROGRAM 3	ACT 56	ACTUATOR - PART V AND PART VI
STORED PROGRAM 4	TRUSS	TRUSS, TRANSFER VALVE, TUBING, QUICK DISCONNECT
STORED PROGRAM 5	PUMP 1	FIXED ANGLE PUMP - PART I
STORED PROGRAM 6	PUMP 2	FIXED ANGLE PUMP - PART II AND PART III
STORED PROGRAM 7	WPUMP	WOBBLE PLATE PUMP - PART I AND PART II
STORED PROGRAM 8	INFIL	INTENSIFIER, FILTER
STORED PROGRAM 9	RESAC	RESERVOIR - ACCUMULATOR
STORED PROGRAM 10	QDECK	SYSTEM RELIABILITY, OVERALL VEHICLE COST
INPUT DATA PROGRAM	-	---

1.1 INPUT DATA

The input data cards required for the program are shown in Table C-II.

TABLE C-II
INPUT DATA CARDS

Input Card Number	Card Space 1-14	Card Space 15-28	Card Space 29-42	Card Space 43-56				Format
1	CG	CC						
2	CSA	CFA	CYA	CZA				
3	CSB	CFB	CYB	CZB				4E14.6
4	CSC	CFC	CYC	CZC				
5	CSD	CFD	CYD	CZD				
	Card Space 1-10	Card Space 11-20	Card Space 21-30	Card Space 31-40	Card Space 41-50	Card Space 51-60	Card Space 61-70	
6	TORQ	VELS	TRAA	AKVEL	EINT	AVPR	PREI	
7	DPRE	PREM	DMOM	AMAX	AAAA1	AAAA2	AAAA3	
8	AAAA4	AAAA5	AAAA6	AAAA7	AAAA8	AAAA9	AAA10	
9	AIPA1	AIPA2	AIPA3	AIPA4	AKENG	PPP10		7E10.0
10	ANUMB	ANUMV	AMOM	XMDC	XMDD	XMDB	XMDA	
11	XMDE	XXXX1	XXXX2	STV1	STV2	TA	TB	
12	TC	TD	TE	PPPP1	PPPP2	PPPP3	PPPP4	
13	PPPP5	PPPP6	PPPP7	PPPP9	ANGL1	ANGL2		
14	PUMS1	PUMS2	S5	S6	FFFF2	FFFF3	FFFF4	
15	ACCU	REAC	SSS1	SSS2	SSS3	RSPA1	RSPA2	
16	RSPA3	TOILW	RRRR1	RRRR3	RRRR4	QQQQ1	QQQQ2	
17	QQQQ3	VNAFQ						

Table C-2

INPUT DATA CARDS (CONTINUED)

Input Card Number							Format
51	Pump	3.347E+0	3.347E+0	4.724E+0	7.09E-1	1.41E+0	
52	Bearing	3.543E+0	3.543E+0	4.921E+0	7.09E-1	1.48E+0	
53	Array	3.740E+0	3.740E+0	5.118E+0	7.09E-1	1.53E+0	
54		3.937E+0	3.937E+0	5.512E+0	7.87E-1	2.04E+0	
55		4.134E+0	4.134E+0	5.709E+0	7.87E-1	2.12E+0	
56		4.331E+0	4.331E+0	5.906E+0	7.87E-1	2.20E+0	
57		4.724E+0	4.724E+0	6.496E+0	8.66E-1	3.02E+0	
58		5.118E+0	5.118E+0	7.087E+0	9.45E-1	4.02E+0	
59		5.512E+0	5.512E+0	7.480E+0	9.45E-1	4.38E+0	
60		4.724E-1	4.724E-1	1.457E+0	4.724E-1	1.4E-1	
61		5.906E-1	5.906E-1	1.654E+0	5.118E-1	1.9E-1	
62		6.693E-1	6.693E-1	1.851E+0	5.512E-1	2.6E-1	
63		7.874E-1	7.874E-1	2.047E+0	5.906E-1	3.3E-1	5E12.0
64		9.843E-1	9.843E-1	2.441E+0	6.693E-1	5.1E-1	
65		1.181E+0	1.181E+0	2.635E+0	7.480E-1	7.8E-1	
66		1.378E+0	1.378E+0	3.150E+0	8.268E-1	1.00E+0	
67		1.578E+0	1.578E+0	3.543E+0	9.055E-1	1.47E+0	
68		1.772E+0	1.772E+0	3.937E+0	9.843E-1	1.97E+0	
69		1.969E+0	1.969E+0	4.331E+0	1.063E+0	2.56E+0	
70		2.165E+0	2.165E+0	4.724E+0	1.142E+0	3.20E+0	
71		2.362E+0	2.362E+0	5.118E+0	1.221E+0	4.03E+0	
72		2.560E+0	2.560E+0	5.512E+0	1.299E+0	5.05E+0	
73		2.756E+0	2.756E+0	5.906E+0	1.378E+0	5.96E+0	
74		2.963E+0	2.963E+0	6.299E+0	1.457E+0	7.41E+0	
75		3.150E+0	3.150E+0	6.693E+0	1.535E+0	8.79E+0	
76		3.347E+0	3.347E+0	7.087E+0	1.614E+0	1.04E+1	
77		3.543E+0	3.543E+0	7.480E+0	1.693E+0	1.21E+1	
78		4.724E-1	1.103E+0	3.15E-1	4.0E-2		
79		5.906E-1	1.260E+0	3.54E-1	6.0E-2		
80		6.693E-1	1.378E+0	3.94E-1	1.3E-1		
81		7.874E-1	1.654E+0	4.72E-1	1.6E-1		
82		9.843E-1	1.850E+0	4.72E-1	2.5E-1		
83		1.181E+0	2.165E+0	5.12E-1	3.4E-1		
84		1.378E+0	2.441E+0	5.51E-1	5.0E-1		
85		1.578E+0	2.677E+0	5.91E-1	6.3E-1		
86		1.772E+0	2.953E+0	6.30E-1	6.9E-1		
87		1.969E+0	3.150E+0	6.30E-1	7.5E-1		
88		2.165E+0	3.543E+0	7.09E-1	1.00E+0		4E12.0
89		2.362E+0	3.740E+0	7.09E-1	1.25E+0		
90		2.559E+0	3.937E+0	7.09E-1	1.50E+0		
91		2.756E+0	4.331E+0	7.87E-1	1.56E+0		
92		2.953E+0	4.528E+0	7.87E-1	2.13E+0		
93		3.150E+0	4.921E+0	8.66E-1	2.25E+0		
94		3.347E+0	5.118E+0	8.66E-1	2.88E+0		
95		3.543E+0	5.512E+0	9.45E-1	3.50E+0		

Input Card Number												Format
96	TT1	TT2	T4	VLIFA	VLIFP	VHYSB	VTEST					
97	VFLRF	VPNUB	VWCST	VCYCA	VDEVL	VPEND	VOPER					
98	VTCST	VREPR	ANUMB	RUNQ								7E11.4
99	PPPP8	S7	S8	S9	Z1	Z2	Z3	JQ	KQ	LQ	MQ	7F5.1,3X,4I2
100	Repeat 99 RUNQ times with different values											

INPUT DATA CARDS (CONTINUED)

Input Card Number	Array										Format
	Truss Array										
18		.028	.035	.042	.049	.058	.065	.072			
19		.083	.095	.109	.120	10.0					
20		10.15	10.50	11.00	11.60	12.10	12.87	13.44			7E10.0
21		14.23	15.20	17.30	19.61	19.61					
22	Tubing	1.25E-1	2.8E-2	3.2E-2	3.5E-2	4.2E-2	0.0E+0	0.0E+0	0.0E+0	0.0E+0	
23	Array	1.88E-1	3.2E-2	3.5E-2	4.2E-2	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	
24		2.5E-1	3.5E-2	4.2E-2	4.9E-2	5.8E-2	6.5E-2	7.2E-2	0.0E+0	0.0E+0	
25		3.13E-1	3.5E-2	4.2E-2	4.9E-2	5.8E-2	6.5E-2	7.2E-2	0.0E+0	0.0E+0	
26		3.75E-1	3.5E-2	4.2E-2	4.9E-2	5.8E-2	6.5E-2	7.2E-2	0.0E+0	0.0E+0	
27		5.0E-1	3.5E-2	4.2E-2	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	
28		6.25E-1	3.5E-2	4.2E-2	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	
29		7.5E-1	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	9E13.5
30		8.75E-1	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	
31		1.0E+0	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	
32		1.25E+0	4.9E-2	5.8E-2	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	
33		1.5E+0	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	1.34E-1	0.0E+0	
34		1.75E+0	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	1.34E-1	0.0E+0	
35		2.0E+0	6.5E-2	7.2E-2	8.3E-2	9.5E-2	1.09E-1	1.25E-1	1.34E-1	0.0E+0	
36		1.53E-2	1.95E-2	2.4E-2	3.45E-2	4.39E-2	6.72E-2	1.058E-1			7E10.0
37		1.585E-1	2.02E-1	2.43E-1	3.35E-1	4.25E-1	5.1E-1	6.0E-1			
38	Pump	7.87E-1	7.87E-1	1.457E+0	3.54E-1	9.0E-2					
39	Bearing	9.84E-1	9.84E-1	1.654E+0	3.54E-1	1.0E-1					
40	Array	1.181E+0	1.181E+0	1.850E+0	3.54E-1	1.2E-1					
41		1.378E+0	1.375E+0	2.175E+0	3.94E-1	1.9E-1					
42		1.575E+0	1.575E+0	2.441E+0	4.72E-1	2.9E-1					
43		1.772E+0	1.772E+0	2.677E+0	4.72E-1	3.4E-1					
44		1.969E+0	1.969E+0	2.835E+0	4.72E-1	3.5E-1					5E12.0
45		2.165E+0	2.165E+0	3.150E+0	5.12E-1	4.7E-1					
46		2.362E+0	2.362E+0	3.347E+0	5.12E-1	5.1E-1					
47		2.559E+0	2.559E+0	3.543E+0	5.12E-1	5.4E-1					
48		2.756E+0	2.756E+0	3.937E+0	6.30E-1	8.6E-1					
49		2.953E+0	2.953E+0	4.134E+0	6.30E-1	1.04E+0					
50		3.150E+0	3.150E+0	4.331E+0	6.30E-1	1.10E+0					

Normally the Truss Array (data cards 18 thru 21), the Tubing Array (data cards 22 thru 37), and the Pump Bearing Array (data cards 38 thru 95) will not change. The definitions and explanation of the remaining data cards are as follows:

The data cards 1 thru 5 are the reliability environmental modifiers, which are determined from the following equation:

$$\text{Reliability Modifier} = \frac{(K_V)(K_T)(K_S)(K_{op})(K_F)(t)}{10^6}$$

(see Appendix B)

<u>Data Card #1</u>

CG - reliability modifier during ground tests

CC - reliability modifier during countdown

Data card #2 describes the reliability modifiers for the actuator, engine truss and pumps.

<u>Data Card #2</u>

CSA - reliability modifier during engine start

CFA - reliability modifier during 1st burn

CYA - reliability modifier during coast

CZA - reliability modifier during 2nd burn

Data card #3 describes the reliability modifiers for the motorpump, quick disconnect and transfer valves.

Data Card #3

CSB - reliability modifier during engine start

CFB - reliability modifier during 1st burn

CYB - reliability modifier during coast

CZB - reliability modifier during 2nd burn

Data card #4 describes the reliability modifiers for the accumulator-reservoir and filter.

Data Card #4

CSC - reliability modifier during engine start

CFC - reliability modifier during 1st burn

CYC - reliability modifier during coast

CZC - reliability modifier during 2nd burn

Data card #5 describes the reliability modifiers for the tubing and fittings.

Data Card #5

CSD - reliability modifier during engine start

CFD - reliability modifier during 1st burn

CYD - reliability modifier during coast

CZD - reliability modifier during 2nd burn

Data Card #6

TORQ - required maximum torque (stall) to engine (inch-pounds)

VELS - required maximum angular velocity (based on loaded actuator velocity) (Radians/Second)

TRAA - required total operating angular travel (Radians) (does not include snubbing)

Data Card #6 - Continued

AKVEL - required open loop gain of actuator (1/Second)

EINT - engine inertia (inch-pound-second^2)

AVPR - ratio of actual valve flow rate to required valve flow rate (loaded actuator) NOTE: this parameter is included for the case where a miniature servo-valve could be used but a larger valve along with a flow limiter is actually employed.

PREI - lowest system pressureto be investigated (pounds/inch^2)

Data Card #7

DPRE - pressure increment to be used during program run (pounds/inch^2)

PREM - maximum system pressure to be investigated (pounds/inch^2)

DMOM - moment arm increment to be used during program run (inches)

AMAX - longest moment arm to be investigated (inches)

AAAA1 - is actuator pressure feedback or derivative pressure feedback valve used? (If answer is yes, set AAAA1) = 1.0, if no, set to 0.0)

AAAA2 - is actuator mechanical feedback used? (If answer is yes, set AAAA2 = 1.0, if no, set to 0.0)

AAAA3 - is actuator rod end housing used for bearing surface? (If yes, set AAAA3 = 1.0, if no, set to 0.0)

Data Card #8

AAAA4 - is actuator derivative pressure feedback used? (If yes, set AAAA4 = 1.0, if no, set to 0.0)

AAAA5 - is actuator mechanical feedback used? (If yes, set AAAA5 = 1.0, if no, set to 0.0)

AAAA6 - is actuator static load error washout used? (If yes, set AAAA6 = 1.0, if no, set to 0.0)

AAAA7 - is actuator flow limiter used? (If yes, set AAAA7 = 1.0, if no, set to 0.0)

AAAA8 - are actuator snubbers used? (If yes, set AAAA8 = 1.0, if no, set to 0.0)

AAAA9 - is the actuator a new design? (If yes, set AAAA9 = 1.0, set to 0.0)

AAA10 - Does the actuator require qualification? (If yes, set AAA10 =1.0, if no set to 0.0)

Data Card #9

AIPA1 - is the actuator direct current position instrumentation used? (If yes, set AIPA1 = 1.0, if no, set to 0.0)

AIPA2 - is actuator direct current feedback used? (If yes, set AIPA2 = 1.0, if no, set to 0.0)

AIPA3 - are actuator position switches used? (If yes, set AIPA3 = 1.0, if no, set to 0.0)

AIPA4 - is potentiometer body required? (If yes, set AIPA4 = 1.0, if no, set to 0.0)

AKENG - fixed spring rate of engine bell (pounds/inch)

PPP10 - ratio of the required pump flow for intensifier to system flow (unloaded actuators). The seventh parameter of data card #4 is left blank.

Data Card #10

ANUMB - number of actuator per hydraulic system

ANUMV - number of actuator per system transfer valve

AMOM - shortest moment arm to be investigated (inches)

XMDC - truss dimension (inches) see Figure 1

XMDD - truss dimension (inches) see Figure 1

XMDB - truss dimension (inches) see Figure 1

XMDA - truss dimension (inches) see Figure 1

Data Cards #11

XMDE - truss dimension (inches) see Figure 1

XXXX1 - is truss a new design? (If yes, set XXXX1 = 1.0, if no, set to 0.0)

XXXX2 - is tubing a new design? (If yes, set XXXX2 = 1.0, if no, set to 0.0)

STV1 - is transfer valve a new design? (If yes, set STV1 = 1.0, if no, set to 0.0)

STV2 - does transfer valve require qualification? (If yes, set STV2 = 1.0, if no, set to 0.0)

TA - tube length from ground checkout pump to system pump (inches)

TB - tube length from pump to filter (inches)

Data Card #12

TC - tube length from filter to reservoir-accumulator (inches)

TB - tube length from reservoir-accumulator to transfer valve (inches)

TE - tube length from transfer valve to actuator (inches)

PPPP1 - ratio of the maximum required pump flow rate (for fixed angle pump) to maximum system flow rate (unloaded actuators)

PPPP2 - is fixed angle pump a new design? (If yes, set PPPP2 = 1.0, if no, set to 0.0)

PPPP3 - does fixed angle pump required qualification? (If yes, set PPPP3 = 1.0, if no, set to 0.0)

PPPP4 - is wobble plate pump a new design? (If yes, set PPPP4 = 1.0, if no, set to 0.0)

Data Card #13

PPPP5 - does wobble plate pump require qualification? (If yes, set PPPP5 = 1.0, if no, set to 0.0)

PPPP6 - is intensifier a new design? (If yes, set PPPP6 = 1.0, if no, set to 0.0)

PPPP7 - does intensifier require qualification? (If yes, set PPPP7 = 1.0, if no, set to 0.0)

ANGL1 - angle of fixed angle pump (radians)

ANGL2 - angle of wobble plate pump (radians)

Data Card #14

PUMS1 - fixed angle pump speed (revolutions per second)

PUMS2 - wobble plate pump speed (revolutions per second)

S5 - is compensator used in fixed angle pump? (If yes, set S5 = 1.0, if no, set to 0.0)

S6 - is compensator used in wobble plate pump? (If yes, set S6 = 1.0, if no set to 0.0)

FFFF2 - ratio of required filter flow to the maximum actuator flow (unloaded actuators)

FFFF3 - is filter a new design? (If yes, set FFFF3 = 1.0, if no, set to 0.0)

FFFF4 - does filter require qualification? (If yes, set FFFF4 = 1.0, if no, set to 0.0)

Data Card #15

ACCU - when accumulator is used by itself (set ACCU = 1.0, if not, set to 0.0)

REAC - when reservoir-accumulator are used separate. (set REAC = 1.0, if not, set to 0.0)

SSSI - is accumulator used? (If yes, set SSSI = 1.0, if no, set to 0.0)

SSS2 - ratio of return pressure to system pressure if return pressure is a function of system pressure

SSS3 - return pressure as fixed actual value if the return pressure is to be held constant (pounds/inch^2)

RSPA1 - is direct current position instrumentation used in the reservoir? (If yes, set RSPA1 = 1.0, if no, set to 0.0)

RSPA2 - is position switch used in reservoir? (If yes, set RSPA2 = 1.0, if no, set to 0.0)

Data Card #16

RSPA3 - is potentiometer body integral part of the reservoir? (If yes, set RSPA3 = 1.0, if no, set to 0.0)

TOILW - hydraulic fluid density used in system (pounds per cubic inch)

RRRR1 - ratio of total volume of fluid supplied by the accumulator to the total volume of fluid consumed by all actuators when traveling full stroke

RRRR3 - is reservoir and/or accumulator a new design? (If yes, set RRRR3 = 1.0, if no, set to 0.0)

RRRR4 - does reservoir and/or accumulator require qualification? (If yes, set RRRR4 = 1.0, if no, set to 0.0)

QQQQ1 - is quick disconnect a new design? (If yes, set QQQQ1 = 1.0, if no, set to 0.0)

QQQQ2 - does quick disconnect require qualification? (If yes, set QQQQ2 = 1.0, if no, set to 0.0)

Data Card #17

QQQQ3 - ratio of quick disconnect rated flow to the maximum system flow rate (unloaded actuators)

VNAFQ - required actuator system natural frequency with all springs included (radians/second)

Data Card #96

TT1 - ground operating time (see note on data card 98)

TT2 - countdown time (see note on data card 98)

TT4 - flight operating time (see note on data card 98)

VLIFA - required life of a single actuator includes total running time - ground checkout, flight, etc., (hours)

Data Card #96 - (Continued)

VLIFP - required life of a single pump. Includes total running time - ground checkout, flight, etc., (hours)

VHYSB - total number of independent hydraulic systems to be used for the particular stage of the vehicle

VTEST - total number of tests required for a single hydraulic system under investigation

Data Card #97

VFLRF - cost of flight failure

VPNUB - total number of launch vehicles within the program

VWCST - the cost of one pound of weight for a particular stage being investigated (dollars per pound)

VCYCA - required life of a single actuator in total number of cycles - ground checkout, flight, etc.(cycles)

VDEVL - total time allowed to develop the complete hydraulic system. Equal to the total time from contract go-ahead until a qualified system is delivered (weeks)

VPEND - dollar penalty per week for delays in development time for the complete system (dollars per week)

VOPER - required time for average hydraulic test on the system under consideration (hours)

Data Card #98

VTCST - total cost of average test performed on a single hydraulic system under investigation (dollars per test)

VREPR - average ratio of component repair cost to initial component cost

ANUMP - number of actuators main pumps

RUNQ - number of cases to be run with actuator variations

Data Card #99 (98 + RUNQ)

PPPP8 - which airborne pump used for ground checkout? (No airborne pump used set PPPP8 = 0.0, fixed angle pump used set PPPP8 = 1.0, wobble plate pump used set PPPP8 = 2.0)

S7 - number of fixed angle pumps per hydraulic system

S8 - number of wobble plate pumps per hydraulic system

S9 - number of intensifiers per hydraulic system

Z1 - number of accumulators per hydraulic system

Z2 - number of reservoirs per hydraulic system

Z3 - number of reservoir-accumulator and filters per hydraulic system

JQ - actuator configuration; JQ = 1 standard, JQ = 2 majority vote, JQ = 2 tandem

KQ - system, configuration; KQ = 1 single, KQ = 2 dual

LQ - pump configuration*

MQ - number of run

*LQ = 1 - intensifier primary power source, fixed angle pump auxilliary power source

LQ = 2 - intensifier primary power source, fixed wobble plate pump auxilliary power source

LQ = 3 - fixed angle pump primary power source, fixed wobble plate pump auxilliary power source

LQ = 4 - fixed wobble plate pump primary power source, fixed angle pump primary power source

1.2 METHODS FOR STUDYING ALTERNATE REDUNDANT CONFIGURATIONS

The computer program has the capability of evaluating any of the three basic types of actuators for either a single or dual hydraulic system. It is only necessary to change card 99 to complete a study of these configurations.

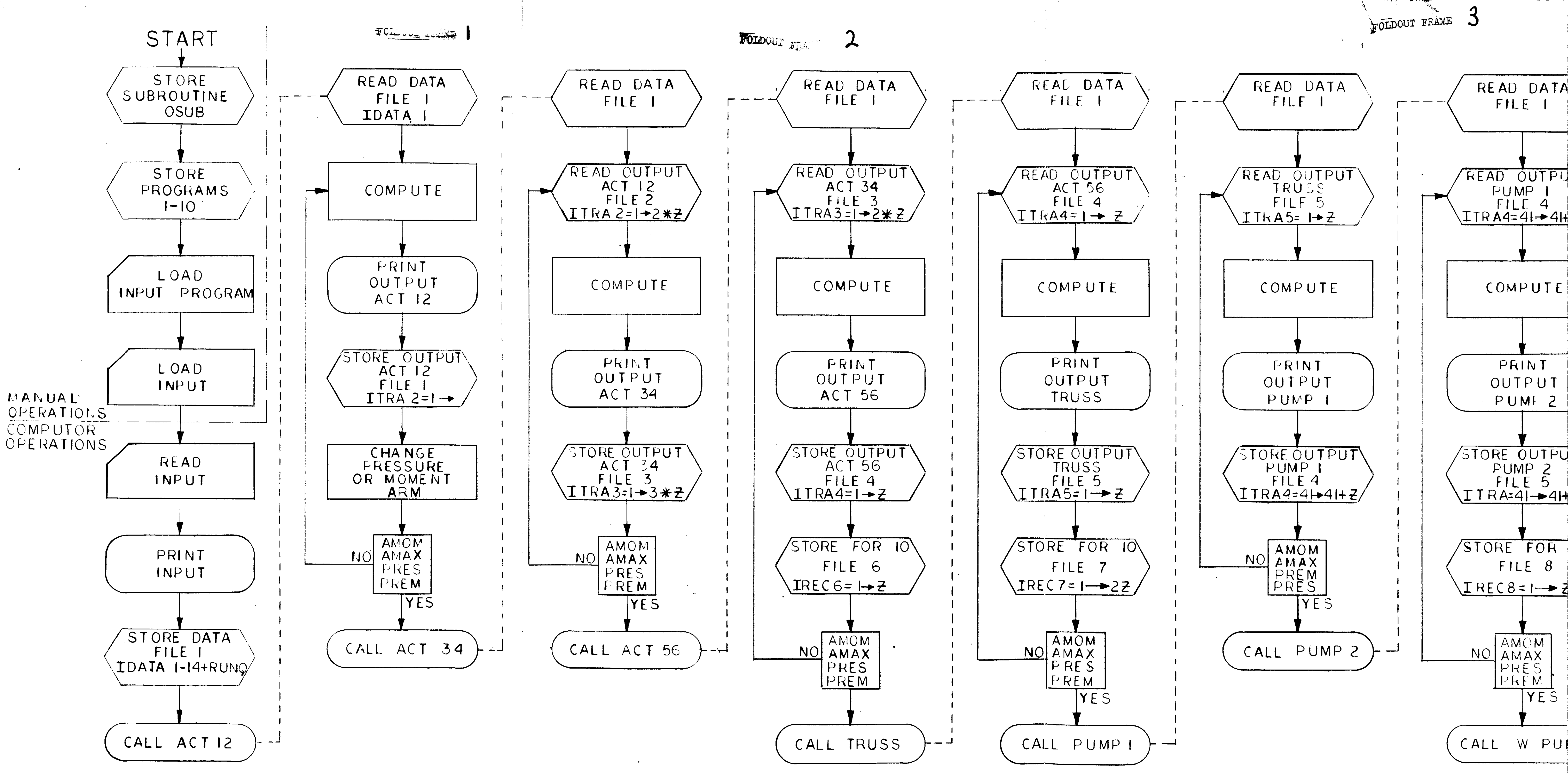
The type of actuator is determined by setting JQ to 1, 2, or 3.

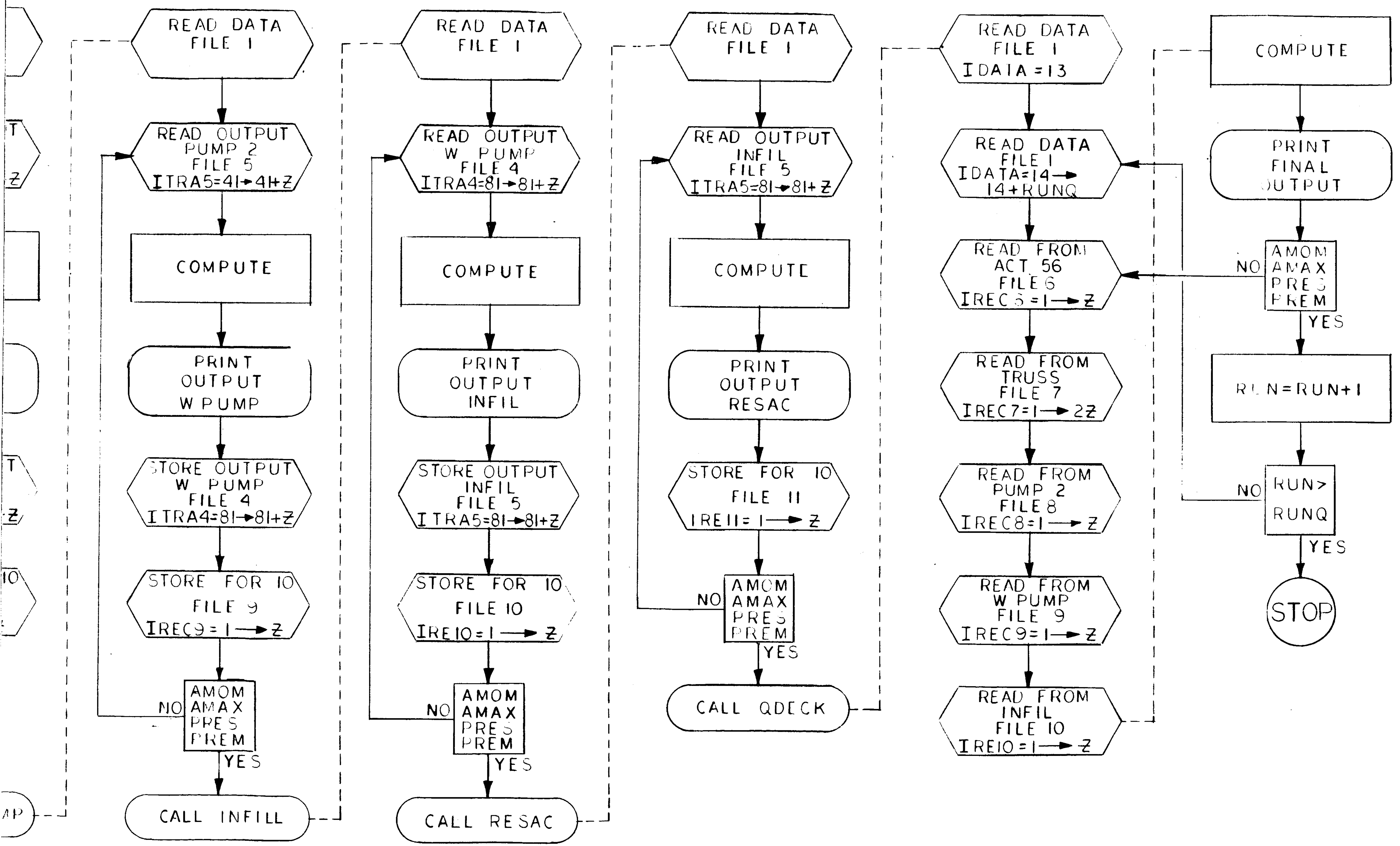
A change to the dual power supply system can also be made by changing KQ from 1 to 2. Also the appropriate primary power supply and accumulator-reservoir quantities must be altered to reflect a change in KQ from 1 to 2.

One limitation to the number of configurations which can be investigated without re-running all the component decks does exist. The initial data inputs, cards 6 through 11, size the pumps on a proportional quantity of the maximum actuator flow. Thus, when a certain type pump is sized for ground checkout, it can not be resized for flight since the individual component programs will record data for only one size of each pump at any one time. To change the type pump used for flight it is necessary to re-run the complete component program with the appropriate flow change. However, an intensifier which would be used only for flight power generation, can be sized during the initial component calculations and can be investigated by changing only card 99.

1.3 Computer Program Listing

The following is a listing of the component and subroutine programs which form the overall final study program. The definition of the terms used in the program are given in reference 1. Figure C-1 is the flow chart of the computer program.


FOLDOUT FRAME 1
FOLDOUT FRAME 2
FOLDOUT FRAME 3
START
STORE SUBROUTINE OSUB
STORE PROGRAMS 1-10
LOAD INPUT PROGRAM
LOAD INPUT
MANUAL OPERATIONS
COMPUTOR OPERATIONS
READ INPUT
PRINT INPUT
STORE DATA FILE 1 IDATA 1-14+RUNO
CALL ACT 12
READ DATA FILE 1 IDATA 1
COMPUTE
PRINT OUTPUT ACT 12
STORE OUTPUT ACT 12 FILE 1 ITRA 2=1→
CHANGE PRESSURE OR MOMENT ARM
AMOM AMAX PRES PREM
NO
YES
CALL ACT 34
READ DATA FILE 1
READ OUTPUT ACT 12 FILE 2 ITRA 2=1→2*Z
COMPUTE
PRINT OUTPUT ACT 34
STORE OUTPUT ACT 34 FILE 3 ITRA3=1→3*Z
AMOM AMAX PRES PREM
NO
YES
CALL ACT 56
READ DATA FILE 1
READ OUTPUT ACT 34 FILE 3 ITRA3=1→2*Z
COMPUTE
PRINT OUTPUT ACT 56
STORE OUTPUT ACT 56 FILE 4 ITRA4=1→Z
STORE FOR 10 FILE 6 IREC6=1→Z
AMOM AMAX PRES PREM
NO
CALL TRUSS
READ DATA FILE 1
READ OUTPUT ACT 56 FILE 4 ITRA4=1→Z
COMPUTE
PRINT OUTPUT TRUSS
STORE OUTPUT TRUSS FILE 5 ITRA5=1→Z
STORE FOR 10 FILE 7 IREC7=1→2Z
AMOM AMAX PRES PREM
NO
YES
CALL PUMP 1
READ DATA FILE 1
READ OUTPUT TRUSS FILE 5 ITRA5=1→Z
COMPUTE
PRINT OUTPUT PUMP 1
STORE OUTPUT PUMP 1 FILE 4 ITRA4=41→41+Z
AMOM AMAX PREM PRES
NO
YES
CALL PUMP 2
READ DATA FILE 1
READ OUTPUT PUMP 1 FILE 4 ITRA4=41→41+
COMPUTE
PRINT OUTPUT PUMP 2
STORE OUTPUT PUMP 2 FILE 5 ITRA=41→41+
STORE FOR FILE 8 IREC8=1→Z
AMOM AMAX PRES PREM
NO
YES
CALL W PU



Z = TOTAL NUMBER OF PRESSURE AND MOMENT ARM CHANGES

FIGURE C-1
COMPUTER PROGRAM
FLOW DIAGRAM

```
C                               INPUT DATA PROGRAM

C  INPUT DATA DECK
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      DIMENSION T1(12),T2(12),TUBE(9,14),FIT(14),BRI(5,22)
      DIMENSION BTI(5,18),BTII(4,18)
      DIMENSION  XA(3),XB(3),XC(3),XD(3)
  920 FORMAT (2X,7E13.5)
  820 FORMAT (7E10.0)
  850 FORMAT (4E14.6)
  600 FORMAT (7F5.1,3X,4I2)
  601 FORMAT (7E11.4)
  700 FORMAT(1H1,2X,60HTHRUST VECTOR CONTROL SYSTEMS OPTIMIZATION PROGRA
     1M                ,//)
  103 FORMAT (5E12.0)
  104 FORMAT (4E12.0)
  203 FORMAT (3X,5E13.5)
  204 FORMAT (4X,4E13.5)
  899 FORMAT (9E8.0)
  999 FORMAT (9E13.5)
      IDATA = 1
      READ  (2,850) CG,CC
      READ  (2,850) CSA,CFA,CYA,CZA,CSB,CFB,CYB,CZB,CSC,CFC,CYC,CZC,CSD,
     1  CFD,CYD,CZD
      READ (2,820)   TORQ,VELS,TRAA,AKVEL,EINT,AVPR,PREI
     1          ,DPRE,PREM,DMOM,AMAX,AAAA1,AAAA2,AAAA3
     2          ,AAAA4,AAAA5,AAAA6,AAAA7,AAAA8,AAAA9,AAA10
     3          ,AIPA1,AIPA2,AIPA3,AIPA4,AKENG,PPP10
      READ (2,820)   ANUMB,ANUMV,AMOM,XMDC,XMDD,XMDB,XMDA
     1          ,XMDE,XXXX1,XXXX2,STV1,STV2,TA,TB
     2          ,TC,TD,TE,PPPP1,PPPP2,PPPP3,PPPP4
     3          ,PPPP5,PPPP6,PPPP7,PPPP9,ANGL1,ANGL2
      READ (2,820)   PUMS1,PUMS2,S5,S6,FFFF2,FFFF3,FFFF4
     1          ,ACCU,REAC,SSSI,SSS2,SSS3,RSPA1,RSPA2
     2          ,RSPA3,TOILW,RRRR1,RRRR3,RRRR4,QQQQ1,QQQQ2
     3          ,QQQQ3,VNAFQ
      READ  (2,820) (T1(I),I=1,12)
      READ  (2,820) (T2(I),I=1,12)
      READ  (2,899) ((TUBE(M,N),M=1,9),N=1,14)
      READ (2,820)  (FIT(N),N=1,14)
      READ  (2,103) ((BRI(M,N),M=1,5),N=1,22)
      READ  (2,103) ((BTI(M,N),M=1,5),N=1,18)
      READ  (2,104) ((BTII(M,N),M=1,4),N=1,18)
      VELA=AVPR*VELS
      XA(1) = CFA
      XA(2) = CYA
      XA(3) = CZA
      XB(1) = CFB
      XB(2) = CYB
      XB(3) = CZB
```

```
      XC(1) = CFC
      XC(2) = CYC
      XC(3) = CZC
      XD(1) = CFD
      XD(2) = CYD
      XD(3) = CZD
      WRITE (1-IDATA) AMAX,PREM,TORQ,VELA,PREI,AMOM,TRAA,DMOM,DPRE
     1  ,AAAA1,AAAA2,AAAA3,AAAA8
      WRITE (1-IDATA) AMAX,PREM,TORQ,VELA,AAAA2,AAAA4,AAAA6,AAAA7,
     1   AAAA8
      WRITE (1-IDATA) AMAX,PREM,TORQ,VELA,AAAA1,AAAA2,AAAA4,AAAA5,AAAA6,
     1  AAAA7,AAAA8,AAAA9,AAA10,AKVEL,TOILW,AIPA1,AIPA2,AIPA3,AIPA4,
     2 CG,CC,CSA,CFA,CYA,CZA
      WRITE (1-IDATA) AMAX,PREM,TORQ,VELA,EINT,ANUMB,XMDC,XMDD,XMDB,
     1 XMDA,XMDE,AAAA6,XXXX1,XXXX2,STV1,STV2,TA,TB,TC,TD,TE,QQQQ1,
     2 QQQQ2,QQQQ3,VNAFQ,ANUMV,CG,CC,CSA,CSB,CSD,
     3 (T1(I),I=1,12),(T2(I),I=1,12),(FIT(N),N=1,14)
      WRITE (1-IDATA)    ((TUBE(M,N),M=1,9),N=1,14)
      WRITE (1-IDATA) AMAX,PREM,ANUMB,PPPP1,ANGL1,PUMS1,((BRI(M,N),M=
     1  1,5),N=1,22)
      WRITE (1-IDATA)   ((BTI(M,N),M=1,5),N=1,18)
      WRITE (1-IDATA)   ((BTII(M,N),M=1,4),N=1,18)
      WRITE (1-IDATA) AMAX,PREM,PPPP2,PPPP3,S5,TOILW,CG,CC,CSB
      WRITE (1-IDATA) AMAX,PREM,ANUMB,PPPP4,PPPP5,PPPP9,ANGL2,PUMS2,S6,
     1  TOILW,CC,CG,CSA
      WRITE (1-IDATA) AMAX,PREM,ANUMB,PPP10,PPPP6,PPPP7,ANGL2,PUMS2,
     1  FFFF2,FFFF3,FFFF4,TOILW,CG,CC,CSA,CSC
      WRITE (1-IDATA) AMAX,PREM,ANUMB,SSSI,SSS2,SSS3,RSPA1,RSPA2,RSPA3,
     1  TOILW,RRRR1,RRRR3,RRRR4,ACCU,REAC,CG,CC,CSC
      WRITE (3,700)
      WRITE (3,850) CG,CC
      WRITE (3,850) CSA,CFA,CYA,CZA,CSB,CFB,CYB,CZB,CSC,CFC,CYC,CZC,CSD,
     1  CFD,CYD,CZD
      WRITE (3,920)   TORQ,VELS,TRAA,AKVEL,EINT,AVPR,PREI
     1        ,DPRE,PREM,DMOM,AMAX,AAAA1,AAAA2,AAAA3
     2        ,AAAA4,AAAA5,AAAA6,AAAA7,AAAA8,AAAA9,AAA10
     3        ,AIPA1,AIPA2,AIPA3,AIPA4,AKENG,PPP10
      WRITE (3,920)   ANUMB,ANUMV,AMOM,XMDC,XMDD,XMDB,XMDA
     1        ,XMDE,XXXX1,XXXX2,STV1,STV2,TA,TB
     2        ,TC,TD,TE,PPPP1,PPPP2,PPPP3,PPPP4
     3        ,PPPP5,PPPP6,PPPP7,PPPP9,ANGL1,ANGL2
      WRITE (3,920)   PUMS1,PUMS2,S5,S6,FFFF2,FFFF3,FFFF4
     1        ,ACCU,REAC,SSSI,SSS2,SSS3,RSPA1,RSPA2
     2        ,RSPA3,TOILW,RRRR1,RRRR3,RRRR4,QQQQ1,QQQQ2
     3        ,QQQQ3,VNAFQ
      WRITE (3,920) (T1(I),I=1,12)
      WRITE (3,920) (T2(I),I=1,12)
      WRITE (3,999) ((TUBE(M,N),M=1,9),N=1,14)
      WRITE (3,920) (FIT(N),N=1,14)
      WRITE (3,203) ((BRI(M,N),M=1,5),N=1,22)
      WRITE (3,203) ((BTI(M,N),M=1,5),N=1,18)
      WRITE (3,204) ((BTII(M,N),M=1,4),N=1,18)
      READ  (2,601) TT1,TT2,T4,VLIFA,VLIFP,VHYSB,VTEST,VFLRF,VPNUB,VWCST
     1      ,VCYCA,VDEVL,VPEND,VOPER,VTCST,VREPR,ANUMB,RUNQ
      WRITE(1-IDATA)TT1,TT2,T4,VLIFA,VLIFP,VHYSB,VTEST,VFLRF,VPNUB,VWCST
     1      ,VCYCA,VDEVL,VPEND,VOPER,VTCST,VREPR,ANUMB,RUNQ,
     2 XA(1),XA(2),XA(3),XB(1),XB(2),XB(3),XC(1),XC(2),XC(3),XD(1),XD(2)
     3  ,XD(3)
      WRITE (3,601) TT1,TT2,T4,VLIFA,VLIFP,VHYSB,VTEST,VFLRF,VPNUB,VWCST
     1      ,VCYCA,VDEVL,VPEND,VOPER,VTCST,VREPR,ANUMB,RUNQ
```

```
      NRUNQ = RUNQ
      DO 500 I=1,NRUNQ
      READ  (2,600)   PPPP8,S7,S8,S9,Z1,Z2,Z3,JQ,KQ,LQ,MQ
      WRITE (1-IDATA) PPPP8,S7,S8,S9,Z1,Z2,Z3,JQ,KQ,LQ,MQ
      WRITE (3,600)   PPPP8,S7,S8,S9,Z1,Z2,Z3,JQ,KQ,LQ,MQ
  500 CONTINUE
      CALL LINK (ACT12)
      END
// XEQ
         .4E-2           .13E-4
      .1073E-3        .15537E-3        .11832E-4       .463536E-3
        .51E-5        .73848E-5        .11832E-4       .220320E-4
        .28E-5        .40544E-5        .11832E-4        .12096E-4
       .384E-4       .556032E-4        .11832E-4       .165888E-3
  500000.      .1395       .2445       18.0      17400.      1.0      3000.
   500.       3500.         1.0        12.0         1.0      1.0       0.0
    1.0         1.0         0.0         0.0         0.0      1.0       1.0
    1.0         0.0         0.0         1.0      222700.     0.4        11.0
    2.0         2.0        11.0        6.31        27.8      5.81      18.14
    4.5         1.0         1.0         1.0         0.0      24.0      12.0
   12.0        12.0       108.0         0.1         1.0       1.0       1.0
    1.0         1.0         1.0         0.4        .262      .262
  243.0       117.0         1.0         1.0        .2        1.0       1.0
    0.0         1.0         1.0       .0133        10.0      1.0       1.0
    1.0       .0314         1.0         1.0         1.0      1.0       1.0
    1.0        37.0
   .028        .035        .042        .049        .058      .065      .072
   .083        .095        .109        .120        10.0
  10.15       10.50       11.00       11.60       12.10     12.87     13.44
  14.23       15.20       17.30       19.61       19.61
 1.25E-1  2.8E-2  3.2E-2  3.5E-2  4.2E-2  0.0E+0  0.0E+0  0.0E+0  0.0E+0
 1.88E-1  3.2E-2  3.5E-2  4.2E-2  0.0E+0  0.0E+0  0.0E+0  0.0E+0  0.0E+0
  2.5E-1  3.5E-2  4.2E-2  4.9E-2  5.8E-2  6.5E-2  7.2E-2  0.0E+0  0.0E+0
 3.13E-1  3.5E-2  4.2E-2  4.9E-2  5.8E-2  6.5E-2  7.2E-2  0.0E+0  0.0E+0
 3.75E-1  3.5E-2  4.2E-2  4.9E-2  5.8E-2  6.5E-2  7.2E-2  0.0E+0  0.0E+0
  5.0E-1  3.5E-2  4.2E-2  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2
 6.25E-1  3.5E-2  4.2E-2  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2
  7.5E-1  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1
 8.75E-1  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1
  1.0E+0  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1
 1.25E+0  4.9E-2  5.8E-2  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1
  1.5E+0  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1 1.34E-1  0.0E+0
 1.75E+0  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1 1.34E-1  0.0E+0
  2.0E+0  6.5E-2  7.2E-2  8.3E-2  9.5E-2 1.09E-1 1.25E-1 1.34E-1  0.0E+0
   1.53E-2    1.95E-2    2.4E-2    3.45E-2    4.39E-2    6.72E-2   1.058E-1
  1.585E-1    2.02E-1   2.43E-1    3.35E-1    4.25E-1     5.1E-1     6.0E-1
     7.87E-1       7.87E-1      1.457E+0      3.54E-1      9.0E-2
     9.84E-1       9.84E-1      1.654E+0      3.54E-1      1.0E-1
    1.181E+0      1.181E+0      1.850E+0      3.54E-1      1.2E-1
    1.378E+0      1.375E+0      2.175E+0      3.94E-1      1.9E-1
    1.575E+0      1.575E+0      2.441E+0      4.72E-1      2.9E-1
    1.772E+0      1.772E+0      2.677E+0      4.72E-1      3.4E-1
    1.969E+0      1.969E+0      2.835E+0      4.72E-1      3.5E-1
    2.165E+0      2.165E+0      3.150E+0      5.12E-1      4.7E-1
    2.362E+0      2.362E+0      3.347E+0      5.12E-1      5.1E-1
    2.559E+0      2.559E+0      3.543E+0      5.12E-1      5.4E-1
    2.756E+0      2.756E+0      3.937E+0      6.30E-1      8.6E-1
    2.953E+0      2.953E+0      4.134E+0      6.30E-1     1.04E+0
    3.150E+0      3.150E+0      4.331E+0      6.30E-1     1.10E+0
    3.347E+0      3.347E+0      4.724E+0      7.09E-1     1.41E+0
```

```
3.543E+0    3.543E+0    4.921E+0    7.09E-1     1.48E+0
3.740E+0    3.740E+0    5.118E+0    7.09E-1     1.53E+0
3.937E+0    3.937E+0    5.512E+0    7.87E-1     2.04E+0
4.134E+0    4.134E+0    5.709E+0    7.87E-1     2.12E+0
4.331E+0    4.331E+0    5.906E+0    7.87E-1     2.20E+0
4.724E+0    4.724E+0    6.496E+0    8.66E-1     3.02E+0
5.118E+0    5.118E+0    7.087E+0    9.45E-1     4.02E+0
5.512E+0    5.512E+0    7.480E+0    9.45E-1     4.38E+0
4.724E-1    4.724E-1    1.457E+0    4.724E-1    1.4E-1
5.906E-1    5.906E-1    1.654E+0    5.118E-1    1.9E-1
6.693E-1    6.693E-1    1.851E+0    5.512E-1    2.6E-1
7.874E-1    7.874E-1    2.047E+0    5.906E-1    3.3E-1
9.843E-1    9.843E-1    2.441E+0    6.693E-1    5.1E-1
1.181E+0    1.181E+0    2.635E+0    7.480E-1    7.8E-1
1.378E+0    1.378E+0    3.150E+0    8.268E-1    1.00E+0
1.578E+0    1.578E+0    3.543E+0    9.055E-1    1.47E+0
1.772E+0    1.772E+0    3.937E+0    9.843E-1    1.97E+0
1.969E+0    1.969E+0    4.331E+0    1.063E+0    2.56E+0
2.165E+0    2.165E+0    4.724E+0    1.142E+0    3.20E+0
2.362E+0    2.362E+0    5.118E+0    1.221E+0    4.03E+0
2.560E+0    2.560E+0    5.512E+0    1.299E+0    5.05E+0
2.756E+0    2.756E+0    5.906E+0    1.378E+0    5.96E+0
2.963E+0    2.963E+0    6.299E+0    1.457E+0    7.41E+0
3.150E+0    3.150E+0    6.693E+0    1.535E+0    8.79E+0
3.347E+0    3.347E+0    7.087E+0    1.614E+0    1.04E+1
3.543E+0    3.543E+0    7.480E+0    1.693E+0    1.21E+1
4.724E-1    1.103E+0    3.15E-1     4.0E-2
5.906E-1    1.260E+0    3.54E-1     6.0E-2
6.693E-1    1.378E+0    3.94E-1     1.3E-1
7.874E-1    1.654E+0    4.72E-1     1.6E-1
9.843E-1    1.850E+0    4.72E-1     2.5E-1
1.181E+0    2.165E+0    5.12E-1     3.4E-1
1.378E+0    2.441E+0    5.51E-1     5.0E-1
1.578E+0    2.677E+0    5.91E-1     6.3E-1
1.772E+0    2.953E+0    6.30E-1     6.9E-1
1.969E+0    3.150E+0    6.30E-1     7.5E-1
2.165E+0    3.543E+0    7.09E-1     1.00E+0
2.362E+0    3.740E+0    7.09E-1     1.25E+0
2.559E+0    3.937E+0    7.09E-1     1.50E+0
2.756E+0    4.331E+0    7.87E-1     1.56E+0
2.953E+0    4.528E+0    7.87E-1     2.13E+0
3.150E+0    4.921E+0    8.66E-1     2.25E+0
3.347E+0    5.118E+0    8.66E-1     2.88E+0
3.543E+0    5.512E+0    9.45E-1     3.50E+0
   100.        3.25       .0414        0.0        250.        1.0        100.
 .2000E9       20.        320.      .1500E6        52.     .1200E5        .25
   400.        35.         2.          5.
1.0  1.0  1.0  0.0  0.0  0.0  1.0    1 1 4 1
1.0  1.0  1.0  0.0  0.0  0.0  1.0    2 1 4 2
1.0  1.0  2.0  0.0  0.0  0.0  2.0    1 2 4 3
1.0  1.0  2.0  0.0  0.0  0.0  2.0    2 2 4 4
1.0  1.0  2.0  0.0  0.0  0.0  2.0    3 2 4 5
// ENDATA
```

```
C                           STORED SUBROUTINE

      SUBROUTINE OSUB (DIAM,SPRE,I,Z,RWT,RFRG,RFRC,RFRS,RFRF)
C  J REPLACED WITH Z  1=0.   2=1.
C I=4 IS NEVER USED   THEREFORE ELIMINATE 64 LET IT GO TO 65
C  DIAT = DIAI+DIAO
      IF (DIAM-4.475-Z*.485) 3,4,4
    4 ALPH=1.28E-1
      CLER=5.0E-3
      WIDH=2.75E-1
      GO TO 50
    3 IF (DIAM-1.475-Z*.353) 5,6,6
    6 ALPH=1.09E-1
      CLER=3.5E-3
      WIDH=2.1E-1
      GO TO 50
    5 IF (DIAM-.734-Z*.244) 7,8,8
    8 ALPH=1.18E-1
      CLER=3.0E-3
      WIDH=1.39E-1
      GO TO 50
    7 IF (DIAM-.362-Z*.174) 9,10,10
   10 ALPH=1.3E-1
      CLER=2.5E-3
      WIDH=1.03E-1
      GO TO 50
    9 IF (DIAM-.07-Z*.14) 11,12,12
   12 ALPH=1.88E-1
      CLER=2.0E-3
      WIDH=7.0E-2
      GO TO 50
   11 IF (DIAM-.05-Z*.109) 13,14,14
   14 ALPH=1.9E-1
      CLER=2.0E-3
      WIDH=6.0E-2
      GO TO 50
   13 IF (DIAM-.036-Z*.09) 15,16,16
   16 ALPH=1.9E-1
      CLER=2.0E-3
      WIDH=5.0E-2
      GO TO 50
   15 ALPH=2.08E-1
      CLER=2.0E-3
      WIDH=4.0E-2
   50 DIAT = 2.*(DIAM+(1.-2.*Z)*WIDH)
      RWT=.0574*DIAT*WIDH*WIDH
      ZZ=DIAT*ALPH*WIDH*(1.-.5*ALPH)
      ZZZ= .1529*SPRE/(.4E5-SPRE) + 46.9/(.2E4+SPRE)
      GO TO (61,62,63,65,65,66,67),I
   61 RFRG= (ZZ+ .1512/(DIAT*DIAT*ALPH)+2.3E-3/CLER+
     3(2.91E+1*ALPH*WIDH))*
     4(((1.835E-1*SPRE)/(4.0E+4-SPRE))+(7.04E+1/(2.0E+3+SPRE)))
      RFRC=.20*RFRG
      RFRS=.15*RFRG
      RFRF=.05*RFRG
      RETURN
```

```
62 RFRG= (ZZ+ .1512/(DIAT*DIAT*ALPH)+2.3E-3/CLER)* ZZZ
   RFRC=.10*RFRG
   RFRS=.05*RFRG
   RFRF=.01*RFRG
   RETURN
63 RFRG= (ZZ+2.3E-3/CLER+
  2(2.91E+1*ALPH*WIDH))*
  3(((1.835E-1*SPRE)/(4.0E+4-SPRE))+(7.04E+1/(2.0E+3+SPRE)))
   RFRC=.20*RFRG
   RFRS=.15*RFRG
   RFRF=.05*RFRG
   RETURN
65 RFRG= (ZZ+2.3E-3/CLER)* ZZZ
   RFRC=.10*RFRG
   RFRS=.05*RFRG
   RFRF=.01*RFRG
   RETURN
66 RFRG =ZZ* ZZZ
   RFRC=.10*RFRG
   RFRS=.10*RFRG
   RFRF=.05*RFRG
   RETURN
67 RFRG= (ZZ+ .1512/(DIAT*DIAT*ALPH))* ZZZ
   RFRC=.15*RFRG
   RFRS=.05*RFRG
   RFRF=.02*RFRG
   RETURN
   END
// DUP
*STORE      WS  UA  OSUB
```

```
C                          STORED PROGRAM 1

C  ACTUATOR 1
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  ACTUATOR 12       )
      WRITE (3,1002)
      IDATA = 1
      ITRA2 =1
      READ (1-IDATA) AMAX,PREM,TORQ,VELA,PREI,AMOM,TRAA,DMOM,DPRE
     1  ,AAAA1,AAAA2,AAAA3,AAAA8
   13 PRES=PREI
   11 VELL=VELA*AMOM
      TRAL=TRAA*AMOM
      FORC=TORQ/AMOM
      FLOW=FORC*VELL/PRES
      AV2F1=((VELA*TORQ)**0.5)/(PRES**0.75)
      AV2F2=1.0+.000308*PRES
      AV2FI=.308*AV2F2*AV2F1+.118*(AV2F2*AV2F1)**0.5
      AV2FV=.0594*AV2F1
      AV2FJ=.309*AV2F1
      AV2FB=.0242*AV2F1*PRES**0.5
      AV2FX=1.562*AV2F1+.575*(AV2F2*AV2F1)**0.5
      AV2FW=.217*(AV2FI**2.0-AV2FJ**2.0)*AV2FX
      AV2FA =.00227*(PRES**0.5/AV2F1)+2.27/(AV2F1*PRES**0.5)
      AV2CW=2.12E-7*(AV2FJ**3.0)*(PRES**1.5)
      AV2CA =.0000025/AV2FV
      AV2BX=.0000444*PRES*AV2FJ**2.0/AV2FV
      AV2BA =1.71/(AV2FJ * PRES**0.5)
      AV2K1=1.18*((AV2BX)+2.0*AV2FV)+3.0*AAAA1*AV2FV
      AV2KX=1.31*AV2K1+.000128*AV2FJ*PRES
      AV2KW=.000223*AV2K1*PRES*AV2FJ**2.0
      AV2KA =.0468/(AV2FV*AV2FJ*PRES)
      AV2MA =.00542/(AV2FV*AV2FJ*PRES)
      AV2HW=.0434*AV2FJ**3.0
     0WA1W=AV2FW+4.0*AV2CW+2.0*(1.25E-9*(AV2FJ**4.0)*(PRES**2.0))/
     1(AV2FV)+2.0*AV2KW+.1685*AV2KW+AV2HW+.0215*AV2FJ*AV2FX+.892*AV2CW
     2+.0332*AV2FJ**3.0
     0QA1A=AV2FA +4.0*AV2CA +2.0*AV2BA +AV2KA +AV2MA +.00007/AV2FV
     1  +AV2FA+.00261/AV2FJ
     0QA1B=1.1*AV2FA +.000016/(AV2FV)+.6*AV2BA +.1*AV2KA +.1*AV2MA
     1  +.000261/AV2FJ
      QA1C=.000261/AV2FJ+.1*AV2MA +.2*AV2KA
      QA1D=.00005/AV2FJ+.02*AV2MA +.1*AV2KA
      QA1G=.1*AV2FA
      QA1H= QA1G
      QA1I=.1*AV2FA +.000008/AV2FV+.12*AV2BA
      QA1J=QA1I
      CALL OSUB(1.015*AV2FI,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+6.0*RWT
      QA1A=QA1A+6.0*RFRG
```

```
      QA1B=QA1B+6.0*RFRC
      QA1E=4.0*RFRS
      QA1F=4.0*RFRF
      QA1G=QA1G+2.0*RFRS
      QA1H=QA1H+2.0*RFRF
      CALL OSUB(1.015*AV2FI,PRES/2.0,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+4.0*RWT
      QA1A=QA1A+4.0*RFRG
      QA1B=QA1B+4.0*RFRC
      QA1C=QA1C+4.0*RFRS
      QA1D=QA1D+4.0*RFRF
      CALL OSUB(.92*AV2FJ,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1C=QA1C+RFRS
      QA1D=QA1D+RFRF
      AV12J=.912*AV2FJ**1.5/PRES**.25
      AV12X=25.7*AV12J
      AV12I=6.14*AV12J
      AV12W=215.*AV12J**3.0
      AV1MC=AV12J**3.0*PRES
      AV1MI=4.19*AV12J
      AV1MA =.00041*AV12J*PRES
      AV1FW=.00143*AV1MC/AV12J
      AV1FA =.00473/AV1FW**.333
      AV1DA =.0024/AV1FW**.333
      AV1HA =36.5/(PRES*AV1MI)
      AV1CA =7.53*AV12J**2.0+.02
      AV1NI=.692*AV12I
      AV1NW=.43*AV12W
      AV11I=7.93*AV2FJ**2.0/AV2FX
      AV11A =.042*AV2FJ**2.0/AV12J
      AV1YI=1.01*AV11I
     0WA2W=2.0*AV12W+.088*PRES*AV12J**3.0+.516*AV1MC+7.766*AV1FW
     1 +.00437*PRES*AV1MI**3.+.00229
     2            +3.9*(AV1MI)**3.0+.43*AV12W+2.2*AV1NW +.00402*
     3AV2FJ**2.0+.208*AV11I**3.0+.000215*PRES*AV11I**3.0
      AV12A =.335*(PRES**0.5)*(AV12J**2.0)*(1.0/(AV12J**1.2)-6.9)
      IF (AV12A -.0001)815,815,816
  815 AV12A =.0001
  8160QA2A=2.0*AV12A +AV1MA +.00026/(AV1MC)+2.0*AV1FA +2.0*AV1DA
     1+AV1HA +2.0*AV1CA +.0008+.0182*AV1DA +.364*AV1DA +.35*AV1MI
     2+.337*AV12A +.00248*AV12J+AV11A +2.02*AV12A +.000322/(AV11I)
     0QA2B=1.6*AV12A +.1*AV1MA +.0000026/(AV1MC)+AV1FA +AV1DA +.5*
     1AV1HA +.2*AV1CA +.035*AV1MI+.02*AV12A +.1*AV11A +1.8*AV12A
     2+.0000322/(AV11I)
      QA2C=.2*AV12A +.5*AV1HA +.0000322/(AV11I)
      QA2D=.06*AV12A +.25*AV1HA +.00001288/(AV11I)
      QA2G=.02*AV1CA +.0175*AV1MI+.8*AV12A
      QA2H=.02*AV1CA +.007*AV1MI+.4*AV12A
     0QA2I=.01*AV1MA +.0000013/AV1MC+.1*AV1FA +.1*AV1DA +.0175*AV1MI
     1+.01*AV12A +.01*AV11A +.8*AV12A
     0QA2J=.01*AV1MA +.0000013/AV1MC+.1*AV1FA +.1*AV1DA +.007*AV1MI
     1+.006*AV12A +.01*AV11A +.4*AV12A
      CALL OSUB(.176,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      QA2A=QA2A+2.0*RFRG
      QA2B=QA2B+2.0*RFRC
      QA2C=QA2C+RFRS
      QA2D=QA2D+RFRF
```

```
      QA2I=QA2I+RFRS
      QA2J=QA2J+RFRF
      CALL OSUB(1.925*AV1MI,0.1*PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA2W=WA2W+RWT
      QA2A=QA2A+RFRG
      QA2B=QA2B+RFRC
      QA2C=QA2C+RFRS
      QA2D=QA2D+RFRF
      CALL OSUB(4.0*AV1NI,0.1*PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA2W=WA2W+RWT
      QA2A=QA2A+RFRG
      QA2B=QA2B+RFRC
      QA2G=QA2G+RFRS
      QA2H=QA2H+RFRF
      CALL OSUB(1.01*AV1YI,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA2W=WA2W+2.0*RWT
      QA2A=QA2A+2.0*RFRG
      QA2B=QA2B+2.0*RFRC
      QA2G=QA2G+2.0*RFRS
      QA2H=QA2H+2.0*RFRF
      CALL OSUB(1.275*AV1YI,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA2W=WA2W+RWT
      QA2A=QA2A+RFRG
      QA2B=QA2B+RFRC
      QA2C=QA2C+RFRS
      QA2D=QA2D+RFRF
C     ACTUATOR  2
      AV2NI=AAAA1*AV2FJ*(.615+.000128*PRES)
      AV2NW=.000356*AV2FV*PRES*AV2FJ**2.0*AAAA1
      AV2NA =AAAA1*(5.22E-6)*PRES**0.5/(AV2FJ*AV2FV)
      AV2PI=.604*AV2NI
      WA1W=WA1W+2.0*AV2NW+.352*AV2NW
      QA1A=QA1A+2.0*AV2NA +AAAA1*.00052/AV2FJ
      QA1B=QA1B+.2*AV2NA +AAAA1*.000052/AV2FJ
      QA1G=QA1G+.02*AV2NA
      QA1H=QA1H+.01*AV2NA
      QA1I=QA1I+.02*AV2NA
      QA1J=QA1J+.01*AV2NA
      CALL OSUB(1.31*AV2FJ,PRES*.0133,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+AAAA1*RWT*2.0
      QA1A=QA1A+AAAA1*RFRG*2.0
      QA1B=QA1B+AAAA1*RFRC*2.0
      QA1G=QA1G+AAAA1*RFRS*2.0
      QA1H=QA1H+AAAA1*RFRF*2.0
      CALL OSUB(1.12*AV2NI,PRES/2.0,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+AAAA1*RWT*4.0
      QA1A=QA1A+AAAA1*RFRG*4.0
      QA1B=QA1B+AAAA1*RFRC*4.0
      QA1C=QA1C+AAAA1*RFRS*4.0
      QA1D=QA1D+AAAA1*RFRF*4.0
      AVMJX=22.65*AV12J*AAAA2
      AVMJA =.0517/(AV12J*PRES**.333)*AAAA2
      AVMAW=AAAA2*26.05*AV2FX*AV12J**2.0
      AVMAA =AAAA2*.001193*AV2FX/AV12J
     0WA2W=WA2W+AAAA2*4.39*(AV12J**3.0)*(PRES**.333)+AAAA2*24.6*(AV12J
     1**3.0)*(PRES**.333)+AVMAW+.837*AVMAW
      QA2A=QA2A+2.0*AVMJA +.0982*AVMJA +AVMAA +AAAA2*.000202/AVMAW**.333
     0QA2B=QA2B+.4*AVMJA +.0295*AVMJA +.5*AVMAA +AAAA2*.000202/(AVMAW
     1**.333)
      QA2I=QA2I+.08*AVMJA +.00982*AVMJA +.15*AVMAA
```

```
      QA2J=QA2J+.04*AVMJA +.00491*AVMJA +.15*AVMAA
      APRBJ=.0074*FORC**0.5
      APRBY=APRBJ
      APRBI=AAAA3*(1.25*APRBJ+.125)
      APRBW=1.175E-5*(FORC)-.0167
      APRBA =.0343/APRBJ
      APRRI=(1.5*APRBJ+.25)*(1.0-AAAA3)
      APRHK=APRBJ
     0WA3W=APRBW+APRBW*(1.0-AAAA3)+.0907*APRBJ**2.0*(2.94*(APRBI+APRRI)
     1+APRBJ)+.761*APRBJ**3.0+.0903*APRHK**3.0
     0QA3A=.0343/APRBJ+.0256*APRRI+.0041*(2.5*APRBJ+0.25)+.0437/APRBJ
     1+.00175/APRHK+.0001
     0QA3B=.001715/APRBJ+.00128*APRRI+.000615*(2.5*APRBJ+0.25)
     1+.00874/APRBJ
     0QA3I=.001715/APRBJ+.000768*APRRI+.000615*(2.5*APRBJ+0.25)
     1+.00874/APRBJ
     0QA3J=.000343/APRBJ+.000179*APRRI+.00014*(2.5*APRBJ+0.25)
     1+.000874/APRBJ
      APPPI=1.0
  8100APPPK=(1./9.464)*(APRHK+AAAA8*.00159*VELL**2./APRHK+TRAL+.71
     1*APPPI**.5)
      IF ( ABS(APPPK-APPPI)-.00001*APPPK)811,812,812
  812 APPPI=(APPPK+APPPI)/2.0
      GO TO 810
  811 IF (APPPK**2.0-.675*APRHK)813,813,817
  817 APPPJ=(APPPK**2.0-.675*APRHK)**0.5
      IF (APPPJ-0.812)813,814,814
  813 APPPJ=0.812
      APPPK=(APPPJ**2.0+.675*APRHK)**0.5
  814 APPPI=(1.273*FORC/PRES+APPPK**2.0)**0.5
      APPPY=.305*APPPI**0.5
     0APPPX=APRHK+1.42*APPPK**.5+.536*APPPK+.00318*VELL**2./APRHK*
     1AAAA8+2.0*TRAL+.305*APPPI**0.5
      WA4W=.176*APPPY*(APPPI**2.0-APPPK**2.0)+.146*APRHK*APPPX
      QA4A=.258*APPPK/APRHK
      QA4B=.0774*APPPK/APRHK
      QA4C=.1*QA4A
      QA4D=.1*QA4C
      QA4E=QA4C
      QA4F=QA4D
      QA4I=QA4C
      QA4J=QA4D
      WA5W=.175*(APPPI**2.0-APPPK**2.0)+WA4W
      QA5A=QA4A
      QA5B=QA4B
      QA5C=QA4C
      QA5D=QA4D
      QA5E=QA4E
      QA5F=QA4F
      QA5I=QA4I
      QA5J=QA4J
      CALL OSUB(.97*APPPI,.1*PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+1.887*RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1E=QA1E+RFRS
      QA1F=QA1F+RFRF
      CALL OSUB(APPPI,0.1*PRES,1,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
```

```
 QA1E=QA1E+RFRS
 QA1F=QA1F+RFRF
 APPWA =.809*((PRES/(VELL*FORC))**0.5)
0WA8W=AAAA8*1.505E-4*(VELL**2.0/APRHK)*(APPPK*(VELL*FORC/PRES)
1**.5+.0289*VELL*FORC/PRES)
 QA8A=AAAA8*APPWA
 QA8B=AAAA8*.01*APPWA
 QA8I=AAAA8*.002*APPWA
 QA8J=QA8I
 ACBBI=APPPI+(4.65E-5)*APPPI*PRES
 ACBBY=ACBBI+(13.06E-5)*APPPI*PRES
0ACBBA =.019*(TRAL+.00318*VELL**2.0/(APRHK)+APPPY)*(APPPI*PRES**
11.5)/(FORC*VELL)
0WA6W=.225*((TRAL+.0032*AAAA8*VELL**2./APRHK+APPPY)*(ACBBI
1**2.0-APPPI**2.0)+(.71*APPPK**.5+.536*APPPK)*(31.08E-5*APPPK**2.0
2*PRES+241.5E-10*(APPPK*PRES)**2.0)+(7.77E-5*APPPK*PRES)*(ACBBI**
32.0-(APPPK+15.54E-5*APPPK*PRES)**2.0)+4.98E-5*APPPI*PRES*(ACBBY**
42.0-ACBBI**2.0))
 QA6A=ACBBA
 QA6B=.2*ACBBA
 QA6C=.5*ACBBA
 QA6D=.03*ACBBA
 ACBT1=APPPI+5.44E-5*(APPPI*PRES)
 ACBT2=APPPK+8.47E-5*(APPPK*PRES)
 ACBT3=APPPI+2.21E-4*(APPPI*PRES)
 ACBT4=APPPI+1.96E-4*(APPPI*PRES)
 ACBT5=APPPI+1.164E-4*APPPI*PRES
0ACBTA =.019*(TRAL+.00318*VELL**2.0/(APRHK)+APPPY)*(APPPI*PRES**
11.5)/(FORC*VELL)
0WA5W=WA5W+.48*(ACBT1**2.-APPPI**2.)*(TRAL+.00318*AAAA8*VELL**2./
1APRHK+APPPY)+PRES*(ACBT1**2.-ACBT2**2.)*(3.64E-6*APPPI+9.5E-6*
2APPPK)+.31*(APPPK**.5)*(ACBT2**2.-APPPK**2.)+APPPI*PRES*(7.67E-6*
3(ACBT3**2.-ACBT1**2.)+1.11E-5*(ACBT4**2.-ACBT1**2.))+.0338*(ACBT5
4**2.-ACBT1**2.)*(TRAL+.00318*AAAA8*VELL**2./APRHK+APPPY)
0WA5W=WA5W+4.67E-6*APPPI*PRES*(ACBT3**2.-ACBT1**2.)+.00975*APPPI*
1(APPPI**2.-APPPK**2.)+.0687*(APPPK**.5)*(ACBT4**2.-APPPK**2.)
 QA5A=QA5A+ACBTA
 QA5B=QA5B+.2*ACBTA
 QA5C=QA5C+.5*ACBTA
 QA5D=QA5D+.03*ACBTA
 WRITE (3,920)   WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F
1         ,QA1G,QA1H,QA1I,QA1J,WA2W,QA2A,QA2B
2         ,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J,AV2FJ
3         ,WA3W,QA3A,QA3B,QA3I,QA3J,WA4W,QA4A
4         ,QA4B,QA4C,QA4D,QA4E,QA4F,QA4I,QA4J
 WRITE (3,920)  WA5W,QA5A,QA5B,QA5C,QA5D,QA5E,QA5F
1         ,QA5I,QA5J,WA8W,QA8A,QA8B,QA8I,QA8J
2         ,WA6W,QA6A,QA6B,QA6C,QA6D
 WRITE (3,920)  VELA,PRES,TRAL,VELL,FORC,FLOW
 WRITE (3,920)  AV2FI,AV2FW,AV2FX,AV2FB,AV2F1,AV12J,AV12I
1         ,AV12X,AV12A ,AV11I,AV1YI,APPPK,APPPI,APPPY
2         ,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,ACBBY,APRBJ
3         ,APRBW,APRBI,APRRI,APRHK,AVMAW,AVMAA
 WRITE(2-ITRA2) WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F,QA1G,QA1H,QA1I,
1QA1J,WA2W,QA2A,QA2B,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J,WA3W,QA3A,QA3B,
2QA3I,QA3J,WA4W,QA4A,QA4B,QA4C,QA4D,QA4E,QA4F,QA4I,QA4J,WA5W,QA5A,
3QA5B,QA5C,QA5D,QA5E,QA5F,QA5I,QA5J,WA8W,QA8A,QA8B,QA8I,QA8J,WA6W,
4QA6A,QA6B,QA6C,QA6D,PRES,TRAL,VELL,FORC,FLOW,AV2FJ,AMOM
 WRITE (2-ITRA2)    AV2FI,AV2FW,AV2FX,AV2FB,AV2F1,AV12J,AV12I
1         ,AV12X,AV12A ,AV11I,AV1YI,APPPK,APPPI,APPPY
```

```
      2              ,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,ACBBY,APRBJ
      3              ,APRBW,APRBI,APRRI,APRHK,AVMAW,AVMAA
      PRES=PRES+DPRE
      IF (PREM-PRES)10,11,11
   10 AMOM=AMOM+DMOM
      IF (AMAX-AMOM)12,13,13
   12 CONTINUE
      CALL LINK (ACT34)
      END
// DUP
*STORE      WS  UA  ACT12
```

```
C                          STORED PROGRAM 2

C  ACTUATOR 3
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      IDATA = 2
      ITRA2=1
      ITRA3=1
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  ACTUATOR 34        )
      WRITE (3,1002)
      READ  (1-IDATA) AMAX,PREM,TORQ,VELA,AAAA2,AAAA4,AAAA6,AAAA7,
     1   AAAA8
   31 CONTINUE
      READ (2-ITRA2) WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F,QA1G,QA1H,QA1I,
     1QA1J,WA2W,QA2A,QA2B,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J,WA3W,QA3A,QA3B,
     2QA3I,QA3J,WA4W,QA4A,QA4B,QA4C,QA4D,QA4E,QA4F,QA4I,QA4J,WA5W,QA5A,
     3QA5B,QA5C,QA5D,QA5E,QA5F,QA5I,QA5J,WA8W,QA8A,QA8B,QA8I,QA8J,WA6W,
     4QA6A,QA6B,QA6C,QA6D,PRES,TRAL,VELL,FORC,FLOW,AV2FJ,AMOM
      READ  (2-ITRA2)    AV2FI,AV2FW,AV2FX,AV2FB,AV2F1,AV12J,AV12I
     1          ,AV12X,AV12A ,AV11I,AV1YI,APPPK,APPPI,APPPY
     2          ,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,ACBBY,APRBJ
     3          ,APRBW,APRBI,APRRI,APRHK,AVMAW,AVMAA
      ACUUI=.774*AV2FI
      WA1W=WA1W+.00293+.11*AV2FW
      CALL OSUB(.239,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+2.0*RWT
      QA1A=QA1A+2.0*RFRG+.0010+.00139/ACUUI**0.5
      QA1B=QA1B+2.0*RFRC+.0002+.000278/ACUUI**0.5
      QA1C=QA1C+2.0*RFRS+.00025+.00363/ACUUI**0.5
      QA1D=QA1D+2.0*RFRF+.00005+.0000695/ACUUI**0.5
      CALL OSUB(ACUUI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+2.0*RWT
      QA1A=QA1A+2.0*RFRG
      QA1B=QA1B+2.0*RFRC
      QA1C=QA1C+2.0*RFRS
      QA1D=QA1D+2.0*RFRF
      WA1W=WA1W+14.0*(2.66E-14)*(APPPI*PRES)**3.0
      QA1A=QA1A+14.0*(16.08)/(APPPI*PRES)
      CALL OSUB(ACBBI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1C=QA1C+RFRS
      QA1D=QA1D+RFRF
      CALL OSUB(.94*APPPK,PRES/2.0,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      ACSCW=.758*RWT
      WA1W=WA1W+2.0*RWT+2.0*ACSCW
      QA1A=QA1A+2.0*RFRG
      QA1B=QA1B+2.0*RFRC
      QA1C=QA1C+2.0*RFRS
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```
QA1D=QA1D+2.0*RFRF
CALL OSUB(APPPK,PRES/2.0,3,0.,RWT,RFRG,RFRC,RFRS,RFRF)
QA1A=QA1A+2.0*RFRG
QA1B=QA1B+2.0*RFRC
QA1C=QA1C+2.0*RFRS
QA1D=QA1D+2.0*RFRF
WA3W=WA3W+.387
CALL OSUB(.239,PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
QA3A=QA3A+2.0*RFRG+.73
QA3B=QA3B+2.0*RFRC+.073
QA3C=2.0*RFRS+.0365
QA3D=2.0*RFRF+.0073
CALL OSUB(.145,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
QA3A=QA3A+2.0*RFRG
QA3B=QA3B+2.0*RFRC
QA3C=QA3C+2.0*RFRS
QA3D=QA3D+2.0*RFRF
WA3W=WA3W+3.39*ACSCW
QA3A=QA3A+.0339*APPPK
QA3B=QA3B+.00339*APPPK
ABFAI=(.534+.9218E-4*PRES)*(VELA*TORQ/(PRES**1.5))**0.5
ABFAX=1.39*(VELA*TORQ)**0.5/(PRES**.75)
ABFAW=5.7E-5*(VELA*TORQ)**1.5/(PRES**1.25)
CALL OSUB(ABFAI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
WA7W=ABFAW*AAAA7
QA7A=RFRG
QA7B=RFRC
QA7G=RFRS*AAAA7
QA7H=RFRF*AAAA7
CALL OSUB(ABFAI,40.,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
QA7A=QA7A+RFRG
QA7B=QA7B+RFRC
QA7C=RFRS
QA7D=RFRF
CALL OSUB(.346*ABFAI,40.,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
QA7A=(QA7A+RFRG)*AAAA7
QA7B=(QA7B+RFRC)*AAAA7
QA7C=(QA7C+RFRS)*AAAA7
QA7D=(QA7D+RFRF)*AAAA7
ABPBI=.662*ABFAI
ABPBX=.898*ABFAX
ABPBW=.2365*ABFAW
ABPBA =3.54*ABPBI*PRES/(VELA*TORQ)
WA8W=2.0*.2365*ABFAW+WA8W
CALL OSUB(ABPBI,1.5*PRES,6,1.,RWT,RFRG,RFRC,RFRS,RFRF)
QA8A=2.0*RFRG+2.0*ABPBA +QA8A
QA8B=2.0*RFRC+1.6*ABPBA +QA8B
QA8E=2.0*RFRS+.6*ABPBA
QA8F=2.0*RFRF+.06*ABPBA
CALL OSUB(ABPBI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
QA8A=QA8A+2.0*RFRG
QA8B=QA8B+2.0*RFRC
QA8C=2.0*RFRS+.6*ABPBA
QA8D=2.0*RFRF+.06*ABPBA
CALL OSUB(.53*ABPBI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
QA8A=QA8A+2.0*RFRG
QA8B=QA8B+2.0*RFRC
QA8C=QA8C+2.0*RFRS
QA8D=QA8D+2.0*RFRF
QA8I=.6*ABPBA +QA8I
```

```
      QA8J=.06*ABPBA +QA8J
      WA3W=WA3W+.0065
      QA3A=QA3A+.0039
      ABBDI=.89*(VELA*TORQ)**0.5/PRES**.75
      ABBDX=1.67*ABBDI
      CALL OSUB(ABBDI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA9W=RWT+.222*(ABBDI**3.0)+.0000697*PRES*ABBDI**3.0+.0887
      QA9A=.0375/ABBDI+RFRG+3.06/(ABBDI*PRES)+.0202
      QA9B=RFRC+3.06/(ABBDI*PRES)
      QA9C=RFRS+1.58/(ABBDI*PRES)
      QA9D=RFRF+1.58/(ABBDI*PRES)
      CALL OSUB(1.13*ABBDI,40.,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA9W=WA9W+RWT
      QA9A=QA9A+RFRG
      QA9B=QA9B+RFRC
      QA9C=QA9C+RFRS
      QA9D=QA9D+RFRF
      ABFHJ=.2185*(VELA*TORQ/PRES)**0.5
      ABFHI=ABFHJ+(7.5E-6)*(PRES*VELA*TORQ)**0.5
      ABFHW=(5.06E-7)*((VELA*TORQ)**1.5)/(PRES**0.5)
      ABFHA =.0001135*VELA*TORQ/(PRES*ABFHW)
      ABFEW=.0075*VELA*TORQ/PRES
      WA9W=WA9W+ABFHW+ABFEW+.0028*ABFHJ**3.0
      CALL OSUB(.97*ABFHI,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA9W=WA9W+RWT
      QA9A=QA9A+RFRG+ABFHA +.11*ABFEW+.0136/ABFHJ
      QA9B=QA9B+RFRC+.1*ABFHA +.055*ABFEW+.00136/ABFHJ
      QA9C=QA9C+RFRS+.05*ABFHA
      QA9D=QA9D+RFRF+.05*ABFHA
      CALL OSUB(.625*ABFHJ,20.,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA9W=WA9W+RWT
      QA9A=QA9A+RFRG
      QA9B=QA9B+RFRC
      QA9G=.0055*ABFEW+.00034/ABFHJ
      QA9H=QA9G
      QA9I=QA9G+RFRS
      QA9J=QA9G+RFRF
C   ACTUATOR 4
      AVDAI=ABPBI
      AVDAX=ABPBX
      AVD1A =.042*AV2FJ**2.0/AV12J
     0WA1W=WA1W+(AAAA4+AAAA6)*(2.8*ABPBW+.00402*AV2FJ**2.0+.312*(AV11I)
     1**3.0)+.000215*PRES*AV11I**3.0
      QA1A=QA1A+(ABPBA +AVD1A +2.02*AV12A +.000322/AV11I)*(AAAA4+AAAA6)
     0QA1B=QA1B+(.8*ABPBA +.1*AVD1A +1.818*AV12A +3.22E-5/AV11I)*
     1(AAAA4+AAAA6)
      CALL OSUB(1.02*AV11I,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT*(AAAA4+AAAA6)*2.0
      QA1A=QA1A+2.0*RFRG*(AAAA4+AAAA6)
      QA1B=QA1B+2.0*RFRC*(AAAA4+AAAA6)
      QA1G=QA1G+(2.0*RFRS+.808*AV12A )*(AAAA4+AAAA6)
      QA1H=QA1H+(2.0*RFRF+.404*AV12A )*(AAAA4+AAAA6)
      CALL OSUB(1.29*AV11I,PRES/2.0,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT*(AAAA4+AAAA6)
      QA1A=QA1A+RFRG*(AAAA4+AAAA6)
      QA1B=QA1B+RFRC*(AAAA4+AAAA6)
      QA1C=QA1C+(RFRS+3.22E-5/AV11I)*(AAAA4+AAAA6)
      QA1D=QA1D+(RFRF+1.29E-5/AV11I)*(AAAA4+AAAA6)
      QA1I=QA1I+(.01*AVD1A +.808*AV12A +.9*ABPBA )*(AAAA4+AAAA6)
      QA1J=QA1J+(.01*AVD1A +.404*AV12A +.1*ABPBA )*(AAAA4+AAAA6)
```

```
      AVBPI=1.115*AV2FJ
      AVBB2=AAAA2
     0AVBBX=AVBB2*(AV2FI*(1.0+(3.01E-4)*PRES)+AV12I*(1.0+(2.665E-4)*
     1PRES)+58.3*AV12J)
     0AVBBW=1.1*(AV2FX*AV1YI*(AV2FI*(.0753+(.442E-4)*PRES+(.649E-8)*PRES
     1**2.0)-.0527*AV1YI)+(AV2FI**2.0)*AV2FX*(.0231+(.539E-4)*PRES+
     2(.646E-8)*PRES**2.0)+AVDAX*AVDAI*(AV2FI*(.119+(.623E-4)*PRES+
     3(.797E-8)*PRES**2.0)-.0787*AVDAI)+AV12I*AV12J*(PRES**0.5)*(AV12J
     4*(PRES**0.5)*(.107+(.2856E-4)*PRES)-.0835*AV12I))
     0AVBBW=AVBBW+1.1*(.0861+AV2FX*
     1AV2FJ**2.0+AVBB2*APPPK**2.0*(AV2FI*(.0398+(.12E-4)*PRES)+AV12I*
     2(.0398+(.106E-4)*PRES)+2.32*AV12J+.00602*APPPK))
      AVBBA =1.4E-5*PRES/AV12X+.0234/(AVBBW**.333)
      WA1W=WA1W+AVBBW+.00727*APPPK+.0324*AV2FJ**2.5
      QA1A=QA1A+AVBBA +.015+.00196*AV2FJ**0.5
      QA1B=QA1B+.1*AVBBA +.000196*AV2FJ**0.5
      QA1C=QA1C+.01*AVBBA
      QA1D=QA1D+.005*AVBBA
      CALL OSUB(1.115*AV2FJ,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1C=QA1C+RFRS
      QA1D=QA1D+RFRF
      CALL OSUB(1.31*AV2FJ,PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1C=QA1C+RFRS
      QA1D=QA1D+RFRF
      CALL OSUB(1.31*AV2FJ,40.,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+RWT
      QA1A=QA1A+RFRG
      QA1B=QA1B+RFRC
      QA1C=QA1C+RFRS
      QA1D=QA1D+RFRF
      CALL OSUB(1.31*AV2FJ,.5*PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA1W=WA1W+2.0*RWT
      QA1A=QA1A+2.0*RFRG
      QA1B=QA1B+2.0*RFRC
      QA1C=QA1C+2.0*RFRS
      QA1D=QA1D+2.0*RFRF
      QA1G=QA1G+.01*AVBBA
      QA1H=QA1H+.005*AVBBA
     0ATBBW=3.1E-5*FORC*(TRAL+.00318*AAAA8*VELL**2./APRHK+AVBBX*AVBB2)
     1+.2+.0907*APRBJ**2.0*(5.41*APRBJ+.735)
      WA12W=ATBBW
      QA12A=.1205/(ATBBW**.333)
      QA12B=.012/(ATBBW**.333)
      QA12G=QA12B
      QA12H=.1*QA12B
      ATBC1=1.195*APPPK+2.39*AV2FI
      ATBC2=.85*APPPK
      ATBC3=3.11E-5*APPPI*PRES
      ATBC4=1.9*(TRAL+.00318*AAAA8*VELL**2.0/APRHK+APPPY)
     0ATBCW=0.2*ATBC3*(ATBC4*(3.*ATBC1+ATBC2+2.*ATBC3)+ATBC3*(3.*ATBC1
     1+ATBC2+6.*ATBC3)+(ATBC1+ATBC3)*(ATBC1+ATBC2+2.*ATBC3))+APRBJ**2.*
     2(.541*APRBJ+.0735)+1.89E-5*FORC-.0335
      WA10W=ATBCW
      QA10A=.06/(ATBCW**.333)
```

```
      QA10B=.1*QA10A
      QA10G=QA10B
      QA10H=QA10B
      STVFJ=.368*((VELA*TORQ)**.5/(PRES**.75))
     0ABHTW=.031*(TRAL+.00318*AAAA8*VELL**2./APRHK+APPPY)*(.5*ACBT4**2.-
     1ACBT1**2.+1.44*(APPPI+STVFJ)**2.)+.177*(ABFAI+ABBDI)*(ATBC1+
     2ATBC2+4.*ATBC3)*(ATBC1+2.*ATBC3-.0786*(STVFJ**2.+APPPK**2.))
     3+ABFHI**3.*(2.04E-9*PRES**2.+4.08E-5*PRES+.0345)
      WA5W=WA5W+ABHTW
      QA5A=QA5A+.208/(ABHTW**.333)
      QA5B=QA5B+.208/(ABHTW**.333)
      QA5C=QA5C+.0208/(ABHTW**.333)
      QA5D=QA5D+.004/(ABHTW**.333)
      WRITE (3,920)  WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F
     1         ,QA1G,QA1H,QA1I,QA1J,WA2W,QA2A,QA2B
     2         ,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J
      WRITE (3,920)  WA3W,QA3A,QA3B,QA3C,QA3D,QA3I,QA3J
     1         ,WA4W,QA4A,QA4B,QA4C,QA4D,QA4E,QA4F
     2         ,QA4I,QA4J,WA5W,QA5A,QA5B,QA5C,QA5D
     3         ,QA5E,QA5F,QA5I,QA5J,WA6W,QA6A,QA6B
     4         ,QA6C,QA6D,WA7W,QA7A,QA7B,QA7C,QA7D
      WRITE (3,920)  QA7G,QA7H,WA8W,QA8A,QA8B,QA8C,QA8D
     1         ,QA8E,QA8F,QA8I,QA8J,WA9W,QA9A,QA9B
     2         ,QA9C,QA9D,QA9G,QA9H,QA9I,QA9J
      WRITE (3,920)       WA12W,QA12A,QA12B,QA12G,QA12H,WA10W
      WRITE (3,920)  QA10A,QA10B,QA10G,QA10H
      WRITE (3,920)  PRES,TRAL,VELL,FORC,FLOW,AV2FB,AV2F1
     1         ,AV12J,APPPK,APPPI,APPPY,APRBW,APRBI,APRRI
     2         ,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,ACBBY,APRBJ
     3         ,APRHK,AVMAW,AVMAA ,ABFHI,ABFAI,ABFAX,ABFHJ
     4         ,ABBDI,ATBC1,ATBC2,ATBC3,STVFJ,AVBBX,AV2FJ
      WRITE (3-ITRA3) WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F,QA1G,QA1H,QA1I,
     1 QA1J,WA2W,QA2A,QA2B,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J,WA3W,QA3A,QA3B,
     2 QA3C,QA3D,QA3I,QA3J,WA4W,QA4A,QA4B,QA4C,QA4D,QA4E,QA4F,QA4I,QA4J,
     3 WA5W,QA5A,QA5B,QA5C,QA5D,QA5E,QA5F,QA5I,QA5J,WA6W,QA6A,QA6B,QA6C,
     4 QA6D,WA7W,QA7A,QA7B,QA7C,QA7D,QA7G,QA7H,WA8W,QA8A,QA8B,QA8C,QA8D
      WRITE (3-ITRA3) QA8E,QA8F,QA8I,QA8J,WA9W,QA9A,QA9B,QA9C,QA9D,QA9G,
     1 QA9H,QA9I,QA9J,WA12W,QA12A,QA12B,QA12G,QA12H,WA10W,QA10A,QA10B,
     2 QA10G,QA10H,PRES,TRAL,VELL,FORC,FLOW,AV2FB,AV2F1,AMOM,AV12J,APPPK
     3 ,APPPI,APPPY,APRBW,APRBI,APRRI,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,
     4 ACBBY,APRBJ,APRHK,AVMAW,AVMAA,ABFHI,ABFAI,ABFAX,ABFHJ,ABBDI,ATBC1
      WRITE (3-ITRA3) ATBC2,ATBC3,STVFJ,AVBBX,AV2FJ
      IF (AMAX-AMOM)30,30,31
   30 IF (PREM-PRES)32,32,31
   32 CONTINUE
      CALL LINK (ACT56)
      END
// DUP
*STORE       WS  UA  ACT34
```

```
C                              STORED PROGRAM 3
C  ACTUATOR 5
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      IDATA = 3
      ITRA3=1
      ITRA4=1
      IREC6=1
  920 FORMAT (2X,7E13.5)
    2 FORMAT (2X,20H   ACTUATOR 56        )
      READ  (1-IDATA) AMAX,PREM,TORQ,VELA,AAAA1,AAAA2,AAAA4,AAAA5,AAAA6,
     1  AAAA7,AAAA8,AAAA9,AAA10,AKVEL,TOILW,AIPA1,AIPA2,AIPA3,AIPA4,
     2 CG,CC,CSA,CFA,CYA,CZA
      WRITE (3,2)
   61 CONTINUE
      READ  (3-ITRA3) WA1W,QA1A,QA1B,QA1C,QA1D,QA1E,QA1F,QA1G,QA1H,QA1I,
     1 QA1J,WA2W,QA2A,QA2B,QA2C,QA2D,QA2G,QA2H,QA2I,QA2J,WA3W,QA3A,QA3B,
     2 QA3C,QA3D,QA3I,QA3J,WA4W,QA4A,QA4B,QA4C,QA4D,QA4E,QA4F,QA4I,QA4J,
     3 WA5W,QA5A,QA5B,QA5C,QA5D,QA5E,QA5F,QA5I,QA5J,WA6W,QA6A,QA6B,QA6C,
     4 QA6D,WA7W,QA7A,QA7B,QA7C,QA7D,QA7G,QA7H,WA8W,QA8A,QA8B,QA8C,QA8D
      READ  (3-ITRA3) QA8E,QA8F,QA8I,QA8J,WA9W,QA9A,QA9B,QA9C,QA9D,QA9G,
     1 QA9H,QA9I,QA9J,WA12W,QA12A,QA12B,QA12G,QA12H,WA10W,QA10A,QA10B,
     2 QA10G,QA10H,PRES,TRAL,VELL,FORC,FLOW,AV2FB,AV2F1,AMOM,AV12J,APPPK
     3 ,APPPI,APPPY,APRBW,APRBI,APRRI,APPPJ,APPPX,ACBT1,ACBT4,ACBBI,
     4 ACBBY,APRBJ,APRHK,AVMAW,AVMAA,ABFHI,ABFAI,ABFAX,ABFHJ,ABBDI,ATBC1
      READ  (3-ITRA3) ATBC2,ATBC3,STVFJ,AVBBX,AV2FJ
     0ABHMW=.031*(TRAL+.00318*AAAA8*VELL**2./APRHK+APPPY)*(.5*ACBT4**2.-
     1ACBT1**2.+1.44*(APPPI+STVFJ)**2.)+.177*(ABFAI+ABBDI)*(ATBC1+
     2ATBC2+4.*ATBC3)*(ATBC1+2.*ATBC3-.0786*(STVFJ**2.+APPPK**2.))
     3+ABFHI**3.*(1.02E-9*PRES**2.+2.04E-5*PRES+.0173)
      WA13W=ABHMW
      QA13A=.208/(ABHMW**.333)
      QA13B=QA13A
      QA13C= .1*QA13A
      QA13D=.5*QA13C
      QA13G=QA13C
      QA13H=QA13D
      ABFAI=ABFAI*AAAA7
      ABFAX=ABFAX*AAAA7
      ABHBX=1.3*ABFHI+1.70*ABBDI*(1.0+2.05E-4*PRES)
     0ABHBW=         .0864*ABFHI**3.*(1.3*((2.0E-4)*PRES+(1.0E-8)*PRES
     1**2.0)+.2195)+ABBDI**3.0*.4770+(4.44E-4)*PRES+(4.47E-8)*PRES**
     22.0+.0635+ABFAX*ABFAI**2.0*(.02365+(.561E-4)*PRES+(.718E-8)*PRES
     3**2.)+.0864*(ACBBI**2.0+((1.608E-4)*PRES+(.647E-8)*PRES**2.0)*
     4ABHBX+(ACBBI**2.0-APPPK**2.0)*(ABHBX-1.3*ABFHI))
      WA12W=ABHBW+WA12W
      QA12C=.0208/(ABHBW**.333)
      QA12A= QA12A+QA12C*10.
      QA12B= QA12B+QA12C*10.
      QA12D=.5*QA12C
      QA12G= QA12C+QA12G
      QA12H= QA12H+.5*QA12C
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      AIPBW=.0876*TRAL*AIPA4
      AIPBA =AIPA4*TRAL*(.212+AIPA1*.338+AIPA2*.338+AIPA3*.274)
      WA3W=WA3W+.252*AIPA4+AIPBW
      QA3A=QA3A+AIPBA +AIPA4*(.0968+AIPA1*.250+AIPA2*.250+AIPA3*.150)
      QA3B=QA3B+.1*AIPBA +.1*AIPA4*(.0968+AIPA1*.25+AIPA2*.25+AIPA3*.15)
      AFCCX=AAAA5*(.00318*(VELL**2.)/APRHK*AAAA8+TRAL+62.*AV12J)
      AFCCI=27.0*AV12J
      AFCHX=AAAA5*(2.0*AFCCX-62.0*AV12J)
      ATUBA =.0487*APRBJ+(.0343/APRBJ)+.00743
     0WA3W=WA3W+73.5*AFCCX*AV12J**2.0+.2475*AFCHX*AFCCI**2.0+AAAA5*.286
     1*AIPBW+.704*AFCCI**3.0*AAAA5+AAAA5*.0002+2.*APRBW
     0QA3A=QA3A+AAAA5*.00196/AV12J+.0385*AFCCI*AFCHX+.0301*AIPBA *AAAA5
     1+AAAA5*(.000132/AFCCI)+AAAA5*.070 +.05*ATUBA
     0QA3B=QA3B+AAAA5*.00049/AV12J+.00962*AFCCI*AFCHX+AAAA5*.0075*AIPBA
     1+AAAA5*(.000132/AFCCI)+AAAA5*.0175 +.05*ATUBA
     0QA3I=QA3I+AAAA5*.000784/AV12J+.00154*AFCCI*AFCHX+AAAA5*.012*AIPBA
     1+AAAA5*(.000198/AFCCI)+AAAA5*.028+.05*ATUBA
     0QA3J=QA3J+AAAA5*.0000784/AV12J+.00154*AFCCI*AFCHX+AAAA5*.0012*
     1AIPBA +AAAA5*(.000132/AFCCI)+AAAA5*.0028 +.05*ATUBA
      WA2W=WA2W+AAAA5*.492*AVMAW  +.0478
      QA2A=QA2A+AAAA5*.15*AVMAA  +.33
      QA2B=QA2B+AAAA5*.015*AVMAA +.033
      QA2G=QA2G+.0033
      QA2H=QA2H+.0033
      QA2I=QA2I+AAAA5*.003*AVMAA
      QA2J=QA2J+AAAA5*.003*AVMAA
      CALL OSUB(26.*AV12J,12.5,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA2W=WA2W+AAAA5*RWT
      QA2A=QA2A+AAAA5*RFRG
      WA3W=WA3W+14.0*2.66E-14*(APPPI*PRES)**3.0
      QA3A=QA3A+14.0*16.08/(APPPI*PRES)
      CALL OSUB(ACBBY,12.5,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WA3W=WA3W+RWT
      QA3A=QA3A+RFRG
      ACVOL = 1.2*TRAL*FORC/PRES+ABFHJ**3.*2.2
      WASW=WA1W+WA2W+WA3W+WA4W+WA6W+WA7W+2.0*WA8W+WA9W+WA12W
     1+TOILW*ACVOL
      QASG=CG*(QA9A+QA2A+QA1A+QA4A+QA6A+QA12A+QA7A+2.0*QA8A+QA3A)
      QASC=CC*(QA9B+QA2B+QA1B+QA4B+QA6B+QA12B+QA7B+2.0*QA8B+QA3B)
     0QASS=CSA*(QA9C+QA9G+QA9I+QA2C+QA2G+QA2I+QA1C+QA1E+QA1G+QA1I+QA4C+
     1QA4E+QA4I+QA6C+QA12C+QA12G+QA7C+QA7G+2.0*(QA8C+QA8E+QA8I)
     2+QA3C+QA3I)
     0QASF=    (QA9D+QA9H+QA9J+QA2D+QA2H+QA2J+QA1D+QA1F+QA1H+QA1J+QA4D+
     1QA4F+QA4J+QA6D+QA12D+QA12H+QA7D+QA7H+2.0*(QA8D+QA8F+QA8J)
     2+QA3D+QA3J)
      WATW=WA3W+WA5W+WA10W+2.0*(WA1W+WA2W+WA7W+WA8W+WA9W)
     1+2.0*TOILW*ACVOL
      QATPG=CG*(QA9A+QA1A+QA2A+QA5A+2.0*QA8A+QA7A)
      QATSG=CG*(QA9A+QA1A+QA2A+QA5A+QA7A)
      QATCG=CG*(QA10A+QA3A)
      QATPC=CC*(QA9B+QA1B+QA2B+QA5B+2.0*QA8B+QA7B)
      QATSC=CC*(QA9B+QA1B+QA2B+QA5B+QA7B)
      QATCC=CC*(QA10B+QA3B)
     0QATPS=CSA*(QA9C+QA9G+QA9I+QA2C+QA2G+QA2I+QA1C+QA1E+QA1G+QA1I
     1+QA5C+QA5E+QA5I+2.0*(QA8C+QA8E+QA8I)+QA7C+QA7G)
     0QATSS=CSA*(QA9C+QA9G+QA9I+QA2C+QA2G+QA2I+QA1C+QA1E+QA1G+QA1I
     1+QA5C+QA5E+QA5I+QA7C+QA7G)
      QATCS=CSA*(QA10G+QA3C+QA3I)
     0QATPF=    (QA9D+QA9H+QA9J+QA2D+QA2H+QA2J+QA1D+QA1F+QA1H+QA1J
     1+QA5D+QA5F+QA5J+2.0*(QA8D+QA8F+QA8J)+QA7D+QA7H)
```

```
      OQATSF=     (QA9D+QA9H+QA9J+QA2D+QA2H+QA2J+QA1D+QA1F+QA1H+QA1J
     1+QA5D+QA5F+QA5J+QA7D+QA7H)
      QATCF=      (QA10H+QA3D+QA3J)
      WAMW=WA1W+3.0*WA2W+WA3W+WA4W+WA6W+WA7W+2.0*WA8W+WA9W+WA10W+WA13W
     1+TOILW*ACVOL
      OQAMG=CG*(QA9A+3.0*QA2A+QA1A+QA4A+QA6A+QA10A+QA13A+QA7A
     1+2.0*QA8A+QA3A)
      OQAMC=CC*(QA9B+3.0*QA2B+QA1B+QA4B+QA6B+QA10B+QA13B+QA7B
     1+2.0*QA8B+QA3B)
      QH2S = (QA2I*QA2I*CSA*CSA)*(1.5-.5*QA2I*CSA)
      QN2S = (QA2G*QA2G*CSA*CSA)*(3.0-2.*QA2G*CSA)
      QA1S=CSA*(QA9C+QA9G+QA9I)
      OQA3S=CSA*(QA1E+QA1G+QA1I+QA4E+QA4I+QA6C+QA10G+QA13G
     1+QA7C+QA7G+2.0*(QA8C+QA8E+QA8I)+QA3C+QA3I)
      QAMS = 1. -(1.-QA1S)*(1.-QA3S)*(1.-QH2S)*(1.-QN2S)
      QH2F = (QA2J*QA2J*CFA*CFA)*(1.5-.5*QA2J*CFA)
      QH2Y = (QA2J*QA2J*CYA*CYA)*(1.5-.5*QA2J*CYA)
      QH2Z = (QA2J*QA2J*CZA*CZA)*(1.5-.5*QA2J*CZA)
      QN2F = (QA2H*QA2H*CFA*CFA)*(3.0-2.*QA2H*CFA)
      QN2Y = (QA2H*QA2H*CYA*CYA)*(3.0-2.*QA2H*CYA)
      QN2Z = (QA2H*QA2H*CZA*CZA)*(3.0-2.*QA2H*CZA)
      QA1F=CFA*(QA9D+QA9H+QA9J)
      QA1Y = QA1F*CYA/CFA
      QA1Z = QA1F*CZA/CFA
      OQA3F=CFA*(QA1F+QA1H+QA1J+QA4F+QA4J+QA6D+QA10H
     1+QA13H+QA7D+QA7H+2.0*(QA8D+QA8F+QA8J)+QA3D+QA3J)
      QA3Y = QA3F*CYA/CFA
      QA3Z = QA3F*CZA/CFA
      QAMF = 1. -(1.-QA1F)*(1.-QA3F)*(1.-QH2F)*(1.-QN2F)
      QAMY = 1. -(1.-QA1Y)*(1.-QA3Y)*(1.-QH2Y)*(1.-QN2Y)
      QAMZ = 1. -(1.-QA1Z)*(1.-QA3Z)*(1.-QH2Z)*(1.-QN2Z)
C  ACTUATOR 6
      ACTIM=TRAL/VELL
      ACTQL=(AV2FB+14.2*AV2FJ**3.0)*2.0
      ACTQM=FLOW+14.2*AV2FJ**3.0
      OALLLX=(APRRI+APRBI)/2.0+1.836*APRBJ+APRHK+APPPX+AFCCX+.5*TRAL+
     1 .00159*VELL**2.0/APRHK*AAAA8
      ACYCL=21.0E+8/(PRES*TRAL)
      ALIFE=2.533*AV2F1*TORQ*VELA/(PRES*AV2FB**2.0)
      ACTQA=ACTQM+.7*FLOW*(1.0-AAAA7)
      OAKINT=1.0/(.275*(TRAL+.00318*VELL**2.0/APRHK)/(2.4E+5*FORC/PRES)+
     1APPPI**2.0*(ACBBI+APPPI)*(TRAL+APPPY+.00318*VELL**2.0/APRHK)/(14.8
     2E+7*(FORC/PRES)**2.0*(ACBBI-APPPI))+(TRAL+APPPY+.00318*VELL**2.0/
     3APRHK)/(3.14*(ACBBI**2.0-APPPY**2.0)*29.E+6))
      OAKEXT=1.0/((APPPX-TRAL-.71*APPPK**0.5-.00159*VELL**2.0/APRHK-APPPY
     1)/(22.8E+6*(APPPK**2.0-APPPJ**2.0))+(AVBBX+TRAL)/(2.37E+3*FORC))
      OAKSSS=(1.0-AAAA1)*(1.0-AAAA6)*1.0/(1.0/AKEXT+AV2FJ/(84.6*AKVEL*
     1(FORC/PRES)**2.0*PRES**0.5))+(AAAA1)*(1.0-AAAA4)*(1.0-AAAA6)*1.0/
     2(1.0/AKEXT+1.0/AKINT)+1.0E-9
      FLOR=FLOW*(3000./PRES)**0.5
      IF (FLOR-20.) 871,871,872
  871 AAA15=0.
      GO TO 873
  872 AAA15 = 1.
  873 CONTINUE
      ADUM1 =     (71.82*APPPK-9.77*APPPK**2.+2.014*APPPK**3.+APPPI**3.
     1*(.875758-200.9068/PRES-79711.07/PRES**2.)+66628232./PRES**2.0-
     2117434.89/PRES+105.55801-.034223256*PRES+1.0761896E-5*PRES**2.0)
     3*(1.0+.0188*TRAL)
      ADUM2 = (556.78+2.293*FLOR-4.875E14/(FLOR*.25974+133.3)**5.5629)*
```

```
1  AAA15        +(167.49+.3822*FLOR-.8125E+14/(FLOR*.25974+133.3)**
15.5629)*(AAAA7+AAAA1+0.5*AAAA4)
 ADUM3=         (51.41+.0008176*PRES+.00646*PRES*APPPI-20.285E-5*
1APPPI**2.*PRES-.6927*APPPI+1.1711*APPPI**2.)*AAAA8+AIPA4*(261.3+
227.30*AIPA3+35.10*(AIPA1+AIPA2)+31.20*TRAL*(AIPA1+AIPA2+AIPA3))
 ADUM4=(100.0*AFCCI*1.00+250.0)*(1.0+.0188*TRAL)*(AAAA2+.333*AAAA6)
 ABCSS = 5.2*ADUM1 + ADUM2+ADUM3+984.07 +2.3*WASW**.5 +ADUM4
0ATCSS =910.+10.*AAAA8+AIPA4*(25.+(AIPA1+AIPA2+AIPA3-1.)*5.)+
1AAAA2*10.0+AAAA7*20.0+AAAA6*20.0
0ADCSS =(66000.+1.E+4*AAAA8+8000.*AIPA4+2.E+4*AAAA2+14000.*AAAA7
1+1.E+4*AAAA6+1.E+4*(AAAA1+AAAA4)+15.0*ABCSS )*AAAA9+AAA10*154460.
 AUCSS = ABCSS +ATCSS
 ADTIS =AAAA9*62.+AAA10*21.
 ABCST = 20.5*ADUM1 +2.*ADUM2+ADUM3 +1501. +4.6*WATW**.5 +2.*ADUM4
0ATCST =1450.+10.*AAAA8+AIPA4*(25.+(AIPA1+AIPA2+AIPA3-1.)*5.)+
1AAAA2*20.+AAAA7*40.+AAAA6*20.
0ADCST =(92000.+1.E+4*AAAA8+8000.*AIPA4+2.E+4*AAAA2+14000.*AAAA7
1+1.E+4*AAAA6+1.E+4*(AAAA1+AAAA4)+15.*ABCST )*AAAA9+AAA10*184460.
 AUCST =ABCST +ATCST
 ADTIT =AAAA9*65.+AAA10*23.
 ABCSM = 14.5*ADUM1+ADUM2+ADUM3 +1481. +2.3*WAMW**.5 +3.*ADUM4
0ATCSM =1045.+10.*AAAA8+AIPA4*(25.+(AIPA1+AIPA2+AIPA3-1.)*5.)+
1AAAA2*10.0+AAAA7*20.0+AAAA6*20.0
0ADCSM =(84000.+1.E+4*AAAA8+8000.*AIPA4+2.E+4*AAAA2+14000.*AAAA7
1+1.E+4*AAAA6+1.E+4*(AAAA1+AAAA4)+15.*ABCSM )*AAAA9+AAA10*204460.
 AUCSM = ABCSM +ATCSM
 ADTIM =AAAA9*65.+AAA10*23.
 WRITE (3,920) WASW,QASG,QASC,QASS,QASF,ADCSS,AUCSS,ADTIS,WAMW,QAMG
1,QAMC,QAMS,QAMF,ADCSM ,AUCSM ,ADTIM ,WATW,QATPG,QATSG,QATCG,QATPC,
2QATSC,QATCC,QATPS,QATSS,QATCS,QATPF,QATSF,QATCF,ADCST,AUCST,
3ADTIT ,ALIFE,ACTQL,ACYCL,AMOM,PRES,AMAX,PREM ,QAMY,QAMZ
 WRITE(6-IREC6)WASW,QASG,QASC,QASS,QASF,ADCSS,AUCSS,ADTIS,WAMW,QAMG
1,QAMC,QAMS,QAMF,ADCSM ,AUCSM ,ADTIM ,WATW,QATPG,QATSG,QATCG,QATPC,
2QATSC,QATCC,QATPS,QATSS,QATCS,QATPF,QATSF,QATCF,ADCST,AUCST,
3ADTIT ,ALIFE,ACTQL,ACYCL,AMOM,PRES,AMAX,PREM ,QAMY,QAMZ
 WRITE (4-ITRA4) AMOM,PRES,ALLLX,FORC,APRBJ,AKINT,AKEXT,AKSSS,
1  APPPJ,FLOR,AAA15,ACTQA,ACTQM,ACTIM,ACVOL
 IF (AMAX-AMOM)60,60,61
60 IF (PREM-PRES)62,62,61
62 CALL LINK (TRUSS)
 END
// DUP
*STORE      WS   UA   ACT56
```

```
C                              STORED PROGRAM 4

C  TRUSS
      DIMENSION T1(12),T2(12),TUBE(9,14),FIT(14)
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  TRUSS-TUBE-VALVE   )
      WRITE (3,1002)
      IDATA =4
      ITRA4=1
      ITRA5=1
      IREC7 =1
      READ  (1-IDATA) AMAX,PREM,TORQ,VELA,EINT,ANUMB,XMDC,XMDD,XMDB,
     1 XMDA,XMDE,AAAA6,XXXX1,XXXX2,STV1,STV2,TA,TB,TC,TD,TE,QQQQ1,
     2 QQQQ2,QQQQ3,VNAFQ,ANUMV,CG,CC,CSA,CSB,CSD,
     3 (T1(I),I=1,12),(T2(I),I=1,12),(FIT(N),N=1,14)
      READ (1-IDATA)   ((TUBE(M,N),M=1,9),N=1,14)
      CAG=1.
      CAC=.2
      CAS=.2
      CAF=.01
      TMTL1=TB+TC+TD
      TMTL2=TE
      TMTL3=TA
      ANUMV=ANUMV**.5
   11 CONTINUE
      READ  (4-ITRA4) AMOM,PRES,ALLLX,FORC,APRBJ,AKINT,AKEXT,AKSSS,
     1  APPPJ,FLOR,AAA15,ACTQA,ACTQM,ACTIM,ACVOL
      XALFP=ATAN ((AMOM-XMDC)/(XMDD-ALLLX))
      XBETP=ATAN ((ALLLX-XMDA)/(AMOM-XMDB))
      XPHIP=1.57-XBETP
      XSIGP=3.14-XALFP-XPHIP
      XTHEP=ATAN ((XMDE*COS(XBETP))/(2.0*(AMOM-XMDB)))
      XMTLX=(XMDD-ALLLX)/COS(XALFP)
      XMTUX=XMDE/(2.0*SIN(XTHEP))
      XMTUF=FORC*SIN(XALFP)/(2.0*SIN(XSIGP)*COS(XTHEP))
      XMTLF=FORC*SIN(XPHIP)/SIN(XSIGP)
      IF (ABS (XMTLX)-ABS (XMTUX))850,850,851
  850 XMTPX=XMTUX
      GO TO 852
  851 XMTPX=XMTLX
  852 XMRAX=XMTPX/64.34
      IF (ABS (XMTLF)-ABS (XMTUF))853,853,854
  853 XMTPF=XMTUF
      GO TO 855
  854 XMTPF=XMTLF
  855 XTHIX=XMTPF/(216352.*XMRAX)
     0WGT=1.777*XMRAX*XTHIX*(XMTLX+2.*XMTUX)+6.338*APRBJ**3.+.366*
     1APRBJ**2.
      XUSSA =3.*(.00005/XTHIX+.00025/XMRAX)+2.*(.00745/APRBJ)+.1
```

```
      XUSSB =.01+2.*(.000745/APRBJ)
      XUSSG =2.*(.00022/APRBJ)
      XUSSH =XUSSG
      TRWT=WGT
      XRHOP=ATAN ((AMOM-XMDC)/(XMDD-ALLLX-1.0))
      XDELP=ATAN ((AMOM-XMDB)/(ALLLX-XMDA+1.0))
      XZETP=ATAN ((XMDE*(SIN(XDELP)))/(2.0*(AMOM-XMDB)))
      XKTLX=(AMOM-XMDC)/(SIN(XRHOP))
      XKTUX=XMDE/(2.0*(SIN(XZETP)))
     0XMTES=09.11E+7*XMRAX*XTHIX*((COS(XRHOP))*(ABS (XMTLX-XKTLX))/XMTLX
     1+2.0*(COS(XZETP))*(COS(XDELP))*(ABS (XKTUX-XMTUX))/XMTUX)
      AKSYS=1.0/(1.0/XMTES+1.0/AKINT+1.0/AKEXT)
      ASTST=1.0/(1.0/AKSSS+1.0/XMTES)*(1.0-AAAA6)
      ANAFQ=AMOM*(AKSYS/EINT)**0.5
      VFAC1=XMTES*(1.0-(VNAFQ/ANAFQ)**2.0)/AKSYS*(VNAFQ/ANAFQ)**2.0+1.0
      IF(VFAC1-1.0)201,202,202
  202 VFAC2=1.0
      VFAC3=0.0
      GO TO 200
  201 IF(VFAC1-.333)203,204,204
  204 VFAC2=VFAC1
      VFAC3=1.0
      GO TO 200
  203 VFAC2=1.0
      VFAC3=2.0
      GO TO 200
  200 VFAC4=1.0/VFAC2
      TRWT=VFAC4*TRWT
      XUSSA =XUSSA *VFAC4
      XUSSB =XUSSB *VFAC4
      XUSSG =XUSSG *VFAC4
      XUSSH =XUSSH *VFAC4
      DO 302 N=1,11,1
      IF (XTHIX-T1(N)) 301,301,302
  302 CONTINUE
  301 XCON1=T2(N)
     0XRUSU=(.8992*(2.0*XMRAX+XTHIX)**1.09885+.482)*(XMTLX+2.0*XMTUX)*(
     1XCON1)+(37.75*APPPJ**1.5962+78.0)*4.0
      XRUSD=(900.+12.50*(XMTLX+2.0*XMTUX)+10.*XRUSU)*XXXX1
      QTRG=CG*XUSSA
      QTRC=CC*XUSSB
      QTRS=CSA*XUSSG
      QTRF=XUSSH
      WRITE (3,920)   TRWT,QTRG,QTRC,QTRS,QTRF,XRUSU,XRUSD
C  VALVE
      STVF1=(VELA*TORQ*ANUMV)**.5/PRES**.75
      STVF2=1.+3.E-4*PRES
      STVFX=2.27*STVF1+1.82*(STVF1*STVF2)**.5+.382*STVF1**.5
      STVFJ=.368*STVF1
      STVFI=.368*STVF2*STVF1+.079*(STVF2*STVF1)**.5
      STVFV=.111*STVF1
     0WT=.144*(STVFI**2.-STVFJ**2.)*STVFX+.124*(STVFJ**2.)*STVFX
     1+(5.37E-8*(STVFJ**4.)*(PRES**2.)/STVFV)+(3.51E-6*(STVFJ**3.)*
     2(PRES**1.5))+3.07E-8*(STVFJ**3.)*PRES**1.5
     0STVFA =(.00308*((VELA*TORQ*ANUMV)**1.5)/(PRES**1.75))+(4.54/
     1(STVF1*PRES**.5))
      STVBA =1.54/(STVFJ*PRES**.5)
      STRRG=2.*STVFA +(4.7E-5/STVFV)+(5.64E-5/STVFV)
      STRRC=STVFA +.1*STVBA +(4.7E-6/STVFV)+(5.62E-6/STVFV)
      STRRS=.1*STVFA +(4.7E-6/STVFV)
```

```
      STRRF = STRRS
      STVBX=.00036*PRES*STVFJ**2./STVFV
     0WT=WT+4.29E-4*STVBX*PRES*STVFJ**2.+1.237*STVFJ**3.
     1+(4.84E-5*PRES*STVFX*STVFI**2.)+.22+7.35E-5*PRES
      STRRG=STRRG+.00462*STVBX*STVFJ**2.+(.0286/(STVBX*PRES*STVFJ**2.))
      STVUA =4.85/(PRES*STVFX*STVFI**2.)**.333
      CALL OSUB (1.005*STVFI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+RWT
      STRRG=STRRG+.0007+STVUA +RFRG+(3.33E-5*PRES+.02)
      STRRC=STRRC+RFRC+.00046*STVBX*STVFJ**2.+.1*STVUA +.064+6.7E-6*PRES
      STRRS=STRRS+RFRS+(2.3E-4*STVBX*STVFJ**2.)+.1*STVUA
      STRRF=STRRF+RFRF+.00046*STVBX*STVFJ**2.+.01*STVUA
      CALL OSUB(1.28*STVFI,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+RWT
      STRRG=STRRG+RFRG
      STRRC=STRRC+RFRC
      STRRS=STRRS+RFRS
      STRRF=STRRF+RFRF
      CALL OSUB(1.005*STVFI,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+11.*RWT
      STRRG=STRRG+6.*RFRG
      STRRC=STRRC+6.*RFRC
      STRSP =STRRS+2.*RFRS
      STRSS =STRRS+4.*RFRS+.0061
      STRFP =STRRF+2.*RFRF
      STRFS =STRRF+4.*RFRF+.0061
      CALL OSUB(1.005*STVFI,.01*PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      STRRG=STRRG+5.*RFRG
      STRRC=STRRC+5.*RFRC
      STRSP =STRSP +2.*RFRS
      STRSS =STRSS +3.*RFRS
      STRFP =STRFP +2.*RFRF
      STRFS =STRFS +3.*RFRF
      CALL OSUB(.3125,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      STRRG=STRRG+RFRG
      STRRC=STRRC+RFRC
      STRSP =STRSP +RFRS
      STRSV =.1*STVFA
      STRFV = STRSV
      STRFP =STRFP +RFRF
      QTG=CG*STRRG
      QTC=CC*STRRC
      QTFS=CSB*STRSV
      QTEPS =.75*CSB*STRSP
      QTESS =.75*CSB*STRSS
      QTIPS =.25*CSB*STRSP
      QTISS =.25*CSB*STRSS
      QTFF=STRFV
      QTEPF =.75*STRFP
      QTESF =.75*STRFS
      QTIPF =.25*STRFP
      QTISF =.25*STRFS
     0STCSU=1090.+(400.78+2.293*FLOR-4.875E+14/(FLOR*.25975+133.2)**
     15.5629)*AAA15+140.+4.6*WT**.5
      STCSD=11000.*STV1+15230.*STV2
      WRITE (3,920) WT,QTG,QTC,QTFS,QTEPS,QTESS,QTIPS,QTISS,QTFF,QTEPF
     1  ,QTESF,QTIPF,QTISF,STCSD,STCSU
C   TUBING
      FLOW=ACTQM
      TMT2J=((1.02E-3*FLOW*(.794*TMTL1+TMTL2))/(.1*PRES))**.25
```

```
      TMT1J=TMT2J*(ANUMB**.333)
      TMT2I=TMT2J*((1.0+6.83E-5*PRES)/(1.0-6.83E-5*PRES))**.5
      TMT1I=TMT1J*((1.0+6.83E-5*PRES)/(1.0-6.83E-5*PRES))**.5
      TMT2T=(TMT2I-TMT2J)/2.0
      TMT1T=(TMT1I-TMT1J)/2.0
      M=1
      N=1
      DO 901 N=1,14,1
      IF (TMT2I-TUBE(M,N))902,902,901
  901 CONTINUE
  902 TMT2I=TUBE(M,N)
      WTF2=FIT(N)
      DO 903 M=2,9,1
      IF (TMT2T-TUBE(M,N))904,904,903
  903 CONTINUE
  904 TMT2T=TUBE(M,N)
      M=1
      N=1
      DO 911 N=1,14,1
      IF (TMT1I-TUBE(M,N))912,912,911
  911 CONTINUE
  912 TMT1I=TUBE(M,N)
      WTF1=FIT(N)
      DO 913 M=2,9,1
      IF (TMT1T-TUBE(M,N))914,914,913
  913 CONTINUE
  914 TMT1T=TUBE(M,N)
      TMT2J=TMT2I-2.0*TMT2T
      TMT1J=TMT1I-2.0*TMT1T
      FVOL=.785*(TMTL1*(TMT1J**2.0)+2.0*TMTL2*(TMT2J**2.0))
     1+.785*(TMTL3*(TMT1J**2.0))
      QLTG1=CG*((2.8E-6)*TMT1I)/TMT1T
      QLTG2=CG*((2.8E-6)*TMT2I)/TMT2T
      QBTG1=CG*(1.05E-6)/(TMT1T*TMT1I)
      QBTG2=CG*(1.05E-6)/(TMT2T*TMT2I)
      QFG1=2.*CG*(.06*TMT1I+1.47E-3/(TMT1I*TMT1T))
      QFG2=2.*CG*(.06*TMT2I+1.47E-3/(TMT2I*TMT2T))
      QLAG=TA*QLTG1+QFG1
      QLBG=TB*QLTG1+2.*QFG1
      QLCG=TC*QLTG1+QFG1
      QLDG=TD*QLTG1+QFG1
      QLEG=TE*QLTG2+QFG2
      QBAG=TA*QBTG1+QFG1
      QBBG=TB*QBTG1+2.*QFG1
      QBCG=TC*QBTG1+QFG1
      QBDG=TD*QBTG1+QFG1
      QBEG=TE*QBTG2+QFG2
      QTAA=CAG*(QLAG+QBAG)
      QTBA=CAG*(QLBG+QBBG)
      QTCA=CAG*(QLCG+QBCG)
      QTDA=CAG*(QLDG+QBDG)
      QTEA=CAG*(QLEG+QBEG)
      QLAC=(CC/CG)*QLAG
      QLBC=(CC/CG)*QLBG
      QLCC=(CC/CG)*QLCG
      QLDC=(CC/CG)*QLDG
      QLEC=(CC/CG)*QLEG
      QBAC=(CC/CG)*QBAG
      QBBC=(CC/CG)*QBBG
      QBCC=(CC/CG)*QBCG
```

```
      QBDC=(CC/CG)*QBDG
      QBEC=(CC/CG)*QBEG
      QTAB=CAC*(QLAC+QBAC)
      QTBB=CAC*(QLBC+QBBC)
      QTCB=CAC*(QLCC+QBCC)
      QTDB=CAC*(QLDC+QBDC)
      QTEB=CAC*(QLEC+QBEC)
      QTAC=CAS*(CSD/CG)*QLAG
      QTBC=CAS*(CSD/CG)*QLBG
      QTCC=CAS*(CSD/CG)*QLCG
      QTDC=CAS*(CSD/CG)*QLDG
      QTEC=CAS*(CSD/CG)*QLEG
      QTAD =CAF*QLAG/CG
      QTDD =CAF*QLDG/CG
      QTED =CAF*QLEG/CG
      QTBD =CAF*QLBG/CG
      QTCD =CAF*QLCG/CG
      WT1=.894*(TMT1T*TMT1J+TMT1T**2.)
      WF1=2.*WTF1
      FVWT1=.0239*TMT1J**2.0
      WA=TA*(FVWT1+WT1)+WF1
      WB=TB*(FVWT1+WT1)+WF1
      WC=TC*(FVWT1+WT1)+WF1
      WD=TD*(FVWT1+WT1)+WF1
      WE=(.894*(TMT2T*TMT2J+TMT2T**2.)+.245*TMT2J**2.)*TE+2.*WTF2
      DO 702 N=1,11,1
      IF (TMT1T-T1(N))701,701,702
  702 CONTINUE
  701 TCON1=T2(N)
      DO 704 N=1,11,1
      IF (TMT2T-T1(N))703,703,704
  704 CONTINUE
  703 TCON2=T2(N)
      TUCD1 =(450.+12.50*TMTL1)*XXXX2
      TUCD2 =(450.+12.50*TMTL2)*XXXX2
      TUCD3 =(450.+12.50*TMTL1/4.)*XXXX2
      TUCU1 =(.8992*(TMT1I)**1.09885+.482)*TMTL1*TCON1
      TUCU2 =(.8992*(TMT2I)**1.09885+.482)*TMTL2*TCON2
      TUCU3 =(.8992*(TMT1I)**1.09885+.482)*TMTL1/4.*TCON1
      QPORT=TMT1I*(ANUMB*QQQQ3/2.0)**0.5
      QDWGW=1.84E-6*PRES**2.0*TMT1I**3.0*(ANUMB*QQQQ3/2.0)**1.5
      CALL OSUB(QPORT,PRES,3,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      QDWGA =RFRG+.02
      CALL OSUB(1.1*QPORT,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      QDWGA =QDWGA +RFRG
      CALL OSUB(1.1*QPORT,40.,7,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      QDWGA =QDWGA +RFRG
      CALL OSUB(1.35*QPORT,40.,3,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      QDWGA =QDWGA +RFRG
      CALL OSUB(1.35*QPORT,40.,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      QDWGA =QDWGA +RFRG
      QDWGB =QDWGA *.01
      QDWGC =QDWGA *.001
      QDWGD =QDWGC
      QDCSU=(68.55*(TMT1I*(QQQQ3*ANUMB/2.0)**.5)**2.26286+832.53)
      QDCSD=(20000.+10.*QDCSU)*QQQQ1+42000.*QQQQ2
      QDWGA =CG*QDWGA
      QDWGB =CC*QDWGB
      QDWGC =CSB*QDWGC
      WRITE(3,920) WA,WB,WC,WD,WE,QTAA,QTBA,QTCA,QTDA,QTEA,QTAB,QTBB,
```

```
      1QTCB,QTDB,QTEB,QTAC,QTBC,QTCC,QTDC,QTEC,QTAD,QTBD,QTCD,QTDD,QTED,
      2 TUCD1,TUCD2,TUCD3,TUCU1,TUCU2,TUCU3,QDWGW,QDWGA,QDWGB,QDWGC,QDWGD
      3  ,QDCSD,QDCSU
       WRITE (7-IREC7)   TRWT,QTRG,QTRC,QTRS,QTRF,XRUSU,XRUSD,
      1 WT,QTG,QTC,QTFS,QTEPS,QTESS,QTIPS,QTISS,QTFF,QTEPF
      2  ,QTESF,QTIPF,QTISF,STCSD,STCSU
       WRITE(7-IREC7)  WA,WB,WC,WD,WE,QTAA,QTBA,QTCA,QTDA,QTEA,QTAB,QTBB,
      1QTCB,QTDB,QTEB,QTAC,QTBC,QTCC,QTDC,QTEC,QTAD,QTBD,QTCD,QTDD,QTED,
      2 TUCD1,TUCD2,TUCD3,TUCU1,TUCU2,TUCU3,QDWGW,QDWGA,QDWGB,QDWGC,QDWGD
      3  ,QDCSD,QDCSU
       WRITE (5-ITRA5) PRES,AMOM,ACTQA,ACTQM,ACTIM,ACVOL,FVOL,TMT1I
       IF (AMAX-AMOM)10,10,11
    10 IF (PREM-PRES)12,12,11
    12 CONTINUE
       CALL LINK (PUMP1)
       END
// DUP
*STORE      WS  UA  TRUSS
```

```
C                        STORED PROGRAM 5

C  FIXED ANGLE PUMP I
      DIMENSION BRI(5,22),BTI(5,18),BTII(4,18)
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  FIXED ANGLE PUMP 1)
      WRITE (3,1002)
      IDATA =6
      ITRA5=1
      ITRA4=41
      READ  (1-IDATA) AMAX,PREM,ANUMB,PPPP1,ANGL1,PUMS1,((BRI(M,N),M=
     1  1,5),N=1,22)
      READ  (1-IDATA)  ((BTI(M,N),M=1,5),N=1,18)
      READ  (1-IDATA)  ((BTII(M,N),M=1,4),N=1,18)
      PUMS=PUMS1
      ANGL=ANGL1
      TANA=SIN (ANGL)/COS (ANGL)
   11 CONTINUE
      READ  (5-ITRA5) PRES,AMOM,ACTQA,ACTQM,ACTIM,ACVOL,FVOL,TMT1I
      FLOW=ANUMB*ACTQA*PPPP1
      PAPW1=1.0
 1020PAPWP=(((8.49E-3*(PAPW1**2.))/(7.08-5.3E-5*PRES))+((4.88E-6*
     1PRES)/(PUMS*TANA *(2.98+2.44E-4*PRES)*(7.08-5.3E-5*PRES)))+(FLOW
     2/(PUMS*TANA *(2.98+2.44E-4*PRES)*(7.08-5.3E-5*PRES)))+((1.24E-4*
     3PRES*PAPW1)/(PUMS*TANA *(7.08-5.3E-5*PRES))))**.333
      IF (ABS (PAPWP-PAPW1)-1.0E-5*PAPWP)100,100,101
  101 PAPW1=(PAPWP+PAPW1)/2.
      GO TO 102
  100 PAPWI=PAPWP*(3.98+4.14E-4*PRES)
      PAPEW=.181*(PAPWP**3.0)
      PAPWJ=PAPWP*(2.98+2.44E-4*PRES)
      PAPWK=PAPWP*(1.98+7.4E-5*PRES)
     0PAPEA =(5.25E-7*PAPEW*(PAPWJ**2.)*(PUMS**2.)*PRES*TANA*
     1(2.98+2.44E-4*PRES))/(FLOW*PAPWP)
      PAPWX = 2.71*TANA*PAPWJ
      PAPDX=1.51*TANA*PAPWJ
      PAPC1=.122*PAPWP*((2.98+2.44E-4*PRES)*TANA*PRES)**.333
      PAPCI=PAPC1+.20
      PAPFI=1.26*PAPWP
      PAPT1=PAPCJ+PAPFI+1.7E-4*PAPWP*PRES
      DO 108 N=1,22,1
      IF (PAPT1-BRI(1,N))107,107,108
  108 CONTINUE
  107 PAPTK=BRI(2,N)
      PAPTI=BRI(3,N)
      PAPTY=BRI(4,N)
      PAPTW=BRI(5,N)
      DO 109 L=1,18,1
      IF (PAPCI-BTI(1,L))110,110,109
  109 CONTINUE
```

```
  110 PAPGK=BTI(2,L)
      PAPGI=BTI(3,L)
      PAPGY=BTI(4,L)
      PAPGW=BTI(5,L)
      DO 111 J=1,18,1
      IF (PAPCI-BTII(1,J))112,112,111
  111 CONTINUE
  112 PAPUI=BTII(2,J)
      PAPUY=BTII(3,J)
      PAPUW=BTII(4,J)
      PAPCZ=2.05*PAPWK
      PAPCX=1.135*(PAPCZ+1.35*PAPC1-(PAPTY+.050))+.33
     0PAPCW=.224*((PAPTY+.05)*(PAPTK**2.0)+PAPCX*(PAPGK**2.0)-9.0*
     1(PAPFI**2.0)*(PAPTY+.05)-2.05*(PAPWK**3.0)-
     2(PAPCI**2.0)*(1.35*PAPC1+.33))
     0WT=   9.*PAPEW+(.863*PAPWP**3.*(.249+2.74E-5*PRES*TANA*(2.98+
     12.44E-4*PRES)))+1.656*(PAPTY+.05)*(PAPFI**2.)-(.55*PAPWP**3.)
     2+PAPCW+PAPUW+PAPTW+PAPGW
     0QPAA=9.098*PAPEA +((1.98E-5*PRES)/PAPWJ)+(.00163/PAPWP**2.)+
     1(.331*((PUMS/60.)**.333))+(.0081/PAPWP**2.)
     0QPBA1=.925*PAPEA +(.495E-5*PRES/PAPWJ)+(1.63E-4/PAPWP**2.)+(
     1.0331*((PUMS/60.)**.333))+(8.1E-4/PAPWP**2.)
      QPEA2=.21*PAPEA +(6.E-6*PRES/PAPWJ)
      QPFA=.05*PAPEA +(1.E-6*PRES/PAPWJ)
     0QPJA=.05*PAPEA +(1.E-6*PRES/PAPWJ)+(1.63E-5/PAPWP**2.)+(.0165*(
     1(PUMS/60.)**.333))+(8.1E-5/PAPWP**2.)
     0QPIA2=.725*PAPEA +(1.E-6*PRES/PAPWJ)+(1.63E-4/PAPWP**2.)+(.0331
     1*((PUMS/60.)**.333))+(2.43E-3/PAPWP**2.)
      WRITE (3,920)   PRES,AMOM,FLOW,PUMS,PAPWK,PAPWP,PAPTI,PAPDX,PAPCZ,
     1  PAPC1,PAPWX,PAPGI,PAPUI,PAPWJ,PAPWI,PAPUY,PAPTY,TANA
     2 ,WT,QPEA2,QPFA,QPIA2,QPJA,QPAA,QPBA1
     3  ,ACTQA,ACTQM,ACTIM,ACVOL,FVOL,TMT1I
      WRITE (4-ITRA4) PRES,AMOM,FLOW,PUMS,PAPWK,PAPWP,PAPTI,PAPDX,PAPCZ,
     1  PAPC1,PAPWX,PAPGI,PAPUI,PAPWJ,PAPWI,PAPUY,PAPTY,TANA
     2 ,WT,QPEA2,QPFA,QPIA2,QPJA,QPAA,QPBA1
     3  ,ACTQA,ACTQM,ACTIM,ACVOL,FVOL,TMT1I
      IF (AMAX-AMOM)10,10,11
   10 IF (PREM-PRES)12,12,11
   12 CONTINUE
      CALL LINK (PUMP2)
      END
// DUP
*STORE      WS  UA  PUMP1
```

```
C                               STORED PROGRAM 6

C  FIXED ANGLE PUMP 2
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      IDATA = 9
      ITRA4 = 41
      ITRA5 = 41
      IREC8 = 1
  920 FORMAT (2X,7E13.5)
 1003 FORMAT (2X,20H  FIXED ANGLE PUMP 2)
      WRITE (3,1003)
      READ  (1-IDATA) AMAX,PREM,PPPP2,PPPP3,S5,TOILW,CG,CC,CSB
   11 CONTINUE
      READ  (4-ITRA4) PRES,AMOM,FLOW,PUMS,PAPWK,PAPWP,PAPTI,PAPDX,PAPCZ,
     1  PAPC1,PAPWX,PAPGI,PAPUI,PAPWJ,PAPWI,PAPUY,PAPTY,TANA
     2 ,WT,QPEA2,QPFA,QPIA2,QPJA,QPAA,QPBA1
     3  ,ACTQA,ACTQM,ACTIM,ACVOL,FVOL,TMT1I
      PAPKI=.0018*((FLOW*PRES/PUMS)**.333)
      PAPNI=.81*PAPWK
      PAPIK=.68*PAPWK
      PAPIY=.5*PAPWK
      PAPHI=.214*PAPWK
      PAPMI=.0032*(((FLOW*PRES)/(PUMS*PAPKI))**0.5)
      PAPQI=1.32E-2*PAPWP*(PRES**.5)
      PAPSI=PAPQI+.125
      PAVII=1.65*PAPSI
      PAHII=PAPTI+.12
     0WT=WT+                            (.276*PAPDX*PAPKI**2.)+(2.4E-4*
     1FLOW*PRES/PUMS)+.0146*PAPWK**3.+.0715*(PAPWK**2.)*PAPCZ-.069*(
     2PAPHI**2.)*PAPWK+1.36*(1.57*(PAPNI**2.)*PAPIY-PAPNI*PAPKI*PAPIY
     3-1.57*(PAPMI**2.)*(PAPNI-PAPKI))
      PAPCA =.0123/PAPC1
      QPAA=QPAA+(8.4E-4/PAPWK)+.012+(.2/((FLOW*PRES/PUMS)**.333))+PAPCA
      DUM1= .1*PAPCA + .02/(FLOW*PRES/PUMS)**.33
      QPBA1 = QPBA1 +DUM1 + .0012
      QPIA2 = QPIA2 +3.*DUM1 +.0004
      QPJA = QPJA +.1*DUM1 + .4E-4
      PAFCI=PAPCI+.42
      PAFPI=PAFCI+.04
      PAFPK=1.24*PAPCI+9.92E-2
      PAFPX=.216*(PAPCI**.5)
      PAFP2=.393*(PAPCI**.5)
      PAFYI=PAFPI+.05
     0WT=WT+(PAPIY*(.062*PAPWK**2.+.054*PAPCZ*PAPIK))+.042*PAPIK**4.+
     12.62E-4*PAPWK+.0113*PAPWK**2.*(2.21*PAPWX+1.)+.015*PAPWX*PAPWK**
     22.+3.46*PAPQI**3.+.019*(PAPWX**3.)+.216*(PAPQI**2.)+.0148*
     3PAPQI-.048*PAPWX*(PAPQI**2.)+.872*PAPQI**3.+.155*PAPSI**3.
      CALL OSUB(PAVII,.0133*PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
     0QPAA=QPAA+RFRG+(3.65E-4/PAPQI**2.)+(.036/PAPWX)+(.53/(PAPWP*PRES*
     1*.5))+(.0014*PUMS/PAPWK)+(.0053/PAPWK)+.1038
```

```
 0QPBA1=QPBA1+RFRC+(3.65E-6/PAPQI**2.)+(.0036/PAPWX)+(.053/(PAPWP*
 1PRES**.5))+(.00014*PUMS/PAPWK)+(6.12E-4/PAPWK)+.00975
  QPBA2=RFRC+(3.6E-6/PAPQI**2.)+.00343
  QPCA2=RFRS+.00638
  QPCA3=RFRS+3.5E-5
  QPDA2=RFRF+3.5E-5
 0QPIA2=QPIA2+(.0036/PAPWX)+(.053/(PAPWP*PRES**.5))+(1.4E-4*PUMS/
 1PAPWK)+(6.96E-4/PAPWK)+.0005
 0QPJA=QPJA+(3.6E-4/PAPWX)+(.0053/(PAPWP*PRES**.5))+(1.4E-5*PUMS/
 1PAPWK)+(6.9E-5/PAPWK)+.00014
 0WT=WT+RWT+4.28E-3*(PAPCI**2.)+5.26E-4*PAPCI+8.9E-6+7.68E-3*
 1(.366*(PAPTI**2.)+.0878*PAPTI+5.26E-3)+.0117*PAPGI**2.-5.16E-3
 2*PAPGI*PAPUI-6.54E-3*PAPUI**2.
  CALL OSUB(PAPCI,.0133*PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
  QPAA=QPAA+RFRG+.4345*PAPCI+.168
  QPBA1=QPBA1+RFRC+.04345*PAPCI+ .0017
  QPBA2=QPBA2+RFRC+.004345*PAPCI+.0017
  QPCA2=QPCA2+RFRS+.1303*PAPCI+.05
  QPCA3=QPCA3+RFRS+.004345*PAPCI+.0017
  QPDA2=QPDA2+RFRF+.004345*PAPCI+.0017
  WT=WT+RWT+.0696*(PAPCI**2.)+.0146*PAPCI+.0115*PAPCI**.5*PAFPI**2.
  CALL OSUB(PAFPK,.0133*PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
 0WT=WT+RWT+.013*PAFPX*PAFYI+9.8E-4*PAFPK+2.29E-3*PAFPK+.0013*
 1PAPCI+.0046*PAPCI+.01352+.023*PAFYI*PAFPX+(.0346*PAFYI**2.+.18*
 2PAFYI+.0351)*(PAFP2+.07)+.0216*PAFYI
  QPAA=QPAA+RFRG+.0139*(PAPCI+.51)
  QPBA1=QPBA1+RFRC+.00139*(PAPCI+.51)
  QPBA2=QPBA2+RFRC+1.39E-4*(PAPCI+.51)
  QPCA2=QPCA2+RFRS+.00139*(PAPCI+.51)
  QPCA3=QPCA3+RFRS
  QPDA2=QPDA2+RFRF
  CALL OSUB(PAFYI+.1,.0133*PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
  WT=WT+RWT+.0066
  QPAA=QPAA+RFRG
  QPBA1=QPBA1+RFRC
  QPBA2=QPBA2+RFRC
  QPCA2=QPCA2+RFRS
  QPCA3=QPCA3+RFRS
  QPDA2=QPDA2+RFRF
  PAFMI=.3125
  PAFKI=1.36*PAPGI
  PARDI=2.0*PAPWJ
  PARGK=1.08*PARDI
  PARGI=PARGK*(1.0+1.09E-4*PRES)
  PARAX=.19*PAPWI
  PARMI=9.25E-3*((FLOW*(PRES**0.5))**0.5)
  CALL OSUB(PAFMI,.0133*PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
 0WT=WT+RWT+.0278*PAPGI**3.+.177*PAPUI**2.*(PAPUY+.51*PAPCI)+.0142
 1*PAPTY*(PAPTI**2.)+.346*PAPWJ**2.-.506*PAPWJ*PAPWP
  QPAA=QPAA+RFRG+(.049/PAHII)+(.053/PAPUI)+(.155/PAPWJ**2.)
  QPBA1=QPBA1+RFRC+(.0049/PAHII)+(.0053/PAPUI)+(.0155/PAPWJ**2.)
  QPBA2=QPBA2+RFRC+(.0049/PAHII)+(.0053/PAPUI)
  QPCA2=QPCA2+RFRS+(.0049/PAHII)+(.0053/PAPUI)+(.04/PAPWJ**2.)
  QPCA3=QPCA3+RFRS+(4.E-5/PAHII)+(4.2E-5/PAPUI)
  QPDA2=QPDA2+RFRF+(4.E-5/PAHII)+(4.2E-5/PAPUI)
C FIXED ANGLE PUMP 3
  CALL OSUB(PAHII,.0133*PRES,6,1.,RWT,RFRG,RFRC,RFRS,RFRF)
 0WT=WT+RWT+.092*(PARGI**2.)-.0722*(PARGK**2.)+6.4E-4*PARDI**2.+
 1.0453*PAPWI*(PARGI**2.)-.0398*PAPWI**3.+.705*PARMI**3.
  QPAA=QPAA+RFRG+(.364/PARDI)+.0693
```

```
      QPJA=QPJA+(.007/PAPWJ**2.)+(.018/PARDI)
      QPIA2=QPIA2+(.002/PAPWJ**2.)+(.046/PARDI)
      QPEA2=QPEA2+(.004/PAPWJ**2.)+.002
      QPFA=QPFA+(.0015/PAPWJ**2.)+.0002
      QPBA1=QPBA1+RFRC+(.0364/PARDI)+.00693
      QPBA2=QPBA2+RFRC+6.93E-4
      QPCA2=QPCA2+RFRS+(.1/PARDI)+.00493
      QPCA3=QPCA3+RFRS+.000293
      QPDA2=QPDA2+RFRF+.000293
      PACLP=(.462*PARDI)/(PRES**.25)
      PACLK=S5*(1.333*PACLP)
      PACBX=18.0*PACLK
      PACBI=4.66*PACLK
      PARJK=1.7*PAPWJ
      PARJI=.0935*(PARJK**.667)
      PACMK=1.09*((FLOW**.5)/(PRES**.25))
      CALL OSUB(PARMI,PRES*.0133,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+RWT+22.5*PACLP**3.*S5+S5*.885*PACLK**3.+S5*72.*PACLK**3.
      QPAA=QPAA+RFRG+(S5*5.8E-5*PRES**.5/PACLP**2.)+S5*.21
      QPBA1=QPBA1+RFRC+S5*.21+(S5*5.8E-6*PRES**.5/PACLP**2.)
      QPBA2=QPBA2+RFRC+S5*.002
      QPCA2=QPCA2+RFRS+S5*.0033+(S5*2.9E-6*PRES**.5/PACLP**2.)
      QPCA3=QPCA3+RFRS+S5*.0011
      QPDA2=QPDA2+RFRF+S5*.0021
      QPIA2=QPIA2+S5*.003+(S5*3.2E-6*PRES**.5/PACLP**2.)
      QPJA=QPJA+(S5*2.9E-6*PRES**.5/PACLP**2.)
      CALL OSUB(PARGK+.1,PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
     0WT=WT+3.*RWT+.0139*(PARJK**2.334)+.0924*(PARGI**2.-1.13*PAPWI**
     12.)*(PAPWX+PAPDX-PARAX)+.266*PAPTY*((PAFKI**2.)-(PAHII**2.))+(
     2.0166*PARGI**2.-.0039*PAPWJ**2.)*PARJI+.115*PACBX*PACBI**2.*S5+
     3.134*PARGI*(FLOW/PRES**.5)+.43*PACMK**3.
     0QPAA=QPAA+RFRG*3.+(.0124/PARJI**2.)+(.122/PAPWI)+(.068/PACMK)
     1+.008/PAPWJ
     0QPBA1=QPBA1+3.*RFRC+(.0012/PARJI**2.)+(.0122/PAPWI)+(.00843/
     1PACMK)+8.E-4/PAPWK
      QPBA2=QPBA2+3.*RFRC+(.0122/PAPWI)+(.00458/PACMK)+8.E-4/PAPWK
      QPIA2=QPIA2+(.00124/PARJI**2.)+(.0015/PACMK)+(3.5E-4/PAPWK)
      QPCA3=QPCA3+3.*RFRS+(.00122/PAPWI)+(.001128/PACMK)+8.E-5/PAPWJ
      QPDA2=QPDA2+3.*RFRF+(.00122/PAPWI)+(.001128/PACMK)+8.E-5/PAPWJ
      QPJA=QPJA+(.00124/PARJI**2.)+(1.5E-4/PACMK)+(3.5E-5/PAPWK)
      QPGA3=.007/PACMK
      QPHA2=.007/PACMK
      CALL OSUB(PACMK,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      QPAA=(QPAA+RFRG)*CG
      QPBA1=(QPBA1+RFRC)*CC
      QPBA2=(QPBA2+RFRC)*CC
      QPCA2=(QPCA2+RFRS)*CSB
      QPCA3=(QPCA3+RFRS)*CSB
      QPEA2=CSB*QPEA2
      QPIA2=CSB*QPIA2
      QPGA3=CSB*QPGA3
      QPDA2=(QPDA2+RFRF)
      PADS=PAPWP**3.0*TANA*(21.05+(1.72E-3*PRES))
      PADS1=23.4*PADS
      PUWT1=WT+TOILW*PADS1+RWT
      PALF=10425.0/PUMS
      IF (PADS-1.4) 251,252,252
  251 S10=0.0
      GO TO 253
  252 S10=1.0
```

```
2530PFAVU=S5*(1.0-S10)*(160.85*(PADS+.054)**1.582+1494.44)+S5*S10*(
    1471.38+612.51*PADS+154.43/PADS**3.0+400.)+(1.0-S5)*(1.0-S10)*
    2128.68*((PADS+.054)**1.582+875.55+380.0)+(1.0-S5)*S10*(377.10+
    3490.10*PADS+123.54/PADS**3.0+380.0)+140.+4.6*PUWT1**.5
    0PFAVD=S5*((85000.0+18.*PFAVU)*PPPP2+93000.0*PPPP3)+(1.0-S5)*((
    165000.0+18.0*PFAVU)*PPPP2+74460.0*PPPP3)
     PFAVT=48.0*PPPP2+19.0*PPPP3+S5*(6.0*PPPP2+4.0*PPPP3)
     PAOP=0.0
     PFAFD=PFAVD
     PFAFT=PFAVT
     PFAFU=PFAVU
     WRITE (3,920)PUWT1,QPAA,QPBA1,QPBA2,QPCA2,QPCA3,QPEA2,
    1 QPIA2,QPDA2,QPFA,QPHA2,QPJA,PALF,PFAFU,PFAFD,PFAFT,QPGA3
     WRITE (8-IREC8) PUWT1,QPAA,QPBA1,QPBA2,QPCA2,QPCA3,QPEA2,
    1 QPIA2,QPDA2,QPFA,QPHA2,QPJA,PALF,PFAFU,PFAFD,PFAFT,QPGA3
     WRITE (5-ITRA5) ACTGA,PADS1,AMOM,PRES,ACVOL,FVOL,ACTQM,ACTIM,TMT1I
     IF (AMAX-AMOM)10,10,11
  10 IF (PREM-PRES)12,12,11
  12 CONTINUE
     CALL LINK (WPUMP)
     END
// DUP
*STORE      WS  UA  PUMP2
```

```
C                         STORED PROGRAM 7
C     WOBBLE PLATE PUMP 1
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  WOBBLE PLATE       )
      WRITE (3,1002)
      IDATA = 10
      ITRA4 = 81
      ITRA5 = 41
      IREC9 =1
      READ  (1-IDATA) AMAX,PREM,ANUMB,PPPP4,PPPP5,PPPP9,ANGL2,PUMS2,S6,
     1  TOILW,CC,CG,CSA
      PUMS=PUMS2
      ANGL=ANGL2
      TANA=SIN (ANGL)/COS (ANGL)
   11 CONTINUE
      READ  (5-ITRA5) ACTQA,PADS1,AMOM,PRES,ACVOL,FVOL,ACTQM,ACTIM,TMT1I
      FLOW=ANUMB*ACTQA*PPPP9
      PWBB1=0.1
 5030PWBBP=((FLOW/(PUMS*TANA*(20.5-1.92E-4*PRES))-(((PWBB1**2.)*(3.58
     1-3.46E-5*PRES))/(20.5-1.92E-4*PRES))+((4.44E-3*PWBB1)/(20.5-1.92
     2E-4*PRES))+((1.64E-5*PRES*PWBB1)/((1.45*PWBB1+.26)*(TANA**2.0)*
     3PUMS*(20.5-1.92E-4*PRES)))))**.333
      IF(ABS (PWBBP-PWBB1)-1.E-5*PWBBP)501,501,502
  502 PWBB1=(PWBBP+PWBB1)/2.0
      GO TO 503
  501 PWBB1=PWBBP*(3.98+2.46E-4*PRES)+.523
      PWBBK=.84*PWBBP
      PWBBX=5.57*TANA*(2.9*PWBBP+.523)
      PWBBJ=2.9*PWBBP+.523
     0WT=.199*(((PWBBI*2.)-.76*(PWBBP**2.))*PWBBX-(95.5*(PWBBP**3.)
     1-13.5*(PWBBP**2.)-3.08*PWBBP+.438)*TANA-9.0*PWBBX*(PWBBP**2.))
      PWBBA =(1.74E-5*PWBBP*TANA*(PRES**2.))/FLOW
      PWPEI=1.535E-2*PWBBP*PRES**.5
      PWPEA =(1.42E-4*PUMS/PWBBP)
     0WT=WT+8.55E-6*(PWBBP**3.)*(PRES**1.5)+(1.58*PWBBX*(PWBBP**2.)+
     12.23*(PWPEI**3.))+S6*9.*(TANA*(.206*(PWBBP**3.)+.0372*(PWBBP**2.
     2)))+S6*(9.77E-3*PWBBP*TANA*(PWBBJ**3.))/PWBBK+.585*(PWPEI**3.)
      CALL OSUB(PWBBK,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
     0QPAW=PWBBA +PWPEA *9.+RFRG+9.*(3.8E-3*PWBBA +.9*PWPEA )+S6*9.*
     1(.0127*PWBBA )+S6*.05+5.9*PWPEA
     0QPBW1=.1*PWBBA +RFRC+PWPEA *.1+3.4E-3*PWBBA +.81*PWPEA +.0114*
     1PWBBA +.005+.0667*PWPEA
      QPBW2=.1*PWBBA +RFRC+PWPEA *.1
      PWBNP=.00913*PUMS*PWBBP*(PWBBJ**.5)
      PWPJI=1.333*PWBBJ
      PWPJY=.0452*PWBBP*TANA*(PRES**.5)
      PWPG1=((.00332*(PWBBP**3.)+.0006*(PWBBP**2.))*TANA*PRES)**.333
      PWPGP=PWPG1+.225
      PWPPP=1.133*PWPGP
```

```
      0WT=WT+RWT+.617*PWBBJ*TANA*(PWBNP**2.)+.0715*PWBNP*(PWBBJ**2.)
     1+.27*PWBBJ*PWBNP*PWPEI+.428*(PWBNP**3.)+.705*PWBNP*(PWPEI**2.)
     2+.393*PWPJY*PWBBJ**2.+.103*TANA*(PWPJI**3.)+.054*(PWPJI**2.)*
     3(PWPJY+.33)+.191*(PWPGP**3.)-.377*(PWPG1**3.)+.0277*(PWPGP**3.)
       PWBNA =8.15E-4*PUMS/PWBNP
      0QPAW=QPAW+3.*PWBNA +(.005*PUMS/PWBBJ)+2.*PWPEA +(.004*PUMS/PWBBJ
      1)+.1333*PWPGP+.089*PWPGP
      0QPBW1=QPBW1+.3*PWBNA +(5.E-4*PUMS/PWBBJ)+.2*PWPEA +(.0004*PUMS/
      1PWBBJ)+.0133*PWPGP+8.9E-3*PWPGP
       QPBW2=QPBW2+.0133*PWPGP+8.9E-4*PWPGP
       QPCW2=RFRS+.00027*PWPGP+.04*PWPGP+.0025+.09*PWBBA
       QPCW3=RFRS+.00089*PWPGP+1.33E-3*PWPGP+.09*PWBBA
      0QPIW2=1.*PWPEA +(.0004*PUMS/PWBBJ)+(.0005*PUMS/PWBBJ)+(6.5E-4*
      1PUMS/PWBNP)+(8.15E-5*PUMS/PWBNP)+1.8*PWPEA +.015+.046*PWBBA +
      2.0103*PWBBA +2.43*PWPEA +(3.83E-4*PUMS/PWBBP)+.01*PWBBA
       QPDW1=.01*PWBBA +RFRF+.0133*PWPGP+8.9E-3*PWPGP
       QPDW2=.01*PWBBA +RFRF+.00133*PWPGP+8.9E-4*PWPGP
      0QPJW=(1.28E-5*PUMS/PWBBP)+3.42E-4*PWBBA +.081*PWPEA +.0114*
      1PWBBA +.0025+.060*PWPEA +(8.15E-6*PUMS/PWBNP)+(1.63E-4*PUMS/
      2PWBNP)+(5.E-5*PUMS/PWBBJ)+.2*PWPEA +(.0004*PUMS/PWBBJ)
       CALL OSUB(PWPPP,PRES*.0133,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
       WT=WT+RWT
       QPAW=QPAW+RFRG
       QPBW1=QPBW1+RFRC
       QPBW2=QPBW2+RFRC
       QPCW2=QPCW2+RFRS+2.47E-2*PWPGP+(.151*PRES**.25/FLOW**.5)
       QPCW3=QPCW3+RFRS+8.71E-4*PWPGP
       QPDW1=QPDW1+RFRF+7.51E-3*PWPGP+(.022*PRES**.25/FLOW**.5)
       QPDW2=QPDW2+RFRF+8.71E-4*PWPGP
       PWPIA =2.66*TANA*PUMS/(PRES*PWBBP)
       CALL OSUB(PWPGP,.0133*PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
       WT=WT+2.3*RWT  +(4.23E-5*PRES*PWBBP**2./TANA)
       QPAW=QPAW+RFRG+5.*PWPIA +.0871*PWPGP+(.215*PRES**.25/FLOW**.5)
       QPBW1=QPBW1+1.1*RFRC+PWPIA *.5+.00871*PWPGP
       QPBW2=QPBW2+1.01*RFRC+7.48E-3*PWPGP
       QPCW2=QPCW2+1.1*RFRS+(1.49E-3/PWBBP)
       QPCW3=QPCW3+1.1*RFRS
       QPDW1=QPDW1+1.1*RFRF+(7.5E-5/PWBBP)
       QPDW2=QPDW2+RFRF
       QPIW2=QPIW2+.5*PWPIA +(7.5E-4/PWBBP)
       QPJW=QPJW+.05*PWPIA +(7.5E-4/PWBBP)
C     WOBBLE PLATE PUMP 2
       CALL OSUB(PWBBK,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
       QPAW=QPAW+RFRG+(.0149/PWBBP)
       QPBW1=QPBW1+RFRC+(1.49E-3/PWBBP)+(.022*PRES**.25/FLOW**.5)
      0WT=WT-(4.65E-6*PRES*PWBBP**2./TANA)+.05*PWPGP**2.+
      1(3.32E-3*PWPGP)+.0138*PWPGP**2.+(.002*FLOW**1.5/PRES**.75)+.0527
      2*PWBBX*PWBBK**2.+RWT+(.0157*PWPJI**2.)
       PWCHI=.0125*(PWBBJ*PRES)**.333*PWBBK**.667
       PWCII=1.225*PWBBJ
      0WT=WT+6.67E-4*PWBBJ**1.67*PWBBK**1.33*PRES**.667+98.*PWCHI**3.+
      1(.546*PWCHI*PWBBJ**2.)+4.06*PWCHI**3.
       QPAW=QPAW+(4.05E-3/PWCHI**2.)+(1.33E-4*PWBBJ**2./PWCHI**3.)
       QPBW1=QPBW1+(4.05E-4/PWCHI**2.)+(1.33E-5*PWBBJ**2./PWCHI**3.)
       QPBW2=QPBW2+RFRC
       QPCW2=QPCW2+RFRS+(2.E-4/PWCHI**2.)+(6.7E-5*PWBBJ**2./PWCHI**3.)
       QPCW3=QPCW3+RFRS
       QPDW1=QPDW1+RFRF+(2.E-5/PWCHI**2.)+(6.7E-6*PWBBJ**2./PWCHI**3.)
       QPDW2=QPDW2+RFRF
       QPIW2=QPIW2+(2.E-4/PWCHI**2.)+(6.7E-5*PWBBJ**2./PWCHI**3.)
```

```
      QPJW=QPJW+(2.E-5/PWCHI**2.)+(6.7E-6*PWBBJ**2./PWCHI**3.)
      CALL OSUB(PWCII,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      PWCLI=.189*PWBBJ
     0QPAW=QPAW+RFRG+(.1125/PWBBJ)+.014+(.0338/PWBBJ)+(.0225/PWBBJ)+
     1(.0298/PWBBP)
     0QPBW1=QPBW1+RFRC+(.0113/PWBBJ)+.0014+(.00338/PWBBJ)+(.00225/PWBBJ
     1)+(.003/PWBBP)
      QPBW2=QPBW2+RFRC+(.0113/PWBBJ)+(.00225/PWBBJ)
      QPCW2=QPCW2+RFRS+(.0036/PWBBJ)+1.4E-3
      QPCW3=QPCW3+RFRS+(.0013/PWBBJ)+(.0015/PWBBP)
      QPDW1=QPDW1+RFRF+(1.53E-3/PWBBJ)+7.E-5+(1.5E-4/PWBBP)
      QPDW2=QPDW2+RFRF+(.00113/PWBBJ)
      WT=WT+RWT+.054*PWCHI*PWBBJ**2.+.058*PWBBX*PWBBK**2.
      QPJW=QPJW+7.E-5+(.00015/PWBBP)
      QPIW2=QPIW2+1.4E-4+(7.5E-3/PWBBP)
      CALL OSUB(PWCLI,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+RWT
      QPAW=QPAW+RFRG
      QPBW1=QPBW1+RFRC
      QPBW2=QPBW2+RFRC
      QPCW2=QPCW2+RFRS
      QPCW3=QPCW3+RFRS
      QPDW1=QPDW1+RFRF
      QPDW2=QPDW2+RFRF
      CALL OSUB(PWBBI,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
     0WT=WT+RWT*6.+.603*PWBBP**3.+8.55E-4*PWBBP**3.*PRES**.667+(.15*
     1FLOW**1.5/PRES**.75)+(.023*PWCII**3.)+PWBBI**3.*PRES*((1.03E-5)
     2+((1.88E-9)*PRES)+((1.1E-13 )*(PRES**2.)))+2.34E-6*FLOW**1.5
      PWVHI=PWBBI*(1.+1.52E-4*PRES)
      PWHFI=.0911*FLOW**.5
      QPAW=QPAW+6.*RFRG+(.0536/PWBBP)+(16.83/(PWBBP*PRES**.667))
      QPBW1=QPBW1+6.*RFRC+(.00536/PWBBP)+(1.683/(PWBBP*PRES**.667))
      QPBW2=QPBW2+6.*RFRC+(.00536/PWBBP)+(1.683/(PWBBP*PRES**.667))
      QPCW2=QPCW2+6.*RFRS+(.012/PWBBJ)+(.017/PWBBI)+(7.95E-5/FLOW**.5)
      QPCW3=QPCW3+6.*RFRS+(.0153/PWBBJ)+(.0224/PWBBI)+(7.95E-5/FLOW**.5)
      QPDW1=QPDW1+6.*RFRF+(.01/PWBBJ)+(.0224/PWBBI)+(7.95E-5/FLOW**.5)
      QPDW2=QPDW2+6.*RFRF+(.0153/PWBBJ)+(.0224/PWBBI)+(7.95E-5/FLOW**.5)
      QPHW2=.00536/PWBBP
      QPGW1=.0072/PWBBP
      QPGW3=.00536/PWBBP
      QPIW2=QPIW2+(.0072/PWBBP)+(4.23/(PWBBP*PRES**.667))
      QPJW=QPJW+(.0063/PWBBP)+(1.683/(PWBBP*PRES**.667))
      QPAW=QPAW+(.153/PWBBJ)+(.224/PWBBI)+(.008/FLOW**.5)
      QPBW1=QPBW1+(.0153/PWBBJ)+(.0224/PWBBI)+(7.95E-4/FLOW**.5)
      QPBW2=QPBW2+(.0153/PWBBJ)+(.0224/PWBBI)+(7.95E-5/FLOW**.5)
      QPEW2=(8.E-3/PWBBJ)+(.016/PWBBI)+(.07/PWBBI)
      QPFW=(.05/PWBBJ)+(.011/PWBBI)+(.0016/PWBBI)
      CALL OSUB(PWHFI,PRES*.0133,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      PAPCJ=PAPWP*(3.24+2.44E-4*PRES)
      QPAW=QPAW+RFRG+(.33/PWBBI)
      QPBW1=QPBW1+RFRC+(.033/PWBBI)
      QPBW2=QPBW2+RFRC+(.033/PWBBI)
      QPCW2=QPCW2+RFRS+(.09/PWBBI)
      QPCW3=QPCW3+RFRS+(.0033/PWBBI)
      QPDW1=QPDW1+RFRF+(.0017/PWBBI)
      QPDW2=QPDW2+RFRF+(.0033/PWBBI)
     0WT=WT+RWT+(.232*FLOW**1.5/PRES**.75)+(.14*PWHFI**3.)+(.011*PWVHI
     1**3.)+(PWBBI**2.)*(.0298*PWBBX+.15*PWPJY+.0477*PWBBI-.011*
     2PWVHI)-.0967*PWPJY*(PWPJI**2.)-.0436*PWBBI*(PWPGP**2.)
      QPAW=CG*QPAW
```

```
      QPBW1=CG*QPBW1
      QPBW2=CG*QPBW2
      QPCW2=CSA*QPCW2
      QPCW3=CSA*QPCW3
      QPEW2=CSA*QPEW2
      QPGW3=CSA*QPGW3
      QPIW2=CSA*QPIW2
      PWDS=TANA*((20.5*PWBBP**2.0)+(3.7*PWBBP**2.0))
      PWDS1=17.2*PWDS
      WT=WT+TOILW*PADS1
      PUWT2=WT
      PWLF=3175.0/PUMS
      PINFT=48.0*PPPP4+19.0*PPPP5+S6*(6.0*PPPP4+4.0*PPPP5)
     0PINFU=S6*(911.84+207.95*PWDS**0.5-515.22*PWDS+445.03*PWDS**1.5+
     1400.00)+(1.0-S6)*(710.28+161.98*PWDS**0.5-401.33*PWDS+346.66*PWDS
     2**1.5+380.0)+140.+4.6*PUWT2**.5
     0PINFD=S6*((66000.0+18.*PINFU)*PPPP4+88500.0*PPPP5)+(1.0-S6)*((
     130000.0+18.0*PINFU)*PPPP4+69460.0*PPPP5)
      WRITE (9-IREC9) PUWT2,QPAW,QPBW1,QPBW2,QPCW2,QPCW3,QPEW2,
     1 QPGW3,QPIW2,QPDW1,QPDW2,QPFW,QPHW2,QPJW,PWLF,PINFD,PINFU,PINFT
      WRITE (3,920)   PUWT2,QPAW,QPBW1,QPBW2,QPCW2,QPCW3,QPEW2,
     1 QPGW3,QPIW2,QPDW1,QPDW2,QPFW,QPHW2,QPJW,PWLF,PINFD,PINFU,PINFT
      WRITE (4-ITRA4) PRES,AMOM,ACTQA,TMT1I,ACTQM,ACTIM,ACVOL,FVOL,
     1  PADS1,PWDS1
      IF (AMAX-AMOM)10,10,11
   10 IF (PREM-PRES)12,12,11
   12 CONTINUE
      CALL LINK (INFIL)
      END
// DUP
*STORE      WS   UA   WPUMP
```

```
C                              STORED PROGRAM 8

C INTENSIFIER
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      IDATA = 11
      ITRA4 = 81
      ITRA5 = 81
      IRE10 =1
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  INTEN-FILTER       )
      WRITE (3,1002)
      READ (1-IDATA) AMAX,PREM,ANUMB,PPP10,PPPP6,PPPP7,ANGL2,PUMS2,
     1  FFFF2,FFFF3,FFFF4,TOILW,CG,CC,CSA,CSC
      ANGL=ANGL2
      PUMS=PUMS2
      TANA=SIN (ANGL)/COS (ANGL)
   11 CONTINUE
      READ  (4-ITRA4) PRES,AMOM,ACTQA,TMT1I,ACTQM,ACTIM,ACVOL,FVOL,
     1  PADS1,PWDS1
      FLOW=ANUMB*ACTQA*PPP10
      PWBB1=0.1
 5030PWBBP=((FLOW/(PUMS*TANA*(20.5-1.92E-4*PRES)))-
     1(((PWBB1**2.0)*(3.58-3.46E-5*PRES))/(20.5-1.92E-4*PRES))+
     2((4.44E-3*PWBB1)/(20.5-1.92E-4*PRES))+
     3((1.64E-5*PRES*PWBB1)/((1.45*PWBB1+.26)*(TANA**2.0)*PUMS*
     4(20.5-1.92E-4*PRES))))**.333
      IF (ABS (PWBBP-PWBB1)-1.0E-5*PWBBP)501,501,502
  502 PWBB1=(PWBBP+PWBB1)/2.0
      GO TO 503
  501 PWBBI=PWBBP*(3.98+2.46E-4*PRES)+.523
      PWBBK=2.0*PWBBP
      PWBBX=5.57*TANA*(2.9*PWBBP+.523)
      PWBBJ=2.9*PWBBP+.523
      PWBBA =(1.74E-5*PWBBP*TANA*(PRES**2.0))/FLOW
      CALL OSUB(PWBBK,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
     0WT=2.*RWT+.165*(((PWBBI**2.)-.706*(PWBBP**2.))*PWBBX-(95.5*(PWBBP
     1**3.)-13.5*(PWBBP**2.)-3.08*PWBBP+.438)*TANA-5.5*PWBBX*(PWBBP**2.
     2))+9.*(.176*PWBBX*PWBBP**2.)
      QPAI=RFRG*2.+PWBBA *1.1137
      QPBI2=RFRC*2.+.1*PWBBA
      QPCI2=RFRS*2.+.09*PWBBA
      QPDI1=RFRF*2.+.01*PWBBA
      QPII2=.01*PWBBA +(.0308/PWBBP)+(16.9/(PWBBP*PRES**.667))
      QPJI=.0011*PWBBA +(.00252/PWBBP)+(6.23/(PWBBP*PRES**.667))
      CALL OSUB(PWBBI,PRES,5,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      WT=WT+RWT*6.+(2.42*(PWBBP**3.))+(.00342*PWBBP**3.*PRES**.667)
      QPAI=QPAI+6.*RFRG+(.214/PWBBP)+(62.3/(PWBBP*PRES**.667))
      QPBI2=QPBI2+6.*RFRC+(6.23/(PWBBP*PRES**.667))
      QPCI2=QPCI2+6.*RFRS
      QPDI1=QPDI1+6.*RFRF
      PWVHI=PWBBI*(1.0+(1.516E-4*PRES))
```

```
      PWHFI=.0911*(FLOW**.5)
     OWT=WT+(.3*(FLOW**1.5)/PRES**.75) +((PWBBI**3.)*PRES*(2.06E-5+3.75
     1E-9*PRES+2.2E-13*(PRES**2.)))+2.34E-6*(FLOW**1.5)
      CALL OSUB(PWHFI,.0133*PRES,6,1.,RWT,RFRG,RFRC,RFRS,RFRF)
     OWT=WT+RWT+(.232*(FLOW**1.5)/(PRES**.75))+(.149*(PWHFI**3.))+(
     1.022*(PWVHI**3.))+((PWBBI**2.)*(.0298*PWBBX-.022*PWVHI))
      QPAI=QPAI+RFRG+.00795/(FLOW**.5)+(1.426/PWBBI)
      QPBI2=QPBI2+RFRC+(.1426/PWBBI)+(7.95E-5/FLOW**.5)
      QPCI2=QPCI2+RFRS+(.158/PWBBI)+(7.95E-5/FLOW**.5)
      QPDI1=QPDI1+RFRF+(.0929/PWBBI)+(7.95E-5/FLOW**.5)
      QPEI2=.134/PWBBI
      QPFI=.0456/PWBBI
      QPAI=CG*QPAI
      QPBI2=CC*QPBI2
      QPCI2=CSA*QPCI2
      QPEI2=CSA*QPEI2
      QPII2=CSA*QPII2
      PIDS=TANA*((20.5*PWBBP**2.0)+(3.7*PWBBP**2.0))
      PIDS1=17.2*PIDS
      WT=WT+TOILW*PIDS1
      PUWT3=WT
      PILF=3220.0*PWBBP/(PUMS*TANA*(2.9*PWBBP+.523))
      PTRFU=911.48+207.0*PIDS**.5-515.22*PIDS+445.03*PIDS**1.5+ 400.
      PTRFD=(66000.0+18.0*PTRFU)*PPPP6+88500.0*PPPP7
      PTRFT=52.0*PPPP6+23.0*PPPP7
      WRITE (3,920)   QPAI,QPBI2,QPCI2,QPEI2,QPII2,QPDI1,QPFI,QPJI,PILF,
     2PTRFD,PTRFU,PTRFT,PUWT3
C  FILTER
      FLOW=ACTQA*FFFF2
      FOBOW=2.05E-6*PRES*(FLOW**1.5)
      FOBOA =1.814E-4*FLOW/FOBOW
      FOBOJ=.324*(FLOW**0.5)
      FOBOI=FOBOJ+2.27E-5*FLOW**0.5*PRES
      FOEOW=.0202*FLOW
      FOWOW=FOBOJ**3.0*.0048
      FOSOW=.00161*FOBOJ**2.33
      CALL OSUB(FOBOI,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      FOHPW=RWT
      FOHPA =RFRG
      FOHPB =RFRC
      FOHPC =RFRS
      FOHPD =RFRF
      FDBOW=.087*FOBOW
      FDBOA =.008/FOBOJ
      CALL OSUB(.623*FOBOJ,20.,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      FDBKW=RWT
      FDBKA =RFRG
      FDBKB =RFRC
      CALL OSUB(.413*FOBOJ,20.,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      FDBLW=RWT
      FDBLA =RFRG
      FDBLB =RFRC
      FDROW=0.0875*FDBOW
      FIBOW=.0106+3.53E-6*PRES
      FIBAW=.0004
      CALL OSUB(.551,PRES,2,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      FIBAA =RFRG
      FIBAB =RFRC
      FIBAI =RFRS
      FIBAJ =RFRF
```

```
      QFILRA=1.814E-4*FLOW/FOBOW+.0773/FOBOJ+2.0*FOBOA +.64/FLOW
     1+.33*FOHPA +.167*FDBLA +0.428*FDBOA +.00077/FIBOW**.33
     2+.333*FIBAA +16.8/PRES+FOHPA +FDBKA +FDBLA +FIBAA +.1265
     3+1.85E-4*FLOW
      QFILRB=2.27E-5*FLOW/FOBOW+.01030/FOBOJ+.5*FOBOA +.064/FLOW
     1+.033*FOHPA +.0167*FDBLA +.000384/(FIBOW**.33 )+.0333*FIBAA
     2+1.680/PRES+.0097+FOHPB +FDBKB +FDBLB +FIBAB
     3+1.85E-5*FLOW
      QFILRC=2.27E-5*FLOW/FOBOW+.225*FOBOA +.0066*FOHPA +.00068
     1+.0000437/FIBOW**.333+.00333*FIBAA +.336/PRES+FOHPC
      QFILRD=2.27E-6*FLOW/FOBOW+.225*FOBOA +.0033*FOHPA
     1+.000431+.0000215/FIBOW**.333+.000167*FIBAA +.0168/PRES+FOHPD
      QFILRJ=.00012/FOBOJ+2.28E-4/FOBOJ+.025*FOBOA +4.125E-5*FLOW
     1+FIBAJ +.000444
      QFILRI=.025*FOBOA +2.24E-4/FOBOJ+.000669+7.25E-5*FLOW
     1+3.56E-4/FOBOJ+FIBAI
       FILRG=.32/FLOW
       FILRH=.16/FLOW
       QFA=CG*FILRA
       QFB=CC*FILRB
       QFC=CSC*FILRC
       QFI=CSC*FILRI
       QFG=CSC*FILRG
       QFD = FILRD
       QFJ=FILRJ
       QFH = FILRH
      QFILW=3.12*FOBOW+FOEOW+1.225*FOWOW+4.2*FOSOW+2.125*FOHPW+
     1FDBOW+(3.0*FDBLW)/2.0+2.0*FDROW+FIBOW+2.0*FIBAW+
     24.0E-13*(PRES**3.0)+FDBKW+.0336+FDBLW
       FIVOL=.095525*ACTQA*ANUMB**1.5-.07071*ACTQA*ANUMB
       FILW=FILW+FIVOL*TOILW
       FPORT=TMT1I*(FFFF2*ANUMB/2.)**0.5
       FUCSU=(56.+280.*FPORT+9.1/FPORT**2.)+110.+1.15*FILW**.5
       FUCSD=(15000.+10.*FUCSU)*FFFF3+42120.*FFFF4
       WRITE(3,920) FILW,QFA,QFB,QFC,QFG,QFI,QFD,QFH,QFJ,FUCSU,FUCSD
       WRITE (10-IRE10)QPAI,QPBI2,QPCI2,QPEI2,QPII2,QPDI1,QPFI,QPJI,PILF,
     2PTRFD,PTRFU,PTRFT,PUWT3
     3                ,FILW,QFA,QFB,QFC,QFG,QFI,QFD,QFH,QFJ,FUCSU,FUCSD
       WRITE (5-ITRA5) PRES,AMOM,FIVOL,ACTQM,ACTIM,ACVOL,FVOL,PADS1,
     1  PWDS1,PIDS1
       IF (AMAX-AMOM) 10,10,11
    10 IF (PREM-PRES) 12,12,11
    12 CONTINUE
      CALL LINK (RESAC)
      END
// DUP
*STORE      WS  UA  INFIL
```

```
C                              STORED PROGRAM 9

C  RESERVOIR-ACCUMULATOR
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
      IDATA = 12
      ITRA5 = 81
      IRE11 =1
  920 FORMAT (2X,7E13.5)
 1002 FORMAT (2X,20H  RES-ACCUM         )
      WRITE (3,1002)
      READ  (1-IDATA) AMAX,PREM,ANUMB,SSSI,SSS2,SSS3,RSPA1,RSPA2,RSPA3,
     1  TOILW,RRRR1,RRRR3,RRRR4,ACCU,REAC,CG,CC,CSC
   11 CONTINUE
      READ  (5-ITRA5) PRES,AMOM,FIVOL,ACTQM,ACTIM,ACVOL,FVOL,PADS1,
     1  PWDS1,PIDS1
      RPRE=SSS2*PRES+SSS3
      SVOL=ACTQM*ACTIM*ANUMB*RRRR1
      SVOLW=SVOL*TOILW
     0RVOL=SVOL+(0.20+1.667E-6)*(SVOL+FVOL+(ANUMB*ACVOL)+FIVOL+PADS1+
     1PWDS1+PIDS1)
      RVOLW=RVOL*TOILW
      RPAPI=0.0
  720 RPAPT =(2.5464*RVOL+RPAPI*.32490)**.333
      IF (ABS (RPAPT -RPAPI)-.000001*RPAPI)722,722,721
  721 RPAPI=(RPAPT +RPAPI)/2.
      GO TO 720
  722 RPARI=.1365*RPAPI+(4.550E-4*RPRE*RPAPI**2.)/(RPAPI-2.92)
     0WGT=.0093*(RPAPI)**2.+6.80E-6*RPRE*RPAPI**4.+.046+(6.55E-5*(
     1RPAPI+7.)*(RPAPI)**3.*RPRE)/(RPAPI-2.9)
      RHPPI=((RPAPI**2.-.3249)*RPRE/PRES+RPARI**2.)**.5
      RPAPA =7.49/(RPRE*RPAPI)**2.
      RPARA =1.07E-4*RPAPI**2.
      CALL OSUB(RPAPI,RPRE,1,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RFRG*1.0666+RPAPA +RPARA
      RESAB =.5*RPAPA +.5*RPARA +RFRC*1.00666
      RESAC =.025*RPAPA +RFRS*1.00165
      RESAD =.01*RPAPA +RFRF*1.00165
      RESAE =.125*RPARA *REAC
      RESAF = RESAE*.5
      RESAI =.225*RPAPA +.125*RPARA
      RESAJ =.09*RPAPA +.0625*RPARA
      WGT=WGT+1.375E-5*RPRE*RPAPI**2.+RWT*1.872
      RPNXA =2.5E-4*RPRE*RPAPI**2.
      CALL OSUB(1.5,RPRE,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG+RPNXA
      RESAB =RESAB +RFRC+.5*RPNXA
      RESAC =RESAC +RFRS+.1*RPNXA
      RESAD =RESAD +RFRF+.1*RPNXA
      CALL OSUB(.55,RPRE,3,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG
      RESAB =RESAB +RFRC
```

```
      RESAC =RESAC +RFRS
      RESAD =RESAD +RFRF
      CALL OSUB(RHPPI,PRES,1,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG*1.5
      RESAB =RESAB +RFRC*1.05
      RESAE =RESAE +RFRS*1.005*REAC
      RESAF =RESAF +RFRF*1.005*REAC
      WGT=WGT+RWT
      SPAPI=0.0
      SPAGI=RHPPI+.224
  723 SPAPT =(6.366*SVOL+SPAPI*SPAGI**2.0)**.333
      IF (ABS (SPAPT -SPAPI)-.000001*SPAPI)725,725,724
  724 SPAPI=(SPAPT +SPAPI)/2.
      GO TO 723
  725USPAPW=(.012184*SPAPI**3.0+.04383*SPAGI**2.0*SPAPI+(3.52860E-7*
     1PRES*(SPAPI**2.0-SPAGI**2.0)**2./SPAGI))*SSSI
      SPAPA =(7.099E+3*SPAGI/(PRES*(SPAPI**2.-SPAGI**2.)**2.))*SSSI
      SPGNA =(.0015/SPAGI)*SSSI*REAC
      WGTA=.129*RPAPI*(RHPPI+.112)*SSSI*REAC+.093*SPAGI*SSSI*REAC
      SPAGA =2.5320E-4*(RHPPI*RPAPI*SPAGI*SPAPI)*SSSI*REAC
      CALL OSUB(RPARI,PRES,3,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =SPAPA +SPGNA +RFRG*1.05*SSSI*REAC+SPAGA
      RASAB =.5*SPAPA +.1*SPGNA +RFRC*1.01*SSSI*REAC+.5*SPAGA
      RASAC =.05*SPAPA +.125*SPAGA
      RASAD = RASAC
      RASAE =RFRS*1.005*SSSI*REAC+.07*SPGNA
      RASAF =RFRF*1.005*SSSI*REAC+.07*SPGNA
      WGTA=WGTA+RWT*1.68*SSSI*REAC
      CALL OSUB(SPAPI,PRES,1,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =RASAA +RFRG*2.2*SSSI
      RASAB =RASAB +RFRC*2.02*SSSI
      RASAC =RASAC +RFRS*1.0025*SSSI
      RASAD =RASAD +RFRF*1.0025*SSSI
      RASAG =.1*SPAPA +.03*SPGNA
      RASAH = RASAG
      RASAK =.125*SPAGA +.05*SPAPA +1.0025*RFRS*SSSI
          RASAL=RASAK
      WGTA=WGTA+RWT*3.744*SSSI
      SHPCA =3.4652E-5*SPAPI*SSSI
      CALL OSUB(SPAGI,PRES,3,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =RASAA +RFRG*2.2*SSSI*REAC+SHPCA
      RASAB =RASAB +RFRC*2.02*SSSI*REAC+SHPCA *.5
      RASAC =RASAC +RFRS*1.025*SSSI*REAC+SHPCA *.1
      RASAD =RASAD +RFRF*1.025*SSSI*REAC+SHPCA *.05
      RASAK =RASAK +RFRS*1.025*SSSI*REAC+SHPCA *.1
      RASAL =RASAL +RFRF*1.025*SSSI*REAC+SHPCA *.05
      SCACI=SPAPI+3.102E-5*PRES*SPAPI
     0WGTA=WGTA+RWT*3.778*SSSI+.44+(9.678E-6*SPAPI**2.+4.6624E-6*(SPAPI
     1**2.-SPAGI**2.))*PRES*SPAPI*SSSI
      CALL OSUB(SCACI,PRES,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =RASAA +RFRG*1.333*SSSI
      RASAB =RASAB +RFRC*1.0333*SSSI
      RASAC =RASAC +RFRS*1.005*SSSI+.00158*SSSI
      RASAD =RASAD +RFRF*1.005*SSSI+7.9E-4*SSSI
     0WGTA=WGTA+RWT*1.0541*SSSI+.9154*SSSI+SVOLW+(2.1860E-6*PRES*
     1SPAPI*(SPAPI**2.-SPAGI**2.))*ACCU+((2.5970E-7*((1.256*SPAPI-
     22.125)**2.-2.1**2.)*PRES/(1.256*SPAPI-2.125))+.0848+.46383*
     3SPAPI)*ACCU
      CALL OSUB(1.5,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =RASAA +RFRG*1.333*SSSI*REAC
```

```
      RASAB =RASAB +RFRC*1.033*SSSI*REAC
      RASAK =RASAK +RFRS*1.005*SSSI*REAC
      RASAL =RASAL +RFRF*1.005*SSSI*REAC
      CALL OSUB(.5,PRES,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RASAA =RASAA +RFRC*SSSI+.176 *SSSI
      RASAB =RASAB +RFRC*SSSI+.04349*SSSI
      RASAK =RASAK +RFRS*SSSI+8.98E-4*SSSI
      RASAL =RASAL +RFRF*SSSI+4.88E-4*SSSI
     0RHXXW=4.71620E-6*RPRE*RPAPI**3.*(1.+.007662*RPRE)+(2.1860E-6*
     1PRES*SPAPI*(SPAPI**2.-SPAGI**2.))*(SSSI)+(2.5970E-7*((1.256*SPAPI
     2-2.125)**2.-2.1**2.)*PRES/(1.256*SPAPI-2.125))+.0848+.46383*SPAPI
      WGT=WGT+1.722E-4*RPAPI**3.*RPRE
      RCASA =2.69/(RPAPI*RPRE)
      CALL OSUB(RPAPI,RPRE,2,1.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG*1.333+RCASA +.0001*RPRE
      RESAB =RESAB +RFRC*1.033+RCASA *.5+1.E-5*RPRE
      WGT=WGT+RWT*1.748
      CALL OSUB(.644,RPRE,5,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG
      RESAB =RESAB +RFRC
      RHXXA =1.17E-2*RPAPI**2.
      CALL OSUB(1.0625,RPRE,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG*3.+RHXXA
      RESAB =RESAB +RFRC*3.+RHXXA *.5
      RESAC =RESAC +RFRS*3.+RHXXA *.1875
      RESAD =RESAD +RFRF*3.+RHXXA *.09375
      RESAI =RESAI +RHXXA *.0625
      RESAJ =RESAJ +RHXXA *.03125
      CALL OSUB(.75,PRES,6,0.,RWT,RFRG,RFRC,RFRS,RFRF)
      RESAA =RESAA +RFRG
      RESAB =RESAB +RFRC+.0066
      RESAC =RESAC +RFRS
      RESAD =RESAD +RFRF
     0WGT=WGT+(732.173*(SPAPI+3.102E-5*PRES*SPAPI)*(2.701E-6*(SPAPI
     1**2.-SPAGI**2.))+.003)*SSSI+.252*RSPA3+(.4737*(1.-(1.-2.066E-5*
     2PRES*2.)**2.))*SSSI+.3138*RPAPI*RSPA3+SPAPW+RHXXW+.3046+RVOLW
      RSPAA =RSPA3*(.0968+RSPA1*.25+RSPA2*.15)
      RSPBA =RSPA3*(RPAPI/2.)*(.152+RSPA1*.242+RSPA2*.196)
      RESAA =RESAA +RSPAA *.5+RSPBA *.2+.028
     0RECSU=2.7492*(22.3786+RPAPI**3.0*(.875758-200.9068/(RPRE+500.)-
     179711.07/(RPRE+500.)**2.0)+66628232.0/(RPRE+500.0)**2.0-117434.89/
     2(RPRE+500.)+105.55801-.034223256*(RPRE+500.)+1.0761896E-5*(RPRE+
     3500.)**2.0)*(1.0+.0188*(RPAPI/2.))
     0RECSU=(RECSU+2.7492*(71.82*RPARI-9.77*RPARI**2.0+2.014*RPARI**3.0+
     1RHPPI**3.0*(.875758-200.9068/PRES-79711.07/PRES**2.0)+66628232.0/
     2PRES**2.0-117434.89/PRES+105.55801-.034223256*PRES+1.0761896E-5*
     3PRES**2.0)*(1.0+.0188*(RPAPI/2.))+520.)+140.+4.6*WGT**.5
     0RSPAU=RSPA3*(281.30+32.30*RSPA2+40.10*RPAPI+15.60*RPAPI*(RSPA1+
     1RSPA2))
      RECSD=(74000.+(RECSU+RSPAU)*10.)*RRRR3+69460.*RRRR4
      RECSU=RECSU+RSPAU
     0SACSU=(2.7492*(71.82*SPAGI-9.77*SPAGI**2.0+2.014*SPAGI**3.+SPAPI**
     13.0*(.875758-200.9068/PRES-79711.07/PRES**2.0)+66628232.0/PRES**
     22.0-117434.89/PRES+105.55801-.034223256*PRES+1.0761896E-5*PRES**
     32.0)*(1.0+.0188*(SPAGI/5.))+50.+(140.+4.6*WGTA**.5))*SSSI
      SACSD=((20000.+SACSU*10.)*RRRR3+6160.*RRRR4)*SSSI
      QACA=CG*RASAA
      QRA=CG*RESAA
      QACB=CC*RASAB
      QRB=CC*RESAB
```

```
      QACC=CSC*RASAC
      QACG=CSC*RASAG
      QACK=CSC*RASAK
      QRC=CSC*RESAC
      QRI=CSC*RESAI
      QARE=CSC*RESAE
      QACD = RASAD
      QACH = RASAH
      QACL = RASAL
      QRD = RESAD
      QRJ = RESAJ
      QARF = RESAF
      RAPCD=RECSD+SACSD
      RAPCU=RECSU+SACSU
      WRITE(3,920) WGTA,QACA,QACB,QACC,QACG,QACK,QACD,QACH,QACL,WGT,QRA,
     1QRB,QRC,QRI,QRD,QRJ,QARE,QARF,RAPCU,RAPCD,RECSU,RECSD,SACSU,SACSD
      WRITE(11-IRE11)WGTA,QACA,QACB,QACC,QACG,QACK,QACD,QACH,QACL,WGT,
     1 QRA,QRB,QRC,QRI,QRD,QRJ,QARE,QARF,RAPCU,RAPCD,RECSU,RECSD,SACSU,
     2 SACSD
      IF (AMAX-AMOM) 10,10,11
   10 IF (PREM-PRES) 12,12,11
   12 CONTINUE
      CALL LINK (QDECK)
      END
// DUP
*STORE      WS  UA  RESAC
```

```
C                          STORED PROGRAM 10

C    QDECK
      DIMENSION  XA(3),XB(3),XC(3),XD(3),QAMFX(3)
      DEFINE FILE 1(50,290,U,IDATA),2(100,150,U,ITRA2)
      DEFINE FILE 3(150,150,U,ITRA3),4(150,40,U,ITRA4)
      DEFINE FILE 5(150,40,U,ITRA5),6(50,150,U,IREC6)
      DEFINE FILE 7(100,150,U,IREC7),8(50,150,U,IREC8)
      DEFINE FILE 9(50,150,U,IREC9),10(50,150,U,IRE10)
      DEFINE FILE 11(50,150,U,IRE11)
  950 FORMAT(1H1,////,20X,24H COMPUTER PROGRAM NUMBER,I5//,17H PUMP COMB
     1INATION,I5,7X,12HPOWER SYSTEM,I5,7X,19HACTUATOR REDUNDANCY,I5,///)
  951 FORMAT  (16H SYSTEM PRESSURE,F9.0,4H PSI,10X,11H MOMENT ARM,
     1 F9.2,7H INCHES//,27X,24HPROBABILITIES OF FAILURE,34X6HWEIGHT,/
     2 13X6HGROUND5X9HCOUNTDOWN5X5HSTART5X8HFLIGHT 16X5HCOAST5X8HFLIGHT
     325X6HPOUNDS)
  605 FORMAT (9H SYSTEM   ,6F12.8,F10.2,/,9H ACTUATOR,6F12.8,F10.2,/,
     1 10X,32H TOTAL PROGRAM COST (HYDRAULICS),F15.0,8H DOLLARS//)
      IDATA = 13
      RUN = 0.
      READ (1-IDATA)TT1,TT2,T4,VLIFA,VLIFP,VHYSB,VTEST,VFLRF,VPNUB,VWCST
     1      ,VCYCA,VDEVL,VPEND,VOPER,VTCST,VREPR,ANUMB,RUNQ,
     2 XA(1),XA(2),XA(3),XB(1),XB(2),XB(3),XC(1),XC(2),XC(3),XD(1),XD(2)
     3  ,XD(3)
      A=ANUMB
 2000 RUN = RUN + 1.
      READ  (1-IDATA) PPPP8,S7,S8,S9,Z1,Z2,Z3,JQ,KQ,LQ,MQ
      WRITE (3,950) MQ,LQ,KQ,JQ
      IREC6 =1
      IREC7 =1
      IREC8 =1
      IREC9 =1
      IRE10 =1
      IRE11 =1
  999 CONTINUE
      READ (6-IREC6)WASW,QASG,QASC,QASS,QASF,ADCSS,AUCSS,ADTIS,WAMW,QAMG
     1,QAMC,QAMS,QAMF,ADCSM ,AUCSM ,ADTIM ,WATW,QATPG,QATSG,QATCG,QATPC,
     2QATSC,QATCC,QATPS,QATSS,QATCS,QATPF,QATSF,QATCF,ADCST,AUCST,
     3ADTIT ,ALIFE,ACTQL,ACYCL,AMOM,PRES,AMAX,PREM ,QAMY,QAMZ
      READ  (7-IREC7)   TRWT,QTRG,QTRC,QTRS,QTRF,XRUSU,XRUSD,
     1 WT,QTG,QTC,QTFS,QTEPS,QTESS,QTIPS,QTISS,QTFF,QTEPF
     2  ,QTESF,QTIPF,QTISF,STCSD,STCSU
      READ (7-IREC7)  WA,WB,WC,WD,WE,QTAA,QTBA,QTCA,QTDA,QTEA,QTAB,QTBB,
     1QTCB,QTDB,QTEB,QTAC,QTBC,QTCC,QTDC,QTEC,QTAD,QTBD,QTCD,QTDD,QTED,
     2 TUCD1,TUCD2,TUCD3,TUCU1,TUCU2,TUCU3,QDWGW,QDWGA,QDWGB,QDWGC,QDWGD
     3  ,QDCSD,QDCSU
      READ  (8-IREC8) PUWT1,QPAA,QPBA1,QPBA2,QPCA2,QPCA3,QPEA2,
     1 QPIA2,QPDA2,QPFA,QPHA2,QPJA,PALF,PFAFU,PFAFD,PFAFT,QPGA3
      READ  (9-IREC9) PUWT2,QPAW,QPBW1,QPBW2,QPCW2,QPCW3,QPEW2,
     1 QPGW3,QPIW2,QPDW1,QPDW2,QPFW,QPHW2,QPJW,PWLF,PINFD,PINFU,PINFT
      READ  (10-IRE10)QPAI,QPBI2,QPCI2,QPEI2,QPII2,QPDI1,QPFI,QPJI,PILF,
     2PTRFD,PTRFU,PTRFT,PUWT3
     3               ,FILW,QFA,QFB,QFC,QFG,QFI,QFD,QFH,QFJ,FUCSU,FUCSD
      READ (11-IRE11)WGTA,QACA,QACB,QACC,QACG,QACK,QACD,QACH,QACL,WGT,
     1 QRA,QRB,QRC,QRI,QRD,QRJ,QARE,QARF,RAPCU,RAPCD,RECSU,RECSD,SACSU,
```

```
  2 SACSD
    QAMFX(1)=QAMF
    QAMFX(2)=QAMY
    QAMFX(3)=QAMZ
    N=1
    KK=0
500 KK=KK+1
    GO TO(61,62,63,64),LQ
61  QSPG=QPAI
     SPELF=QPDI1  *XA(KK)
     SPILF=QPFI   *XA(KK)
     SPUPF=QPJI   *XA(KK)
     APELF=QPDA2  *XB(KK)
    QCVF=QPHA2    *XB(KK)
    QAPG=QPAA
    QSPC=QPBI2
    QAPC=QPBA1
     SPELS=QPCI2
     SPILS=QPEI2
     SPUPS=QPII2
     APELS=QPCA3
    PUWTS=PUWT3
    PUWTA=PUWT1
    QCVS=QPGA3
    GO TO 111
62  QSPG=QPAI
     SPELF=QPDI1  *XA(KK)
     SPILF=QPFI   *XA(KK)
     SPUPF=QPJI   *XA(KK)
     APELF=QPDW2  *XA(KK)
    QCVF=QPHW2    *XA(KK)
    QAPG=QPAW
    QSPC=QPBI2
    QAPC=QPBW1
     SPELS=QPCI2
     SPILS=QPEI2
     SPUPS=QPII2
     APELS=QPCW3
    PUWTS=PUWT3
    PUWTA=PUWT2
    QCVS=QPGW3
    GO TO 111
63  QSPG=QPAA
     SPELF=QPDA2  *XB(KK)
     SPILF=QPFA   *XB(KK)
     SPUPF=QPJA   *XB(KK)
     APELF=QPDW2  *XA(KK)
    QCVF=QPHW2    *XA(KK)
    QAPG=QPAW
    QSPC=QPBA2
    QAPC=QPBW1
     SPELS=QPCA2
     SPILS=QPEA2
     SPUPS=QPIA2
     APELS=QPCW3
    PUWTS=PUWT1
    PUWTA=PUWT2
    QCVS=QPGW3
    GO TO 111
64  QSPG=QPAW
```

```
      SPELF=QPDW1  *XA(KK)
      SPILF=QPFW   *XA(KK)
      SPUPF=QPJW   *XA(KK)
      APELF=QPDA2  *XB(KK)
      QCVF=QPHA2   *XB(KK)
      QAPG=QPAA
      QSPC=QPBW2
      QAPC=QPBA1
      SPELS=QPCW2
      SPILS=QPEW2
      SPUPS=QPIW2
      APELS=QPCA3
      PUWTS=PUWT2
      PUWTA=PUWT1
      QCVS=QPGA3
  111 IF (KK-1) 1,1,4
  1   QSP=QSPG
      QF=QFA
      QAR=1.-(1.-QACA)*(1.-QRA)
      QQD=QDWGA
      QAP=QAPG
      QTV=QTG
      QTA=QTAA
      QTB=QTBA
      QTC=QTCA
      QTD=QTDA
      QTE=QTEA
      QST=QASG
      QMV=QAMG
      QTANP=QATPG
      QTANS=QATSG
      QTANC=QATCG
      GO TO 10
  2   QSP=QSPC
      QF=QFB
      QAR=1.-(1.-QACB)*(1.-QRB)
      QQD=QDWGB
      QAP=QAPC
      QTV=QTC
      QTA=QTAB
      QTB=QTBB
      QTC=QTCB
      QTD=QTDB
      QTE=QTEB
      QST=QASC
      QMV=QAMC
      QTANP=QATPC
      QTANS=QATSC
      QTANC=QATCC
      GO TO 10
    3 QSPEL= SPELS
      QSPIL= SPILS
      QSPUP= SPUPS
      QFEL=QFC
      QFC=QFI
      QFNF=QFG
      QRLP=QRI
      QALP=1.-(1.-QACG)*(1.-QACK)
      QARIL=QARE
      QAREL=1.-(1.-QRC)*(1.-QACC)
```

```
      QQDEL=QDWGC
      QAPEL= APELS
       TVPEL=QTEPS
       TVSEL=QTESS
       TVPIL=QTIPS
       TVSIL=QTISS
      QTVF=QTFS
      QTAEL=QTAC
      QTBEL=QTBC
      QTCEL=QTCC
      QTDEL=QTDC
      QTEEL=QTEC
      QST=QASS
      QMV=QAMS
      QTANP=QATPS
      QTANS=QATSS
      QTANC=QATCS
      QCV=QCVS
      GO TO 20
 4    QSPEL= SPELF
      QSPIL= SPILF
      QSPUP= SPUPF
      QAPEL= APELF
      QCV=QCVF
      QFEL=QFD      *XC(KK)
      QFC=QFJ       *XC(KK)
      QFNF=QFH      *XC(KK)
      QRLP=QRJ      *XC(KK)
      QALP=1.-(1.-QACH*XC(KK))*(1.-QACL*XC(KK))
      QARIL=QARF    *XC(KK)
      QAREL = 1.-(1.-QRD*XC(KK))*(1.-QACD*XC(KK))
      QTANS=QATSF   *XA(KK)
      QTANC=QATCF   *XA(KK)
      QQDEL=QDWGD   *XB(KK)
       TVPEL=QTEPF *XB(KK)
       TVSEL=QTESF *XB(KK)
       TVPIL=QTIPF*XB(KK)
       TVSIL=QTISF *XB(KK)
      QTVF=QTFF     *XB(KK)
      QTAEL=QTAD    *XD(KK)
      QTBEL=QTBD    *XD(KK)
      QTCEL=QTCD    *XD(KK)
      QTDEL=QTDD    *XD(KK)
      QTEEL=QTED    *XD(KK)
      QST=QASF      *XA(KK)
      QTANP=QATPF   *XA(KK)
      QMV=QAMFX(KK)
      GO TO 20
 10   OQA=1.-(1.-QSP)*(1.-QF)*(1.-QAR)*(1.-QQD)*(1.-QAP)*(1.-QTA)*
     1(1.-QTB)*(1.-QTC)*(1.-QTD)*(1.-QTE)**A
      WAA=QDWGW+FILW+WGTA+WGT+WA+WB+WC+WD+A*WE+PUWTA+PUWTS
      QB = 1.-((1.-QSP)*(1.-QF)*(1.-QAR)*(1.-QTV)*(1.-QTA)*(1.-QTB)*
     1  (1.-QTC)*(1.-QTD))**2*(1.-QAP)*(1.-QQD)*(1.-QTE)**A
      WBB=QDWGW+2.*(WT+FILW+WGTA+WGT+WA+WB+WC+WD)+A*WE+2.*PUWTS+PUWTA
      GO TO 30
 20   OQELA=1.-(1.-QSPEL)*(1.-QAPEL    )*(1.-QQDEL)*(1.-QCV)
     1*(1.-QFEL)*(1.-QAREL)*(1.-QTAEL)*(1.-QTBEL)*
     2(1.-QTCEL)*(1.-QTDEL)*(1.-QTEEL)**A
      OQP1=1.-(1.-QSPEL)*(1.-QAPEL    )*(1.-QQDEL)*(1.-QFEL)*(1.-QAREL)
     1*(1.-QTAEL)*(1.-QTBEL)*(1.-QTCEL)*(1.-QTDEL)*(1.- TVPEL)**2
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```
     2*(1.-QCV)
      QS1=1.-(1.-QP1)*((1.- TVPEL)/(1.- TVSEL))**2
      QELB=1.-(1.-QP1*QS1)*(1.-QP1*QTVF)*(1.-QTEEL)**A
      QILA=1.-(1.-QSPIL)*(1.-QARIL)
      QP10=1.-(1.-QSPIL)*(1.-QARIL)*(1.- TVPIL)**2.
      QS10=1.-(1.-QSPIL)*(1.-QARIL)*(1.- TVSIL)**2
      QILB=1.-(1.-QP10*QS10)*(1.-QP10*QTVF)
      QUPB=1.-(1.-QSPUP**2)*(1.-QSPUP*QTVF)
      QCFB=1.-(1.-QFC**2)*(1.-QFC*QTVF)
      QNFB=1.-(1.-QFNF)**2
      QLRPB=1.-(1.-QRLP**2)*(1.-QRLP*QTVF)
      QLAPB=1.-(1.-QALP**2)*(1.-QALP*QTVF)
      QA =1.-(1.-QELA)*(1.-QILA)*(1.-QSPUP)*(1.-QFC)*(1.-QFNF)*
     1  (1.-QRLP)*(1.-QALP)
     0QB=1.-(1.-QELB)*(1.-QILB)*(1.-QUPB)*(1.-QCFB)*(1.-QNFB)*(1.-QLRPB)
     1*(1.-QLAPB)
 30   GO TO (11,22,33),JQ
 11   QACT=QST
      WACT=WASW
      GO TO 100
 22   QACT=QMV
      WACT=WAMW
 100  GO TO (44,55),KQ
 44   QSYS=QA
      WSYS=WAA
      GO TO 200
 55   QSYS=QB
      WSYS=WBB
 200  QTOTA =1.-(1.-QSYS)*(1.-QACT)**A
      WTOTA =A*WACT+WSYS
      GO TO 40
 33   GO TO (92,92,94,94,94,94),N
 92  0QTOTA =1.-((1.-QA )**2*((1.-QTANC)*(1.-QTV)*(1.-QTANP)
     1*(1.-QTANS))**A*(1.-QTV))/((1.-QQD)*(1.-QAP))
      QACT=1.-(1.-QTANC)*(1.-QTANP)*(1.-QTANS)*(1.-QTV)
      WACT=WATW+WT
      GO TO 40
 94   QTVT=1.-(1.-QTVF)**A
      QPRIM = 1.-(1.-QA)*((1.-QTANP)*(1.-TVPIL)*(1.-TVPEL)**A)
      QSECT = 1.-(1.-QA)*((1.-QTANS)*(1.-TVSEL)*(1.-TVSIL)**A)
      QTOTA =1.-(1.-QPRIM *QSECT)*(1.-QPRIM *QTVT)*(1.-QTANC)
      QACT=1.-(1.-QTANP*QTANS)*(1.-QTANP*QTVF)*(1.-QTANC)
      WTOTA =A*(WATW+WT)+2.*WAA+WT-(QDWGW+PUWTA)
 40   GO TO (81,82,83,84,85,86),N
 81   QVEHG=1.-(1.-QTOTA )*(1.-QTRG)**A
      Q1=QACT
      W1=WACT
      GO TO 900
 82   QVEHC=1.-(1.-QTOTA )*(1.-QTRC)**A
      Q2=QACT
      GO TO 900
 83   QVEHS=1.-(1.-QTOTA )*(1.-QTRS)**A
      Q3=QACT
      GO TO 900
 84   QVEHF=1.-(1.-QTOTA )*(1.-QTRF*XA(KK))**A
      Q4=QACT
      GO TO 900
 85   QVEHY=1.-(1.-QTOTA )*(1.-QTRF*XA(KK))**A
      Q5=QACT
      GO TO 900
```

```
 86   QVEHZ=1.-(1.-QTOTA )*(1.-QTRF*XA(KK))**A
      Q6=QACT
 900  N=N+1
      GO TO (1,2,3,4,500,500,5),N
   5  VHYSW=WTOTA +A*TRWT
C  COST
      XLIFA=.1+VLIFA
      XLIFP=.1+VLIFP
      GO TO (210,220,230),JQ
 210  ADCST=ADCSS
      ADTIM=ADTIS
      AUCST=AUCSS
      GO TO 240
 220  ADCST=ADCSM
      AUCST=AUCSM
      GO TO 240
 230  ADTIM=ADTIT
 240  GO TO (12,222),KQ
  12  STV3=0.0
      GO TO 50
 222  TUCD1=2.*TUCD1
      STV3=2.0
      TUCU1 =2.*TUCU1
  50  GO TO (60,60,233),JQ
 233  TUCD2=2.*TUCD2
      STV3=1.0
      TUCU2 =2.*TUCU2
  60  TUCSD=TUCD1 +TUCD2 *.5*A +TUCD3
      TUCSU = TUCU1+TUCU2+TUCU3
      STCSD=STCSD*STV3
      STCSU=STCSU*STV3
      VHSWC=VHYSW*VHYSB*VPNUB*VWCST
      IF (PPPP8-1.0) 301,302,303
 301  VPMLC=1.0E6
      VPUC=0.0
      S10=0.0
      GO TO 304
 302  VPMLC=PALF
      VPUC=PFAFU
      S10=S7
      GO TO 304
 303  VPMLC=PWLF
      VPUC=PINFU
      S10=S8
 304  IF (ALIFE/XLIFA-ACYCL/VCYCA)306,306,305
 305  VQUAM=ACYCL/VCYCA
      GO TO 308
 306  VQUAM=ALIFE/XLIFA
 308  IF (VQUAM-1.0)310,310,309
 309  VQUAM=1.0
 3100 VHSLC=ANUMB*VHYSB*VPNUB*AUCST*VREPR*(VQUAM-1.0)+VHYSB*VPNUB*VPUC*
     1(XLIFP/VPMLC-1.0)*VREPR*S10
     0VPHDU=ADCST+PFAFD+PINFD+PTRFD+FUCSD+TUCSD+QDCSD+XRUSD+RAPCD+
     1STCSD+((AUCST+XRUSU)*(ANUMB)+PFAFU*S7+PINFU*S8+PTRFU*S9+FUCSU*Z3+
     2TUCSU+QDCSU+RAPCU*Z3+SACSU*Z1+RECSU*Z2+STCSU*STV3)*VHYSB*VPNUB
      IF(PFAFT-PINFT)400,400,401
 400  VHCDT=PINFT
      GO TO 403
 401  VHCDT=PFAFT
 403  IF(VHCDT-PTRFT)404,404,405
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```
404 VHCDT=PTRFT
405 IF(VHCDT-ADTIM)406,406,407
406 VHCDT=ADTIM
407 IF(VHCDT-VDEVL)408,408,409
408 VHCDT=VDEVL
409 VHDTC=(VHCDT-VDEVL)*VPEND
    PIWP=1.00E-3*ACTQL*ANUMB*PRES/VHYSW
    PAOP = 1.35*PIWP
    PWOP= 2.26*PIWP
    IF (PWOP-PAOP)313,314,314
313 PMOP=PAOP
    GO TO 315
314 PMOP=PWOP
    IF(PMOP)316,316,315
316 VHOTC=0.0
    GO TO 318
315 VHOTC=VTEST*VHYSB*VPNUB*(VOPER/(PMOP-1.0)*VTCST)
318 VPCST=VHSWC+VHSLC+VPHDU+VHDTC+VHOTC+ VHYSB*VFLRF*(QVEHS+QVEHF+
   1  QVEHY+QVEHZ+T4/TT1*(QVEHG+QVEHC))
    WRITE (3,951) PRES,AMOM
    WRITE (3,605) QVEHG,QVEHC,QVEHS,QVEHF,QVEHY,QVEHZ,VHYSW ,Q1,Q2,Q3
   1  ,Q4,Q5,Q6,W1,  VPCST
    IF (AMAX-AMOM)998,998,999
998 IF (PREM-PRES)997,997,999
997 IF (RUNQ - RUN) 3000,2000,2000
3000 CONTINUE
    CALL EXIT
    END
// DUP
*STORE      WS  UA   QDECK
```