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REVIEW OF THE BRAYTON ENGINE ELECTRICAL SUBSYSTEM DESIGN AND COMPUTERIZED TECHNIQUE USED TO DOCUMENT WIRING

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APPENDIX A - FORTRAN PROGRAM USED TO DOCUMENT BRAYTON ENGINE ELECTRICAL SUBSYSTEM by Donald R. Packe

16. Abstract
This report presents a general description of the Brayton-B engine space power system, with special emphasis on the electrical subsystem. The interval between delivery of individual components and the initiation of systems testing is covered in detail, with particular attention to the computer-oriented approach used to document all the many interconnections of the electrical components. Applications of this documentation technique are recommended for development of other complex electrical - electronic systems.

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SUMMARY

The Brayton-B engine is being developed as a reliable source of continuous electric power for future space missions. NASA-Lewis Research Center has assumed full system engineering responsibility for its design and development. The engine has been built and is presently undergoing systems testing in a vacuum environment.

This report includes a general description of the major subsystems and their interrelation. The electrical subsystem is covered in more detail to include the function and operation of the major components. The application of computer technology as an aid for developing wire lists for the electrical harnesses is discussed. Advantages of computerized wiring tabulations over detailed wiring diagrams include simplified maintenance, lower cost, convenience, accuracy, and flexibility.

This report is intended primarily to document the approach used to develop the Brayton engine electrical subsystem and to serve as a guide and reference source for possible application of these principles to the development of other complex electrical-electronic systems.

INTRODUCTION

NASA-Lewis has assumed full system engineering responsibility to develop, build, and test the Brayton-B engine for use as a reliable source of electrical power on future space missions. Design criteria for the engine are that it would operate continuously for at least 5 years, control and regulate itself automatically, and provide a minimum of 10 kWe (kilowatts electric) of usable three-phase, 120-volt, 1200-hertz electrical energy.

Design and engineering analyses, material testing, and preliminary design studies conducted at Lewis began in 1963. A review of this phase of the program is presented in reference 1. Functions, design conditions, operating parameters, and electrical and thermodynamic characteristics of the major components were defined, and detailed specifications generated. By 1968 related technology had been developed to the point where contracts could be awarded to individual vendors to design and build the major components based on these specifications. Very close liaison was maintained throughout the life of each contract by the responsible contract manager to insure that the specifications were being rigidly followed and that the vendors complied with the intent of the contract. A comprehensive report covering the analysis and selection of design conditions for the Brayton engine was presented by Klann (ref. 2) in 1968.

Concurrently with fabrication, delivery, and checkout of the major components, Lewis prepared for the next phase: to assemble the components into an integral functioning engine. Key elements in this effort were the total electrical subsystem configuration design, development of interface requirements related to additional development instrumentation, provision for backup power supply interconnections for engine checkout, and, finally, documentation of the entire electrical subsystem wiring. The technique used to document the engine electrical subsystem wiring, as well as the instrumentation and electrical interfaces with the test facility, has proved particularly flexible and effective and is discussed in detail.

A progress report on the prototype engine during early system testing at the NASA-Lewis Space Power Facility was given by Brown (ref. 3) in 1969. Preliminary results of engine performance tests in a vacuum environment are presented in a work entitled "Experimental Performance of a 2 - 15 Kilowatt Brayton Power System in the Space Power Facility Using Krypton" by Fenn, Deyo, Miller, and Vernon of Lewis.

DESCRIPTION OF THE BRAYTON-B ENGINE

Figure 1 shows a schematic diagram of the engine with the four major subsystems enclosed by dashed lines. The engine as shown in the schematic is a completely self-contained system capable of automatic startup and shutdown cycles with steady-state operation at from 0 to 10 kilowatts of user electrical output power.

The heat source subsystem adds heat to an inert working gas through its heat exchanger. At present, the two heat sources being considered for the Brayton engine are radioisotope and a nuclear reactor. The hot gas in the recirculating primary gas loop flows through a single-stage radial-inflow turbine. Expansion of the gas through the turbine spins the shaft and produces useful work. About two-thirds of this work is absorbed in driving a single-stage radial-outflow compressor. The remaining one-third of the shaft work is available to a four-pole brushless alternator. The single shaft of this Brayton Rotating Unit (BRU) is supported by gas journal and thrust bearings and is lubricated by the working gas itself. After expansion in the turbine, the gas flows through a recuperator where a majority of the unused heat energy is transferred back to the cooler

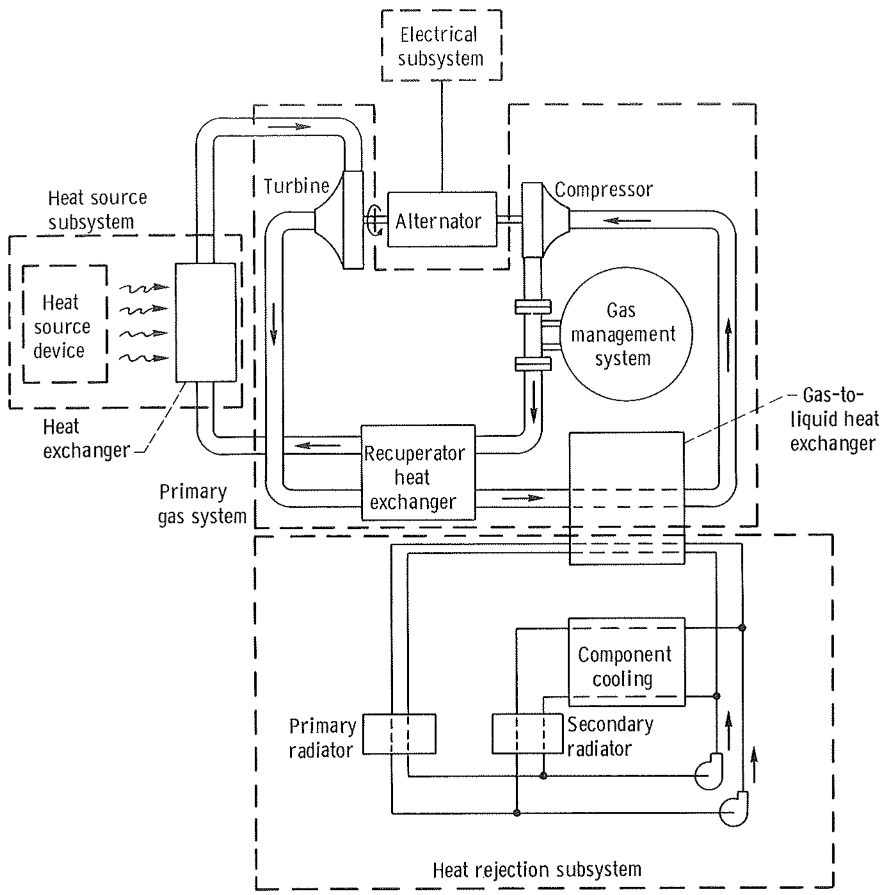


Figure 1. - Brayton engine schematic.

gas flow leaving the compressor. The gas leaving the recuperator is further cooled by the gas-to-liquid heat exchanger which removes the waste heat from the gas loop and transfers it to the liquid heat-rejection subsystem. A gas management system supplies the gas for engine startup by injecting gas into an evacuated loop at the compressor discharge. It also provides jacking gas to the BRU bearings during the startup cycle and controls total gas inventory in the system during steady-state operation. A more detailed description of the events related to startup and shutdown is given by Cantoni and Thomas (ref. 4).

The heat rejection subsystem removes excess engine heat from the gas-to-liquid heat exchanger and provides cooling for the electrical-electronic components. Cooling is provided by redundant liquid loops of recirculating Dow Corning DC-200 fluid. Either loop satisfies the necessary heat-transfer requirements. Each loop circulates in a split path: one path removes heat from the heat exchanger and dissipates it by means of the primary (hot) radiator; the second path cools the alternator and the electronic components, dissipating heat through the secondary (cool) radiator. The pumps for the two coolant loops are powered from the engine electrical subsystem.

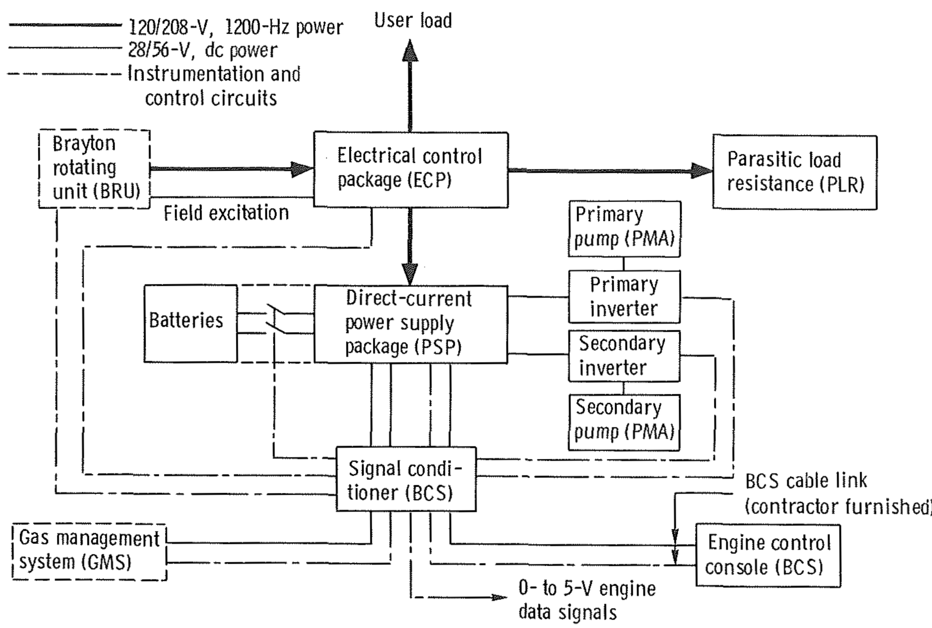
Finally, the electrical subsystem regulates and distributes the electrical output of the alternator and provides all the engine control and logic functions. The electrical output is 208/120 volts, 1200 hertz, three-phase power. The maximum alternator output power depends on the heat source mated to the engine and the pressure level at which the system is operating. The alternator is capable of up to 15 kilowatts power output. Between 1.5 and 2 kilowatts of this power is used for "housekeeping" purposes: operation of the engine control system, speed control and field excitation for the alternator, operation of the coolant pumps, and for battery charging.

DETAILS OF THE ELECTRICAL SUBSYSTEM

The BRU, as the principal turbomachinery package of the engine, is an integral unit which includes the turbine, the compressor, and the alternator. The alternator is a four-pole, solid rotor, modified Lundell type, three-phase brushless machine whose output is 208 volts line-to-line at 1200 hertz. The rotor of the alternator consists of two separate magnetic sections joined together by a nonmagnetic metallic separator. Advantages of a machine of this type are the smooth rotor which minimizes windage losses and the incorporation of short armature coils (compared with a homopolar inductor alternator). Further, the elimination of slip rings or commutator contacts and the absence of rotating windings increase the reliability and life expectancy of the machine. Alternator cooling is accomplished by dual liquid passages in the alternator jacket for circulation of the heat-rejection system coolant. Either liquid passage can provide the needed cooling. Detailed information related to alternator design and performance characteristics is given by Ingle and Corcoran in reference 5.

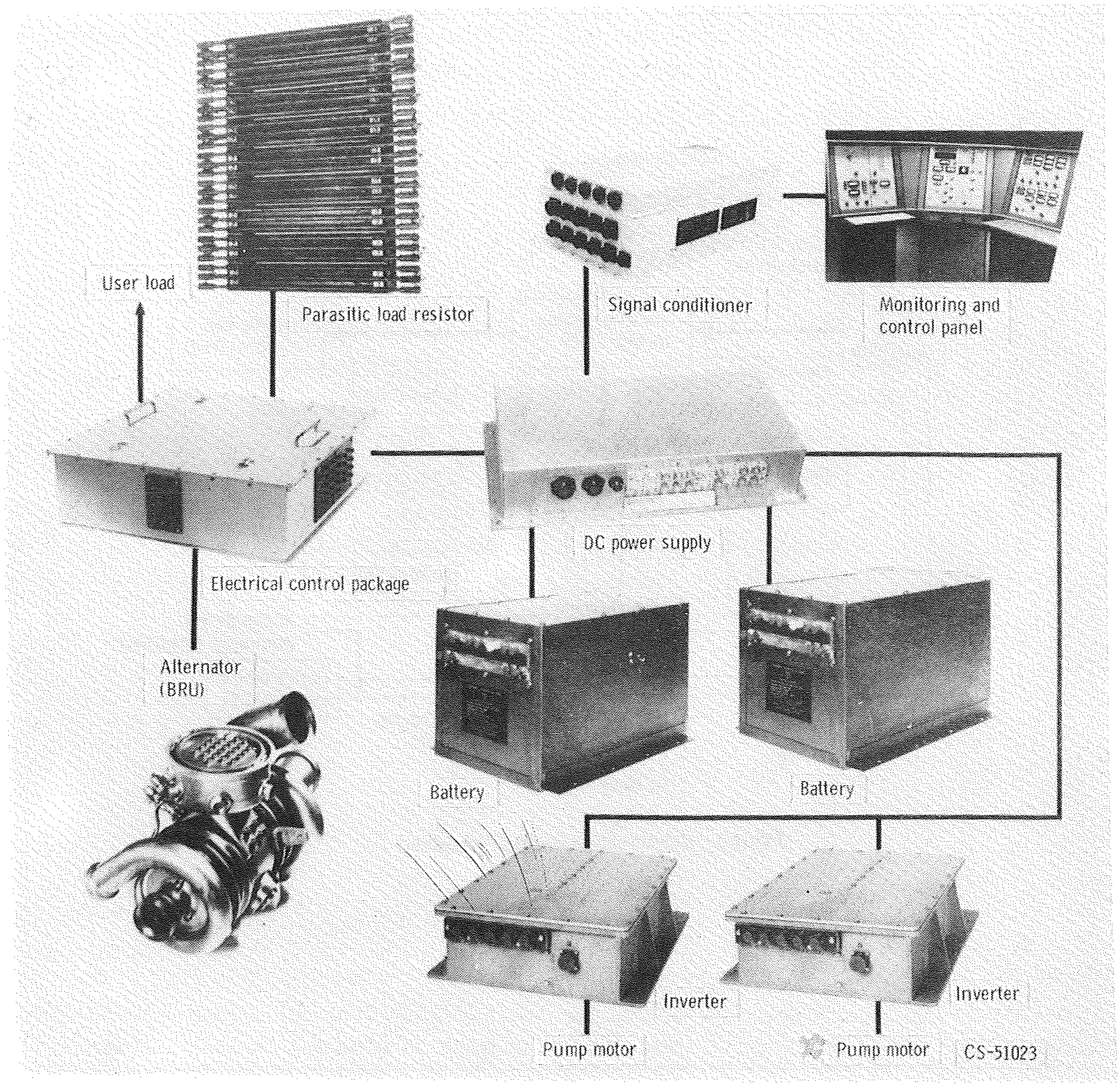
The remainder of the electrical subsystem regulates and distributes engine power and provides all control and logic functions required to operate the Brayton engine. The major packages which comprise the electrical subsystem are the Power Supply Package (PSP), the Electrical Control Package (ECP), the Brayton-Engine Control System (BCS), the inverters, and the pump motors. All power required to operate the electrical subsystem during startup, normal operation, and shutdown is supplied by the engine. Figure 2 is a schematic representation of the electrical subsystem showing individual components and their control and power interconnections.

The PSP supplies the engine with required dc power both during normal operation and when the BRU is shut down. During normal operation, the dc supply rectifies the 1200-hertz alternator output to provide 56 volts dc (±28 V dc from ground reference). When the BRU is inactive, two silver-cadmium batteries provide the required power for system startup and shutdown. Direct current is used to power all control and monitoring functions, to recharge the batteries, and to supply the two 400-hertz inverters which



(a) Block diagram.

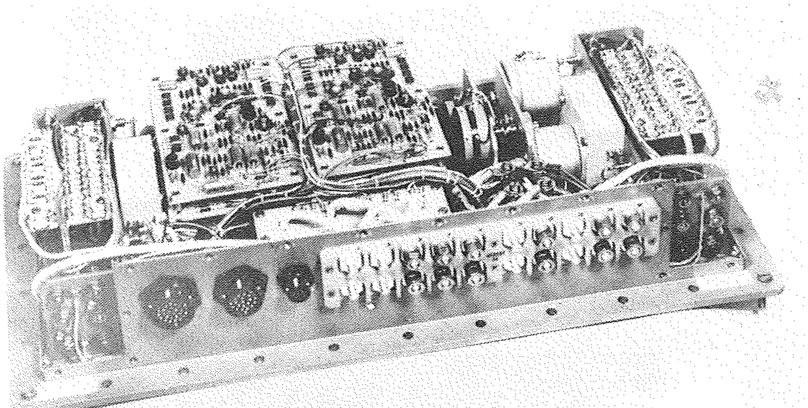
Figure 2. - Brayton engine-electrical subsystem.



(b) Electrical subsystem components.

Figure 2. - Concluded.

drive the liquid-loop pumps. Specifically, the PSP consists of a positive and a negative 28-volt battery, and an electronic unit (see fig. 3). Packaged within this electronic unit are the following: two multiple winding transformers and diode assemblies which convert the 208/120 volts ac input to ±28 volts dc bus power and ±42 volts dc for battery charging; two identical series regulator current limiting circuits used for battery charging; two separate ampere-hour integrator circuits which continuously depict the approximate charge status of each of the batteries; a bistable latching power relay which connects or removes the batteries from the dc bus; control and logic circuitry, which accepts commands from the BCS and dictates the priority and relation of the PSP internal functions; and finally, a system which senses and conditions a number of PSP data



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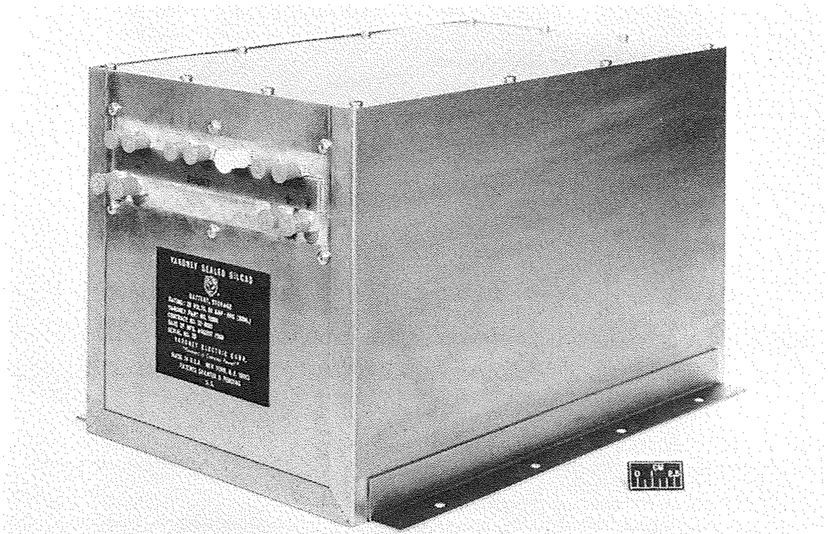
(a) Direct-current power supply (cover removed).



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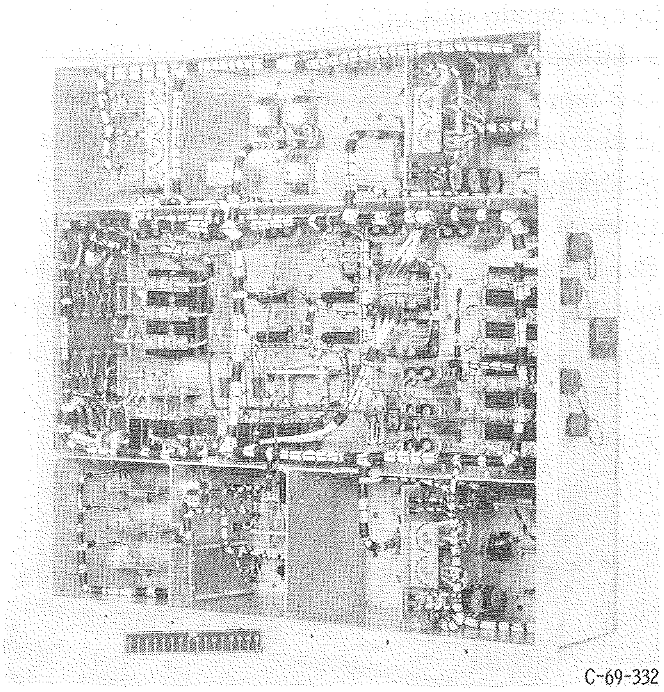
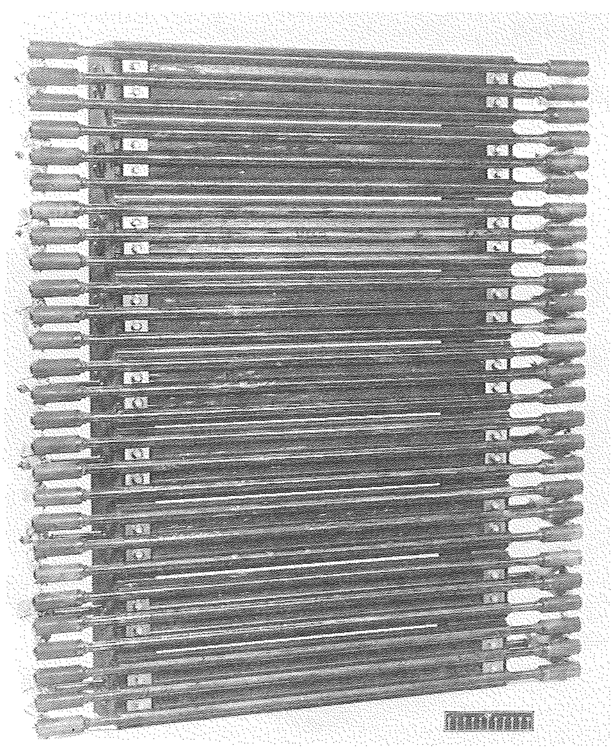
(b) Battery (two required).

Figure 3. - Direct current power supply package.



C-69-332

(a) Speed control-voltage regulator (cover removed).



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(b) Parasitic load resistor.

Figure 4. - Electrical control package.

parameters, converting the information to 0 to 5 volts dc signals for external monitoring.

The ECP provides alternator excitation, regulates the 1200-hertz output voltage, controls the BRU speed, and contains the engine circuit breakers which distribute the electrical power (see fig. 4). Remotely mounted, but still a functional part of the ECP, is the parasitic load resistor which dissipates excess electrical energy as commanded by the speed control in order to maintain the BRU speed within its design range. The alternator field excitation circuitry consists of a series field supply, supplemented as required by a shunt field supply. The series field amplitude is directly proportional to alternator output line current, while the shunt field is varied automatically to maintain constant alternator output voltage. The speed control senses alternator frequency and maintains it within design limits by varying the amount of power being dissipated in the parasitic load resistors.

The BCS provides all control and monitoring functions necessary to operate the engine. It consists of three individual elements: an engine-mounted signal conditioner, a cable link, and a remote control and monitoring console. The signal conditioner is an electronic unit which interfaces between engine electronics (instrumentation and control devices) and the control and monitoring console. The cable system links these two elements of the BCS. The three elements of the BCS are pictured in figure 5. The signal conditioner accepts all engine instrument and control signals and converts them to a common 0 to 5 volts dc output. It also acts as the interface for the returning command and control functions originating from the control console. The control console is a highly compact and specialized system which incorporates human factors engineering in

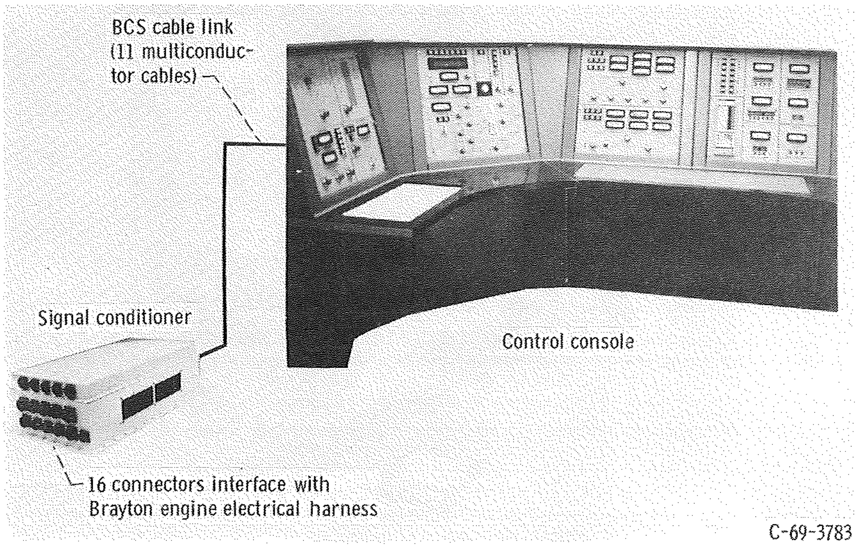
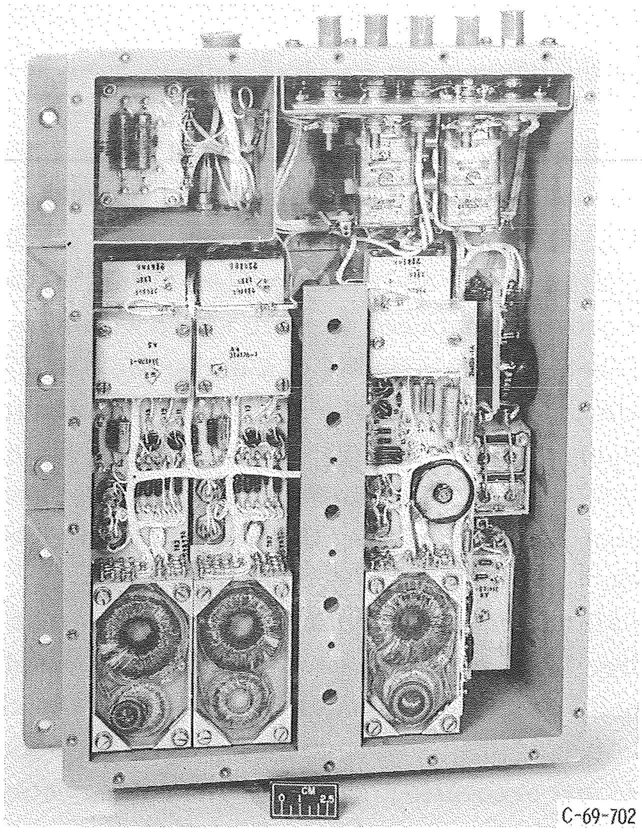
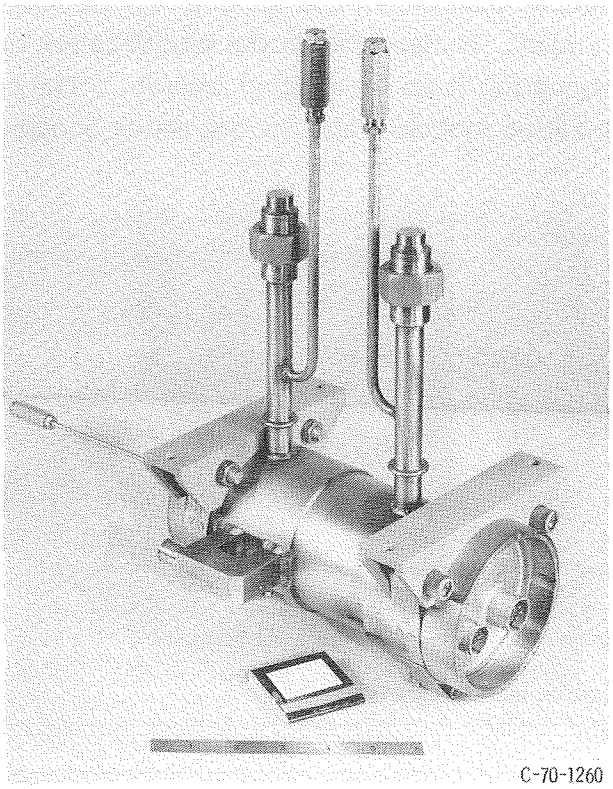


Figure 5. - Brayton-engine control system.



(a) Inverter (cover removed).



(b) Coolant pump-motor assembly.

Figure 6. - Inverter and pump-motor assembly.

its design. It could, with minimum modification, be used for a mission application. The cable link between the signal conditioner and the control and monitoring console consists of 11 multiconductor cables, which collectively contain 183 sensing signals, 43 return signals, 32 dc power leads, 43 shields, and 66 spare conductors. All console circuits are wired on printed circuit cards which are essentially self-diagnostic and indicate a malfunction directly. Most of these cards can be replaced in the event of a malfunction with the system still in operation. Specific criteria incorporated in the design of the ECS include: (1) redundancy whenever appropriate, (2) no interruption in engine operation as a result of a single component failure, (3) totally self-sufficient, being independent of spacecraft or outside sources of power during engine operation, startup, or shutdown.

Two dc-to-ac inverters each provide up to 25 amperes of three-phase, 400-hertz power to operate the two pump-motor assemblies (PMA) in the two coolant loops (see fig. 6). Each inverter takes its input power from the dc power supply and converts it to a quasi-square wave, approximately 45 volts rms output, which is directly connected to the input of each PMA. A 5-volt pulse from the signal conditioner starts or stops either inverter. The inverters are protected against overload by an internal cutoff circuit which turns the inverter off, but will permit restart after the overload is removed.

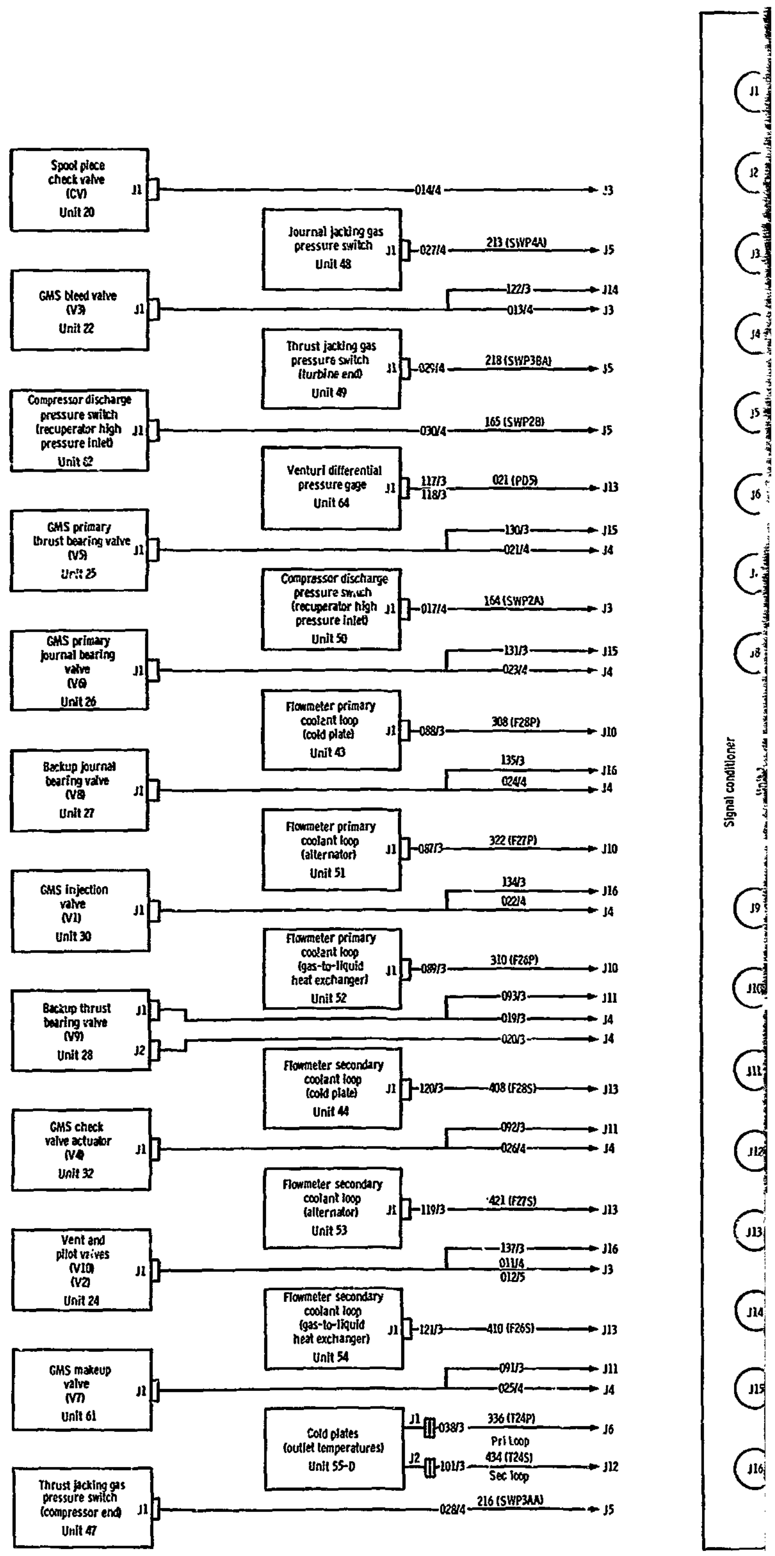
Each PMA is an integral unit consisting of a centrifugal pump and a three-phase, 400-hertz, fractional horsepower induction motor mounted within the same housing. Either pump will operate whenever its respective inverter is turned on. The pumps have a nominal speed of 11 000 rpm at rated pressure and flow. The same coolant liquid which circulates through the heat-rejection subsystem flows within the motor housing and is in direct contact with the electrical windings. The liquid thus also removes heat from the motor windings and lubricates the bearings.

With the exception of the BCS cable link between the engine-mounted signal conditioner and the remote control and monitoring console, no interconnecting electrical subsystem wiring was developed by any of the component manufacturers. All drawings required to integrate the electrical components were developed by Lewis from information furnished by the individual vendors. This effort is discussed in the following section.

DOCUMENTATION OF THE ELECTRICAL SUBSYSTEM WIRING

Drawings

The block diagram of the engine power and control system (fig. 2) describes the conceptual version of the electrical subsystem; however, far more detail was required before engine wiring could be started. Vendor drawings were examined carefully to


Spool piece check valve (CV) Unit 20
Journal jacking gas pressure switch Unit 48
GMS bleed valve (V3) Unit 22
Thrust jacking gas pressure switch (turbine end) Unit 49
Compressor discharge pressure switch (recuperator high pressure inlet) Unit 62
Venturi differential pressure gage Unit 64
GMS primary thrust bearing valve (V5) Unit 25
Compressor discharge pressure switch (recuperator high pressure inlet) Unit 50
GMS primary journal bearing valve (V6) Unit 26
Flowmeter primary coolant loop (cold plate) Unit 43
Backup journal bearing valve (V8) Unit 27
Flowmeter primary coolant loop (alternator) Unit 51
GMS injection valve (V1) Unit 30
Flowmeter primary coolant loop (gas-to-liquid heat exchanger) Unit 52
Backup thrust bearing valve (V9) Unit 28
Flowmeter secondary coolant loop (cold plate) Unit 44
GMS check valve actuator (V4) Unit 32
Flowmeter secondary coolant loop (alternator) Unit 53
Vent and pilot valves (V10) (V2) Unit 24
Flowmeter secondary coolant loop (gas-to-liquid heat exchanger) Unit 54
GMS makeup valve (V7) Unit 61
Cold plates (outlet temperatures) Unit 55-D
Thrust jacking gas pressure switch (compressor end) Unit 47
Pri loop
Sec loop
Signal conditioner

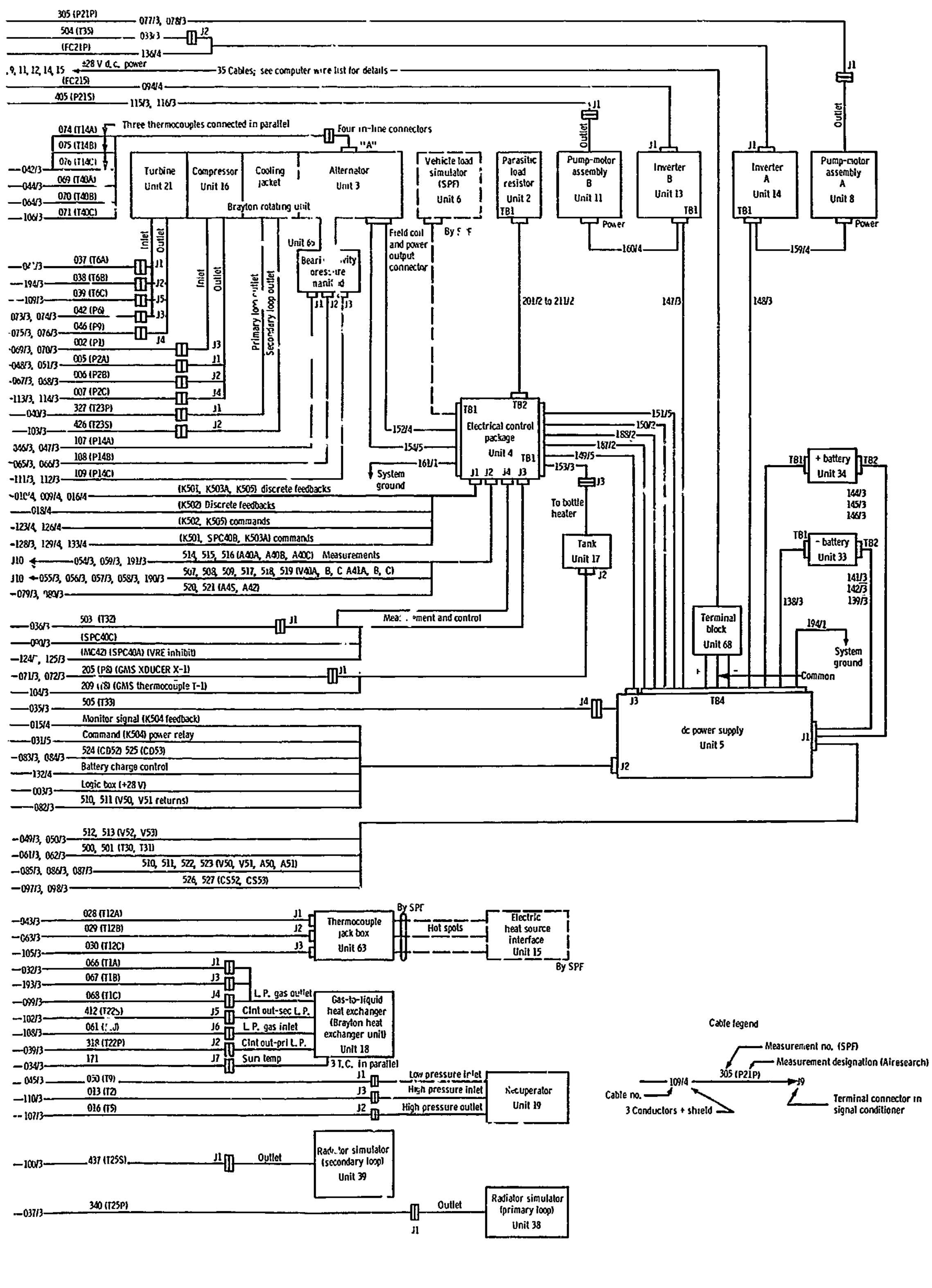


Figure 7. - Brayton power system electrical block diagram.

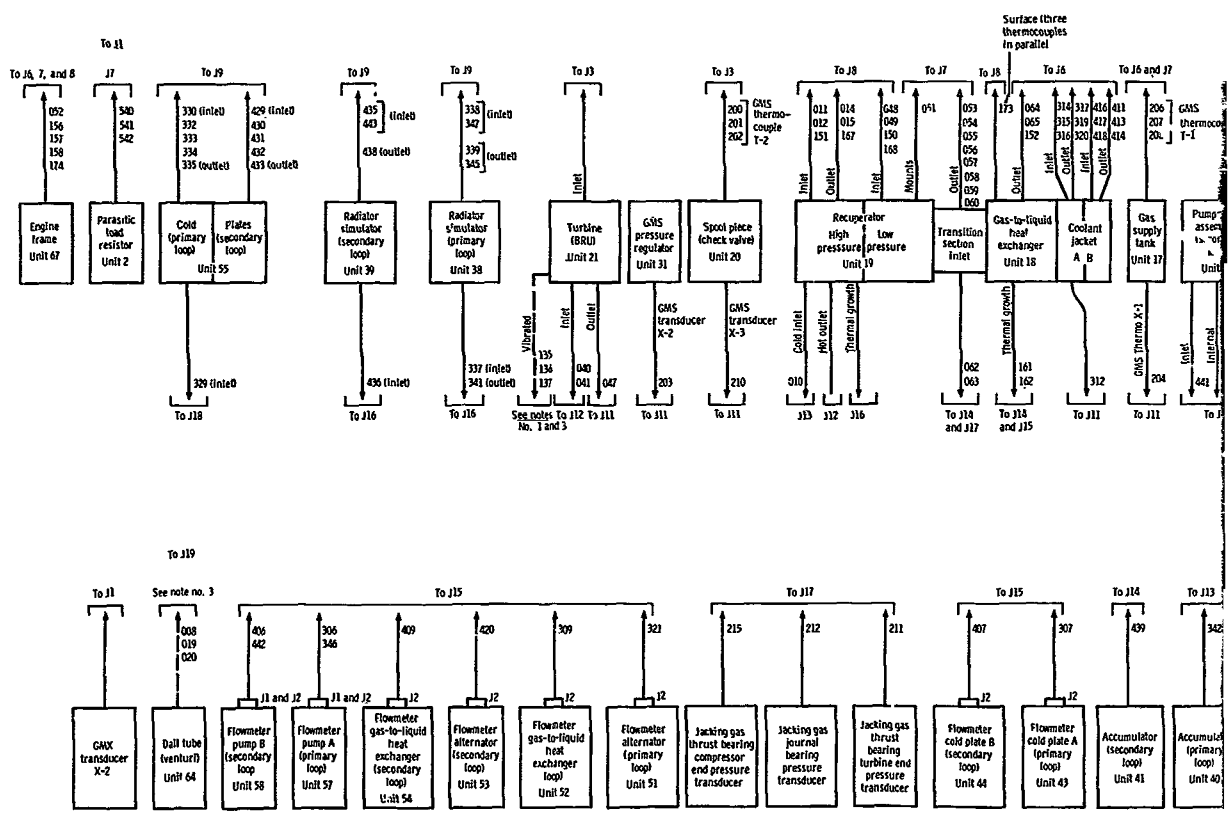
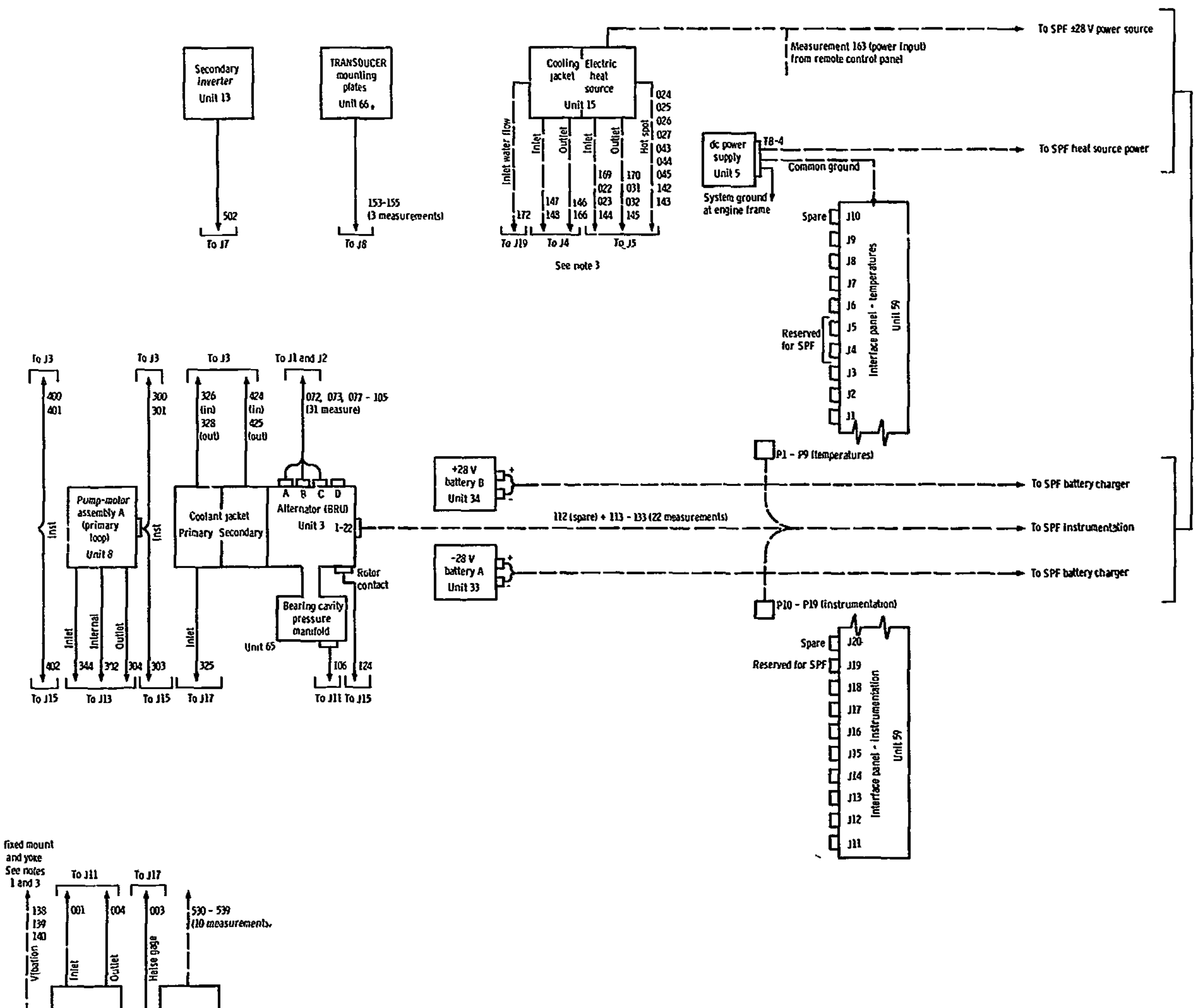


Figure 8.



(1) Vibration measurements are not channeled through interface panels.
(2) For descriptions and location of measurements refer to piping and instrumentation schematic, Brayton power system, SPF tests.
(3) Harnesses indicated in dashed lines shall be

identify all interfacing connectors and terminals. Then, using this added information, the block diagram of figure 7 was developed. Except for the BCS cable link, which was furnished by the contractor, this drawing shows all the cables required to complete the electrical subsystem. In addition, it gives the number of active conductors per cable, identifies the cables by number, provides shielding and grounding information, and indicates circuit designations for all the control and monitoring circuits.

In the same manner, a second block diagram was developed (see fig. 8) to show the interfaces associated with instrumentation and related support systems outside of the basic engine. These peripheral circuits, referred to in this report as the Development System, include thermocouples, flowmeters, pressure transducers, accelerometers, etc., which were installed to better evaluate engine performance during ground testing.

Concurrent with development of the block diagrams, a grounding philosophy was devised to reduce or eliminate the possibility of stray or extraneous voltages. All conductors were shielded, and all shields were grounded at one end only, to a single point on the engine frame, which, in turn, was grounded to earth.

Wire Lists

Detailed wiring diagrams to show point-to-point connections for each conductor were not developed. The number of cables and components that make up the complete electrical subsystem would require many drawings to show all the terminations and would prove too cumbersome. Furthermore, maintaining an up-to-date series of these drawings would be time consuming and costly. As an alternative, computerized wire lists for each of the electrical subsystems were developed, based on the block diagrams of figures 7 and 8. Wire lists in themselves are not new. However, tabulations in a computer-oriented format are a much more recent technique which has found acceptance in both aerospace and military applications. It is particularly adaptable to complex systems where a large number of components are to be interconnected.

Two wire lists were established: one detailing the engine electrical subsystem, and the other, the development system. The tabulations included each conductor in the subsystem with both termination points; in addition, they gave the circuit characteristics, cabling and shielding information, and a brief description of the function of that conductor in the system. In order to facilitate the identification of components, each was assigned a unit number as defined in table I. In addition, a sequential signal number was assigned to identify all conductors from each unit.

The wire lists, one page of which is reproduced in figure 9, show the origin of each conductor (unit number, signal number, connector, and pin), its destination (unit number, signal number, connector, and pin), the cable designation number, electrical char-

TABLE I. - BRAYTON ENGINE, LIST OF UNIT NUMBER DESIGNATIONS

Unit number	Component	Unit number	Component
1	Signal conditioner (engine)	35	Emergency shutoff valve (manual)
2	Parasitic load resistor (PLR)	36	Pilot valve (part of GMS vent valve, unit 24)
3	Alternator (BRU)	37	Emergency vent device
4	Electrical control package (ECP)	38	Primary radiator simulator (A)
5	dc power supply	39	Secondary radiator simulator (B)
6	Vehicle load bank (load simulator)	40	Accumulator - primary coolant loop (A)
7	Engine monitor panel	41	Accumulator - secondary coolant loop (B)
8	Primary pump-motor assembly (PMA A)	42	GMS relief valve
9	SPF (Space Power Facility) aluminum bulkhead interface	43	Flowmeter - primary coldplate
10	SPF concrete wall interface	44	Flowmeter - secondary coldplate
11	Secondary pump-motor assembly (PMA B)	45	Not used
12	Engine control panel	46	Pressure switch - relief valve
13	Secondary inverter (B)	47	Pressure switch - thrust bearing jacking gas (compressor end)
14	Primary inverter (A)	48	Pressure switch - journal bearing jacking gas
15	Electric heat source interface	49	Pressure switch - thrust bearing jacking gas (turbine end)
16	Compressor (BRU)	50	Pressure switch - compressor discharge - primary
17	Gas supply tank	51	Flowmeter - alternator primary coolant
18	Gas-to-liquid heat exchanger (BHXU)	52	Flowmeter - BHXU primary coolant
19	Recuperator (BHXU)	53	Flowmeter - alternator secondary coolant
20	Spool piece check valve (CV)	54	Flowmeter - BHXU secondary coolant
21	Turbine (BRU)	55	Coldplates (four sections)
22	GMS (Gas Management System) bleed valve (V3)	56	GMS extra valve
23	GMS orifice filter transducer A	57	Flowmeter - primary pump coolant
24	GMS vent valve (dump valve - V2)	58	Flowmeter - secondary pump coolant
25	GMS primary thrust bearing valve (V5)	59	Interface panel, Brayton engine to SPF
26	GMS primary journal bearing valve (V6)	60	Interface panel, Brayton engine to SPF
27	GMS backup journal bearing valve (V8)	61	GMS makeup valve (V7)
28	GMS backup thrust bearing valve (V9)	62	Pressure switch - compressor discharge - backup
29	GMS orifice filter transducer B	63	Electric heat source thermocouple jack box
30	GMS injection valve (V1)	64	Dall tube differential pressure
31	GMS pressure regulator	65	Bearing cavity pressure manifold (BRU)
32	GMS check valve actuator (V4)	66	Transducer mounting plates
33	Negative 28 V battery (A)	67	Engine frame
34	Positive 28 V battery (B)	68	Terminal block for BCS power

0 1 ENGINE HARNESS

FROM UNIT	FROM SIG	FROM CONN	FROM PIN	CABLE NUMBR	TO UNIT	TO SIG	TO CONN	TO PIN	VOLTS	AMPS	FREQ	AWG	CIRCUIT FUNCTION/REMARKS
1	557	J13	X	121/3	54								H.X.SEC.CLNT.FL.R(F265) SHIELD
1	576	J13	S-	112/3	65	9	J3	A	+28		DC	20	EXCIT. FOR (P14C) SIGNAL
1	577	J13	T-	112/3	65	12	J3	D	COMM		DC	20	EXCITATION FOR (P14C) RETURN
1	578	J13	U-	112/3	65								EXCITATION FOR (P14C) SHIELD
1	579	J13	V-	114/3	16	13	J4	A	+28		DC	20	EXCITATION FOR (P2C) SIGNAL
1	580	J13	W-	114/3	16	16	J4	D	COMM		DC	20	EXCITATION FOR (P2C) RETURN
1	581	J13	X-	114/3	16								EXCITATION FOR (P2C) SHIELD
1	582	J13	Y-	116/3	11	1	J1	A	+28		DC	20	EXCITATION FOR (P21S) SIGNAL
1	583	J13	Z-	116/3	11	4	J1	D	COMM		DC	20	EXCITATION FOR (P21S) RETURN
1	584	J13	AA	116/3	11								EXCITATION FOR (P21S) SHIELD
1	585	J13	BB	118/3	64	1	J1	A	+28		DC	20	EXCITATION FOR (PD5) SIGNAL
1	586	J13	CC	118/3	64	4	J1	D	COMM		DC	20	EXCITATION FOR (PD5) RETURN
1	587	J13	DD	118/3	64								EXCITATION FOR (PD5) SHIELD
1	592	J14	A	122/3	22	1	J1	A	+28	2	DC	20	OPEN BLEED VALVE SIGNAL (V3)
1	593	J14	B	122/3	22	2	J1	B	COMM	2	DC	20	OPEN BLEED VALVE RETURN (V3)
1	594	J14	C	122/3	22								OPEN BLEED VALVE SHIELD (V3)
1	595	J14	D	123/4	4	38	J1	M	COMM		DC	20	VRE AUX.CONT.CLOSE COMND(K502)
1	596	J14	E	123/4	4	37	J1	L	+28		DC	20	VRE AUX.CONT.CMND.RETN (K502)
1	597	J14	F	123/4	4	36	J1	K	COMM		DC	20	VRE AUX.CONT. OPEN COMND(K502)
1	598	J14	G	123/4	4								SHIELD (K502)
1	599	J14	H	124/3	4	73	J3	L	+28		DC	20	VRE INHIBIT MC-42 SIGNAL
1	600	J14	J	124/3	4	80	J3	V	COMM		DC	20	VRE INHIBIT MC-42 RETURN
1	601	J14	K	124/3	4								VRE INHIBIT MC-42 SHIELD
1	603	J14	M	125/3	4	67	J3	E	+5		DC	20	PAR.L.CONTR.A ON/OFF CMND. (SPC40A)
1	604	J14	N	125/3	4	64	J3	B	COMM		DC	20	PAR.L.CONTR.A CMND. RETN. (SPC40A)
1	605	J14	P	125/3	4								SHIELD (SPC40A)
1	606	J14	R	126/4	4	52	J1	C-	COMM		DC	20	COMD. HTR CONTR(K505)CLOSED
1	607	J14	S	126/4	4	53	J1	D-	+28		DC	20	COMD. HTR CONTR(K505)COMMON
1	608	J14	T	126/4	4	54	J1	E-	COMM		DC	20	COMD.HTR.CONTR(K505)OPEN
1	609	J14	U	126/4	4								SHIELD
1	621	J14	G-	127/3	68	111	TB3	26	-28		DC	20	POWER SUPPLY NEG 28V TO SIGL CONDR.
1	622	J14	H-	127/3	68	112	TB3	26	-28		DC	20	POWER SUPPLY NEG 28V TO SIGL CONDR.
1	623	J14	I-	166/4	68	13	TB1	6	COMM		DC	20	POWER SUPPLY DC COMM TO SIGL CONDR.
1	624	J14	J-	167/3	68	81	TB2	17	+28		DC	20	POWER SUPPLY POS 28V TO SIGL CONDR.
1	625	J14	K-	167/3	68	82	TB2	17	+28		DC	20	POWER SUPPLY POS 28V TO SIGL CONDR.
1	626	J14	M-	165/2	68	86	TB2	18	+28		DC	16	POWER SUPPLY POS 28V TO SIGL CONDR.
1	628	J14	P-	166/4	68	14	TB1	7	COMM		DC	20	POWER SUPPLY DC COMM TO SIGL CONDR.
1	629	J14	Q-	166/4	68	15	TB1	7	COMM		DC	20	POWER SUPPLY DC COMM TO SIGL CONDR.
1	630	J14	R-	006/2	68	45	TB1	12	COMM		DC	16	POWER SUPPLY DC COMM TO SIGL CONDR.
1	632	J15	B	128/3	4	69	J3	G	+5		DC	20	PAR.L.CONTR.B ON/OFF CMND. (SPC40B)
1	633	J15	C	128/3	4	65	J3	C	COMM		DC	20	PAR.L.CONTR.B CMND. RETN. (SPC40B)
1	634	J15	D	128/3	4								SHIELD (SPC40B)
1	635	J15	E	129/4	4	30	J1	D	COMM		DC	20	FIELD CON.CNTR.K501 VRE COMND
1	636	J15	F	129/4	4	29	J1	C	+28		DC	20	FIELD CON.CNTR.K501 RETURN
1	637	J15	G	129/4	4	28	J1	B	COMM		DC	20	FIELD CON.CNTR.K501 BAT COMND
1	638	J15	H	129/4	4								FIELD CON.CNTR.K501 SHIELD
1	639	J15	J	130/3	25	1	J1	A	+28	2	DC	20	OPN PRI.JACK.G.TH.V.SV5 COMND
1	640	J15	K	130/3	25	2	J1	B	COMM	2	DC	20	OPN PRI.JACK.G.TH.V.SV5 RETR
1	641	J15	L	130/3	25								OPN PRI.JACK.G.TH.V.SV5 SHLD

Figure 9. - Typical page from wire list.

acteristics of the circuit (volts, amperes, frequency, and wire gauge) as applicable, and the function of that conductor in the system. The information for each conductor was entered on key-punch cards (fig. 10). A single card could not accommodate all the relevant information for each conductor, therefore the "characteristics" and "function" information were separated, and the cards keyed by the unit and signal number columns.

The computer printout may take several forms as listed in appendix B (table II, p. 37). One option is to print the "characteristics" information in both the direct sequence as punched on the card, then in the inverter sequence, transposing the "from" and "to" data. Thus, two "function" cards were required for each conductor in order to identify it at the two ends. These were keyed to the two pairs of unit and signal numbers appearing on each characteristics card. The characteristics and two function cards print out as two lines of information for each conductor: first going from point A to point B with the function for point A printed, then elsewhere in the list under the appropriate unit and signal numbers, the same conductor goes from point B to point A with the function printed

TITLE BRAYTON CYCLE-ENGINE HARNESS | PROJECT NUMBER | ANALYST | SHEET 1 OF 2

FORTRAN STATEMENT

FROM				CABLE	TO				CHARACTERISTICS			
UNIT	SIG	CONN	PIN	NO.	UNIT	SIG	CONN	PIN	VOLTS	AMPS	FREQ.	AWG.
1	592	J14	A	122/3	22	1	J1	A	+28	2	DC	20
1	593	J14	B	122/3	22	2	J1	B	COMM	2	DC	20
1	594	J14	C	122/3	22							
1	595	J14	D	123/4	4	38	J1	M	COMM		DC	20
1	596	J14	E	123/4	4	37	J1	L	+28		DC	20
1	597	J14	F	123/4	4	36	J1	K	COMM		DC	20
1	598	J14	G	123/4	4							
1	599	J14	H	124/3	4	73	J3	L	+28		DC	20
1	600	J14	J	124/3	4	80	J3	V	COMM		DC	20
1	601	J14	K	124/3	4							

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TITLE BRAYTON CYCLE - ENGINE HARNESS | PROJECT NUMBER | ANALYST | SHEET 2 OF 2

FORTRAN STATEMENT

CIRCUIT FUNCTION/REMARKS	UNIT	SIG
OPEN BLEED VALVE SIGNAL (V3)	1	592
OPEN BLEED VALVE RETURN (V3)	1	593
OPEN BLEED VALVE SHIELD (V3)	1	594
VRE AUX.CONT.CLOSE COMND(K502)	1	595
VRE AUX.CONT.CMND.RETN (K502)	1	596
VRE AUX.CONT. OPEN COMND(K502)	1	597
SHIELD (K502)	1	598
VRE INHIBIT MC-42 SIGNAL	1	599
VRE INHIBIT MC-42 RETURN	1	600
VRE INHIBIT MC-42 SHIELD	1	601
VRE AUX.CONT. OPEN COMND(K502)	4	36
VRE AUX.CONT. CMN.RETN (K502)	4	37
VRE AUX.CONT. CLOSE COMND (K502)	4	38
VRE INHIBIT MC-42 SIGNAL	4	73
VRE INHIBIT MC-42 RETURN	4	80
OPEN BLEED VALVE SIGNAL (V3)	22	1
OPEN BLEED VALVE RETURN (V3)	22	2

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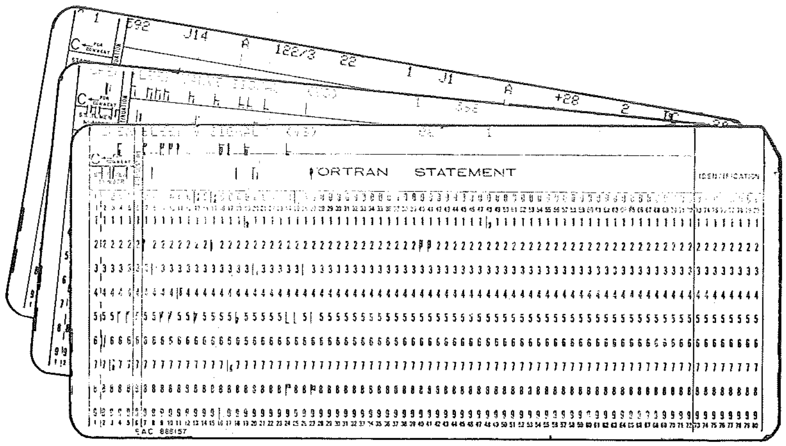
(a) Preliminary data sheets.

Figure 10. - Wire list development.



(b) Typical data cards for one conductor.

Figure 10. - Concluded.

for point B. The completed tabulations for the Brayton engine listed 644 actual conductors in the electrical subsystem harness and 812 in the development harness. A detailed listing of the computer program used to generate the two wire lists is given in appendix A.

Many advantages have become evident in the use of these wire lists over the more conventional use of wiring diagrams:

(1) The computer was programmed to include several self-checking capabilities which flagged potential errors that could result in miswiring. For example, if two wires are identified by the same unit and signal number, the duplications are automatically flagged in the right-hand margin. Should a function card be keyed improperly to a characteristics card, the error appears as a separate printout at the beginning of the wire list. Similarly, a conductor for which one end is connected and the other end is unaccounted for will be printed automatically out of sequence at the head of the list where it can be quickly found for corrective action.

(2) The format is flexible and can be easily modified by a simple program change. For example, wiring can be listed in order by unit and signal number (as shown in fig. 9) or the listing might be in sequency by cable number. Or, if desired, specified columns may be left blank to suit the user's applications. Several other variations are easily available as shown in appendix B (table II).

(3) Revisions are easily accomplished. For each rerouted conductor, no more than three new cards are required: a characteristics and the two function cards. Cards can be punched, and a new printout run off and distributed the same day. The revision date is printed automatically on each page.

(4) More detailed information appears on the wire list than normally appears in the typical wiring diagram: voltages, currents, frequencies, circuit functions, etc.

(5) The wire list is an ideal check list for technicians to install cables and to check out the installation. Further, all the needed information pertaining to a conductor appears on one line, eliminating the need to trace a circuit through a series of drawings.

(6) A particularly useful option performed by the computer is to automatically search the wire list for potential subharness assemblies which will permit separating the harness into smaller increments for fabrication and installation.

In order to further acquaint the reader with the utility of the wire list program, additional details together with a complete example problem are presented in appendix B.

ELECTRICAL SUBSYSTEM BUILDUP

A wood mockup, which had been built earlier to develop physical configuration of the engine, was made available and presented the ideal form on which to fabricate the electrical harnesses. Cable routing was planned so that, when wiring was completed, the two harnesses could be removed from the mockup and reinstalled as separate units on the engine. The wire lists were used to complete the cable terminations and connector assemblies, to ring out the completed wiring, and to serve as a check list for measurement of insulation resistances. The harness assembly during installation on the mockup is shown in figure 11.

Mechanical assembly of the basic engine was accomplished concurrently with fabrication of harnesses on the mockup. At the time the engine was ready for installation of the electrical system, a detailed procedure was provided to expedite mounting and connecting the electrical components and harnesses.

On completion of the electrical installation, a static checkout of the electrical subsystem was performed to verify that all components were connected properly and functioned normally. A checkout procedure, developed for this purpose, detailed the sequence for final interconnection of units and specified precautionary safeguards to prevent damage to any component during initial application of power. Interconnection of units and power buildup were accomplished step-by-step until, at the last phases of checkout, the entire electrical subsystem was connected in its final configuration and functioned normally with an external source of 1200-hertz, three-phase power instead of the BRU alternator.

In performing this procedure, the control console was connected to the engine for the first time. This presented the first opportunity to verify operation of the engine electrical system from a remote station. This also was the first time the engine interfaced with the external development system.

Completion of these tests established confidence in the entire electrical subsystem and verified that the engine was ready to undergo systems testing. Figure 12 shows the

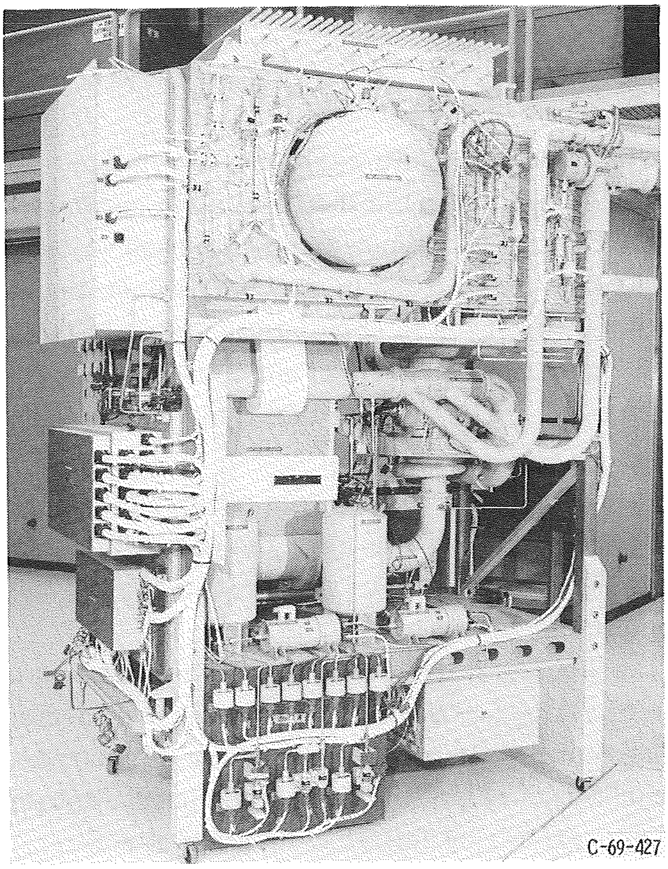


Figure 11. - Engine mockup with electrical harnesses installed.

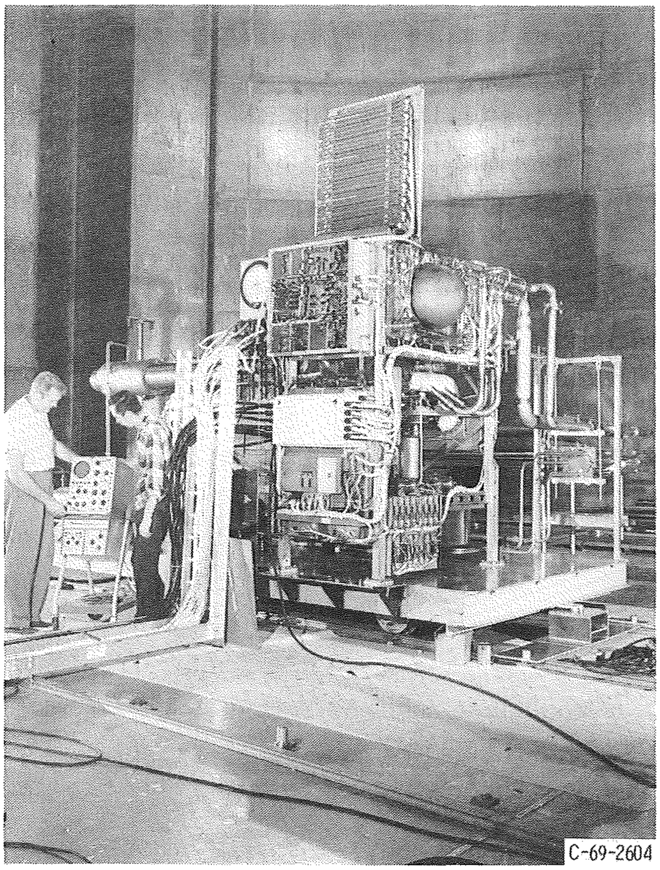


Figure 12. - Engine undergoing systems tests at Space Power Facility.

Brayton-B engine during early checkout operations at the Lewis Space Power Facility at Plum Brook. Subsequent engine testing under vacuum conditions verified that the objective of proper electrical subsystem performance had been achieved.

CONCLUDING REMARKS

Despite its complexity, wiring of the engine system proceeded smoothly and without significant discrepancies. Some minor problems resulting from the integration of information from drawings of many vendors, were easily corrected. The expediency and success with which the component interconnections were completed is attributed directly to the use of the computer. The principal benefits derived from this form of documentation are as follows:

1. The built-in self-checking capability assures a lower probability of error than either drawings or noncomputerized lists.
2. All needed information for any conductor appears on only one line in the tabulation, eliminating the need to trace a circuit through a series of drawings.
3. Ease in accomplishing revisions and reissuing wire lists results in lower maintenance costs.
4. Greater detail can be shown for all electrical conductors as compared with wiring diagrams.
5. Information is condensed into a simple, convenient, flexible format which facilitates installation, checkout, configuration control, and troubleshooting of the system.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 27, 1970,
120-27.

APPENDIX A

FORTRAN PROGRAM USED TO DOCUMENT BRAYTON ENGINE ELECTRICAL SUBSYSTEM

by Donald R. Packe

The following printout is a copy of the FORTRAN program developed to tabulate the Brayton engine electrical harnesses and to print the wire lists. The program is included in this report as a model which, with appropriate modifications, can be adapted at other computer facilities to document the wiring for any complex electrical-electronic system.

```
$IBFTC WIRE     LIST,DECK

C       THIS PROGRAM ORGANIZES WIRE LIST INFORMATION TO ASSIST IN
C       THE DESIGN AND FABRICATION OF ELECTRICAL HARNESSES.
C       IN ADDITION TO PRESENTING THE INFORMATION IN CONVENIENT FORM,
C       IT SEARCHES THE DATA FOR DUPLICATION OF CONNECTIONS,AND FLAGS
C       EACH DUPLICATE CONNECTION AS A POSSIBLE ERROR (NORMALLY EACH
C       TERMINAL CONTAINS ONLY A SINGLE WIRE). THE PROGRAM SORTS ALL
C       INPUT DATA INTO ALPHABETICAL AND NUMERICAL ORDER. FINALLY, THE
C       PROGRAM SEARCHES FOR SELF CONTAINED SUBHARNESSES WITHIN THE
C       TOTAL HARNESS.  THESE SUBHARNESSES WOULD BE CANDIDATES FOR
C       SEPARATE FABRICATION.

C                           LIST OF SYMBOLS
C                     U1='FROM' UNIT NUMBER
C                     S1='FROM' SIGNAL NUMBER
C                     C1='FROM' CONNECTOR NUMBER
C                     P1='FROM' PIN NUMBER
C                     HN=CABLE NUMBER
C                     U2='TO' UNIT NUMBER
C                     S2='TO' SIGNAL NUMBER
C                     C2='TO' CONNECTOR NUMBER
C                     P2='TO' PIN NUMBER
C                     VO=VOLTAGE ON WIRE
C                     AM=CURRENT ON WIRE
C                     FR=FREQUENCY ON WIRE
C                     AW=WIRE SIZE
C                     CFR=DESCRIPTION OF WIRE FUNCTION AT 'FROM' TERMINAL

      DIMENSION HED(4)
      DIMENSION U1(1400), S1(1400), C1(1400), P1(1400), U2(1400), S2(140
     10), C2(1400), P2(1400), VO(1400), AM(1400), FR(1400), AW(1400), CF
     2R(1400,6), HN(1400), CFRX(6)
      COMMON U1,S1,C1,P1,U2,S2,C2,P2,VO,AM,FR,AW,CFR,HN,J,KY
      DATA E1,E2/6HDUP US,6HDUP CP/
      DATA TST1,TST2/6H000001,6H000002/
      DIMENSION HD(13), EROR(2)
      DATA AST,DOTS/1H*,6H....../
101   FORMAT (A3,3X,A3,3X,A4,3X,A3,2XA5,2X,A3,4X,A3,3X,A4,3X,A3, 2X,A6, 1X
     1A5, 1X,A5, 1X,A5)

102   READ (5,104) KY,KZ,HD
C     THE RUN OPTIONS ARE AS FOLLOWS
C        KY=0 OR BLANK- THE DATA IS SORTED IN ORDER OF 'FROM' UNIT AND
C                          SIGNAL NUMBER -- ALL DATA IS PRINTED OUT
```

```
C        KY=1 - - - - - THE DATA IS SORTED IN ORDER OF 'FROM' UNIT AND
C                       CABLE NUMBER -- ALL DATA IS PRINTED OUT
C        KY=2 - - - - - THE DATA IS SORTED IN ORDER OF 'FROM' UNIT AND
C                       CABLE NUMBER -- ONLY 'FROM' UNIT, CONNECTOR, AND
C                       PIN AND 'TO' UNIT, CONNECTOR, AND PIN ARE
C                       PRINTED OUT.  THIS LISTING IS USEFUL AS A
C                       CHECK-OFF LIST FOR TESTING A COMPLETED HARNESS.
C        KZ=0 OR BLANK- EACH 'FROM' AND 'TO' LIST OF UNIT, SIGNAL,
C                       CONNECTOR, AND PIN IS INVERTED AND ADDED TO THE
C                       LIST IN THE INVERTED FORM (I.E. 'FROM' IS
C                       INVERTED TO 'TO' AND VISA VERSA). THIS CUTS IN
C                       HALF THE NUMBER OF INPUT DATA CARDS REQUIRED TO
C                       DEFINE THE HARNESS.
C        KZ=1 - - - - - THE INPUT IS NOT INVERTED -- THIS IS USEFUL FOR
C                       LISTING THE CONTENTS OF THE DATA DECK WHILE
C                       ORGANIZING THE HARNESS INFORMATION.
C        KZ=2 - - - - - THE INPUT DATA IS INVERTED AS IN KZ=0 AND IN
C                       ADDITION, ALL POSSIBLE COMPLETE AND SEVERABLE
C                       SUBHARNESSES WITHIN THE MAIN HARNESS ARE
C                       IDENTIFIED AND PRINTED OUT.
C        HD - - - - - - A 78 CHARACTER FIELD FOR A HEADING TO BE PRINTED
C                       AT THE TOP OF EACH OUTPUT PAGE

      READ (5,103) HED
C     HED IS THE IDENTIFIER HEADING OF THE INFORMATION FIELD OF EACH
C     WIRE -- NORMALLY THIS WILL BE VOLTS, AMPS, FREQUENCY, AND WIRE
C     SIZE

103   FORMAT (A6,1X,A5,1X,A5,1X,A5)
104   FORMAT (2I1,13A6)
      J=1

105   READ (5,101) U1(J),S1(J),C1(J),P1(J),HN(J),U2(J),S2(J),C2(J),P2(J)
     1,VO(J),AM(J),FR(J),AW(J)
C     THIS STATEMENT READS IN THE (FROM) AND (TO) UNIT,SIGNAL,CONNECTOR,
C     AND PIN INFORMATION AS WELL AS CABLE NUMBER AND WIRE OPERATING
C     CONDITIONS SUCH AS VOLTAGE,CURRENT,FREQUENCY,AND WIRE SIZE.

      IF (U1(J).EQ.AST) GO TO 108
      CALL PACKUP (C1(J))
      CALL PACKUP (C2(J))
      CALL PACKUP (P1(J))
      CALL PACKUP (P2(J))
      IF (KZ.EQ.1) GO TO 106
      J=J+1
      U1(J)=U2(J-1)
      S1(J)=S2(J-1)
      C1(J)=C2(J-1)
      P1(J)=P2(J-1)
      U2(J)=U1(J-1)
      S2(J)=S1(J-1)
      C2(J)=C1(J-1)
      P2(J)=P1(J-1)
      HN(J)=HN(J-1)
      VO(J)=VO(J-1)
      AM(J)=AM(J-1)
      FR(J)=FR(J-1)
      AW(J)=AW(J-1)
106   J=J+1
      IF (J.LT.1400) GO TO 105
      WRITE (6,107)
107   FORMAT (54H0 LIST CONTAINS MORE THAN 1400 TERMINATIONS--PROGRAM TE
     1RMINATED )
      STOP

108   J=J-1
      WRITE (6,109) J
109   FORMAT (14H0LIST CONTAINS,I4,13H TERMINATIONS)
```

```
      CALL ORDER
C     SORTS DATA INTO ORDER

      IF (KZ.EQ.2) CALL SEARCH
C     SEE KZ=2 OPTION DESCRIPTION ABOVE
      CALL DUPCHK
C     CHECKS FOR DUPLICATE TERMINATIONS

      DATA BLANK/1H /
      DO 110 L=1,J
      DO 110 K=1,6
110   CFR(L,K)=BLANK

C     DESCRIPTION OF WIRE FUNCTION AT 'FROM' TERMINAL
111   READ (5,112) (CFRX(K),K=1,6),UX,SX
112   FORMAT (6A6,2X,A3,4X,A3)
      IF (CFRX(1).EQ.AST) GO TO 116
      DO 114 JX=1,J
      IF (UX.NE.U1(JX)) GO TO 114
      IF (SX.NE.S1(JX)) GO TO 114
      DO 113 KX=1,6
113   CFR(JX,KX)=CFRX(KX)
      GO TO 111
114   CONTINUE
      WRITE (6,115) (CFRX(K),K=1,6),UX,SX
115   FORMAT (50H THIS FUNCTION/REMARKS CARD HAS NO UNIT/SIG MATCH(,6A6,
     12X,A3,2X,A3,1H))
      GO TO 111
116   JX=0
117   WRITE (6,118) KY,KZ,HD
118   FORMAT (1H1,2I2,2X,13A6,A2)
      WRITE (6,119) HED,(DOTS,KX=1,22)
119   FORMAT (2H0*,10X,4HFROM,9X,7H*CABLE*,12X,2HTO,11X,1H*,4X,15HCHARAC
     1TERISTICS,5X,1H*,36X,1H*/58H *UNIT. SIG . CONN . PIN *NUMBR* UNIT
     2. SIG . CONN . PIN *,A6,1H.,A5,1H.,A5,1H.,A5,38H*      CIRCUIT FUNC
     3TION/REMARKS         */1H ,21A6,A5)
      KQ=0
120   KQ=KQ+1
      JX=JX+1
      EROR(1)=BLANK
      EROR(2)=BLANK
      IF (AND(TST2,U2(JX)).NE.TST2) GO TO 121
      EROR(2)=E2
121   IF (AND(TST1,U2(JX)).NE.TST1) GO TO 122
      EROR(1)=E1
122   IF (U1(JX).EQ.U1(JX-1)) GO TO 123
      WRITE (6,124) (BLANK,KQ=1,40)
      KQ=KQ+2
123   IF (KY.LT.2) WRITE (6,124) U1(JX),S1(JX),C1(JX),P1(JX),HN(JX),U2(J
     1X),S2(JX),C2(JX),P2(JX),VD(JX),AM(JX),FR(JX),AW(JX),(CFR(JX,JY),JY
     2=1,6),EROR
      IF (KY.EQ.2) WRITE (6,124) U1(JX),BLANK,C1(JX),P1(JX),BLANK,U2(JX)
     1,BLANK,C2(JX),P2(JX),(BLANK,K3Q=1,12)
124   FORMAT (2H *,A3,3H . ,A3,3H . ,A4,3H . ,A3,2H *,A5,2H* ,A3,4H  . ,
     1A3,3H . ,A4,3H . ,A3,2H *A6,1H.,A5,1H.,A5,1H.,A5,1H*,6A6,1H*,2A6)
      IF (JX.EQ.J) GO TO 125
      IF (KQ.LT.51) GO TO 120
      GO TO 117
125   GO TO 102
      END
```

```
$IBFTC DUP      LIST,DECK

      SUBROUTINE DUPCHK
C     THIS SUBROUTINE SEARCHES WITHIN EACH UNIT NUMBER FOR DUPLICATE

C     SIGNAL NUMBERS AND FOR DUPLICATE PIN NUMBERS ON EACH CONNECTOR.
      DATA ONE/6H000001/
      DATA TWO/6H000002/
      DATA BLANK/1H /
      DIMENSION U1(1400), S1(1400), C1(1400), P1(1400), U2(1400), S2(140
     10), C2(1400), P2(1400), VO(1400), AM(1400), FR(1400), AW(1400), CF
     2R(1400,6), HN(1400), CFRX(6)
      COMMON U1,S1,C1,P1,U2,S2,C2,P2,VO,AM,FR,AW,CFR,HN,J

      DO 202 K=2,J
      IF (S1(K).EQ.BLANK) GO TO 202

C     BLANK SIGNAL WORDS OR BLANK PIN WORDS ARE IGNORED.
      IF (U1(K).EQ.U1(K-1).AND.S1(K).EQ.S1(K-1)) GO TO 201

C     CHECK FOR DUPLICATE UNIT-SIGNAL

      GO TO 202
201   U2(K)=OR(U2(K),ONE)
      U2(K-1)=OR(U2(K-1),ONE)

C     A DUPLICATE UNIT-SIGNAL EXISTS.  FLAG BOTH LIST ENTRIES.
202   CONTINUE
      KEND=0
203   KSTT=1+KEND
      DO 204 M=KSTT,J
      IF (U1(M).EQ.U1(KSTT)) GO TO 204
      KEND=M-1
      GO TO 205
204   CONTINUE
      KEND=J
205   K1=KEND-1
      DO 208 M=KSTT,K1
      M1=M+1
      IF (P1(M).EQ.BLANK) GO TO 208

      DO 207 MX=M1,KEND
      IF (C1(M).EQ.C1(MX).AND.P1(M).EQ.P1(MX)) GO TO 206

C     CHECK FOR DUPLICATE CONNECTOR-PIN

      GO TO 207
206   U2(M)=OR(U2(M),TWO)
      U2(MX)=OR(U2(MX),TWO)
C     A DUPLICATE CONNECTOR-PIN EXISTS. FLAG BOTH LIST ENTRIES.
207   CONTINUE
208   CONTINUE
      IF (KEND.NE.J) GO TO 203
      RETURN
      END
```

```
$IBFTC ORDR     LIST,DECK

      SUBROUTINE ORDER
C     THIS SUBROUTINE SORTS THE WIRE LIST INTO ORDER ACCORDING TO
C     TWO OPTIONS
C           KQ.EQ.0 OPTION -- THE LIST IS SORTED ACCORDING TO UNIT
C                             AND SIGNAL NUMBER
```

```
C         KQ.NE.0 OPTION -- THE LIST IS SORTED ACCORDING TO UNIT
C                           AND CABLE NUMBER
      DIMENSION U1(1400), S1(1400), C1(1400), P1(1400), U2(1400), S2(140
     10), C2(1400), P2(1400), VO(1400), AM(1400), FR(1400), AW(1400), CF
     2R(1400,6), HN(1400), CFRX(6)
      COMMON U1,S1,C1,P1,U2,S2,C2,P2,VO,AM,FR,AW,CFR,HN,J,KQ
      DO 301 JX=1,J

      HN(JX)=ARS(1,HN(JX))
      CALL PACK1 (U1(JX),S1(JX),CFR(JX,1))

C     PACK1 PACKS UNIT AND SIGNAL NUMBER INTO ONE WORD FOR SORTING
301   U1(JX)=ARS(1,U1(JX))
302   KCHECK=0
      DO 305 K=2,J
      IF (KQ.EQ.0) GO TO 303
      IF (U1(K).GT.U1(K-1).OR.(U1(K).EQ.U1(K-1).AND.HN(K).GE.HN(K-1))) G
     1O TO 305
      GO TO 304

303   IF (CFR(K,1).GE.CFR(K-1,1)) GO TO 305
C     THE FOLLOWING GROUPS EXCHANGE THE (K) AND (K-1) LIST ENTRIES

C     KCHECK.EQ.1 INDICATES LIST IS NOT YET IN ORDER
304   KCHECK=1
      TEMP=U1(K)
      U1(K)=U1(K-1)
      U1(K-1)=TEMP
C
      TEMP=S1(K)
      S1(K)=S1(K-1)
      S1(K-1)=TEMP
C
      TEMP=C1(K)
      C1(K)=C1(K-1)
      C1(K-1)=TEMP
C
      TEMP=P1(K)
      P1(K)=P1(K-1)
      P1(K-1)=TEMP
C
      TEMP=U2(K)
      U2(K)=U2(K-1)
      U2(K-1)=TEMP
C
      TEMP=S2(K)
      S2(K)=S2(K-1)
      S2(K-1)=TEMP
C
      TEMP=C2(K)
      C2(K)=C2(K-1)
      C2(K-1)=TEMP
C
      TEMP=P2(K)
      P2(K)=P2(K-1)
      P2(K-1)=TEMP
C
      TEMP=VO(K)
      VO(K)=VO(K-1)
      VO(K-1)=TEMP
C
      TEMP=AM(K)
      AM(K)=AM(K-1)
      AM(K-1)=TEMP
C
      TEMP=FR(K)
      FR(K)=FR(K-1)
      FR(K-1)=TEMP
```

```
C
      TEMP=AW(K)
      AW(K)=AW(K-1)
      AW(K-1)=TEMP

      TEMP=CFR(K,1)
      CFR(K,1)=CFR(K-1,1)
      CFR(K-1,1)=TEMP
C
      TEMP=HN(K)
      HN(K)=HN(K-1)
      HN(K-1)=TEMP
C
305   CONTINUE
      IF (KCHECK.EQ.1) GO TO 302
      DO 306 JX=1,J
      U1(JX)=ALS(1,U1(JX))
306   HN(JX)=ALS(1,HN(JX))
      RETURN
      END
```

```
$IBFTC PACK     LIST,DECK

      SUBROUTINE PACK1 (A,B,C)
C     THIS SUBROUTINE COMBINES UNIT AND SIGNAL WORDS INTO A SINGLE
C     WORD FOR SORTING BY ORDER SUBROUTINE
      DATA B1,B3/0770000000000,6H 00000/
      AX=A
      K=0
401   IF (AND(B1,AX).NE.B3) GO TO 402
      K=K+6
      AX=ALS(6,AX)
      GO TO 401
402   AX=ARS(K,AX)
      BX=B
      K=0
403   IF (AND(B1,BX).NE.B3) GO TO 404
      K=K+6
      BX=ALS(6,BX)
      GO TO 403
404   BX=ARS(K,BX)
      C=OR(ALS(18,ARS(18,AX)),ARS(18,BX))
      RETURN
      END
```

```
$IBFTC PACKP    LIST,DECK

      SUBROUTINE PACKUP (E)
C     THIS SUBROUTINE LEFT ADJUSTS DATA WORDS,I.E. UNIT, SIGNAL,
C     CONNECTOR, AND PIN DESIGNATORS. LEFT HAND BLANKS ARE PURGED

C     TO ALIGN DATA PRIOR TO SORTING.
      DIMENSION F(4)
      DATA BLANK,S1/6H 00000,0770000000000/
      DO 501 K=1,4
      F(K)=AND(S1,E)
```

```
501   E=ALS(6,E)
      DO 502 L=1,3
      DO 502 K=1,3
      IF (F(K).NE.BLANK) GO TO 502
      T=F(K)
      F(K)=F(K+1)
      F(K+1)=T
502   CONTINUE
      DO 503 K=1,4
      L=5-K
503   E=OR(ARS(6,E),F(L))
      RETURN
      END
```

```
$IBFTC SEARCH  LIST,DECK

      SUBROUTINE SEARCH
C     THIS SUBROUTINE TRACES THROUGH THE DATA TO IDENTIFY WIRE
C     SUB-HARNESS POSSIBILITIES.  IN SEARCHING THROUGH IT DISCOUNTS
C     WIRES TERMINATED ON A THREADED STUD (WHICH MAY ACCOMODATE MORE
C     THAN ONE WIRE) BY IGNORING THE DESIGNATION TB (FOR TERMINAL BLOCK)
C     IN EITHER CONNECTOR COLUMN.  THE TERMINAL BLOCK DESIGNATION MAY
C     CONTAIN FOUR CHARACTERS TBXX WHERE XX MAY BE ANY ARBITRARY
C     IDENTIFIER.
      COMMON U1,S1,C1,P1,U2,S2,C2,P2,VO,AM,FR,AW,CFR,HN,J,KQ
      DIMENSION U1(1400), S1(1400), C1(1400), P1(1400), U2(1400), S2(140
     10), C2(1400), P2(1400), VO(1400), AM(1400), FR(1400), AW(1400), CF
     2R(1400,6), HN(1400), CFRX(6)
      N=1
      CFR(1,3)=U1(1)
      CFR(1,4)=C1(1)
      CFR(1,5)=U2(1)
      CFR(1,6)=C2(1)
      DO 602 K=2,J
      DO 601 KN=1,N
      IF (U1(K).EQ.CFR(KN,3).AND.C1(K).EQ.CFR(KN,4).AND.U2(K).EQ.CFR(KN,
     15).AND.C2(K).EQ.CFR(KN,6)) GO TO 602
601   CONTINUE
      N=N+1
      CFR(N,3)=U1(K)
      CFR(N,4)=C1(K)
      CFR(N,5)=U2(K)
      CFR(N,6)=C2(K)
602   CONTINUE
      DATA TB,SQ/6HTB0000,077770000000/
      DATA BLANK/1H /
      DO 603 K=1,N
603   CFR(K,2)=BLANK
      DO 604 K=1,N
      IF (CFR(K,4).EQ.BLANK.OR.CFR(K,6).EQ.BLANK) CFR(K,2)=TB
604   IF (AND(SQ,CFR(K,4)).EQ.TB.AND.AND(SQ,CFR(K,6)).NE.TB) CFR(K,2)=TB
      WRITE (6,605)
605   FORMAT (97H1THE FOLLOWING IS A CONDENSED LIST OF UNITS AND CONNECT
     1ORS BETWEEN WHICH AT LEAST ONE WIRE EXISTS/96H TERMINAL BLOCKS (TB
     2) AND BLANKS ARE TREATED AS CABLE END POINTS AND ARE MARKED WITH A
     3N ASTERISK/1H0,6X,22HUNIT-CONN*TO*UNIT-CONN)
      DATA AST/6H     */
      DO 606 K=1,N
606   CFR(K,1)=BLANK
      DO 607 K=1,N
      IF (AND(SQ,CFR(K,4)).EQ.TB.OR.AND(SQ,CFR(K,6)).EQ.TB) CFR(K,1)=AST
      IF (CFR(K,2).EQ.TB) CFR(K,1)=AST
```

```
607   CONTINUE
      WRITE (6,608) (CFR(K,1),(CFR(K,KN),KN=3,6),K=1,N)
608   FORMAT (1X,5A6)
      WRITE (6,609)
609   FORMAT (66HLTHE FOLLOWING SUB HARNESSES HAVE BEEN GLEANED FROM THE
     1 ABOVE LIST)
      KF=0
      KB=N+1
610   KA=0
      KC=KB-1
611   KE=0
      DO 615 K=1,N
      IF (CFR(K,2).EQ.TB) GO TO 615
      IF (KA.EQ.1) GO TO 612
      KA=1
      GO TO 614
612   DO 613 KD=KB,KC
      IF (CFR(K,3).EQ.CFR(KD,3).AND.CFR(K,4).EQ.CFR(KD,4).AND.AND(SQ,CFR
     1(KD,4)).NE.TB) GO TO 614
      IF (CFR(K,3).EQ.CFR(KD,5).AND.CFR(K,4).EQ.CFR(KD,6).AND.AND(SQ,CFR
     1(KD,6)).NE.TB) GO TO 614
      IF (CFR(K,3).EQ.CFR(KD,5).AND.CFR(K,4).EQ.CFR(KD,6).AND.CFR(K,5).E
     1Q.CFR(KD,3).AND.CFR(K,6).EQ.CFR(KD,4).AND.AND(SQ,CFR(K,4)).EQ.TB.A
     2ND.AND(SQ,CFR(K,6)).EQ.TB) GO TO 614
613   CONTINUE
      GO TO 615
614   KC=KC+1
      CFR(KC,3)=CFR(K,3)
      CFR(KC,4)=CFR(K,4)
      CFR(KC,5)=CFR(K,5)
      CFR(KC,6)=CFR(K,6)
      CFR(K,2)=TB
      KE=1
      GO TO 615
615   CONTINUE
      IF (KA.EQ.0) RETURN
      IF (KE.EQ.1) GO TO 611
      KF=KF+1
      WRITE (6,616) KF
616   FORMAT (12HLSUB HARNESSI4,5X,24HUNIT-CONN* TO *UNIT-CONN)
      WRITE (6,617) ((CFR(K,KD),KD=3,6),K=KB,KC)
617   FORMAT (22X,A3,1X,A4,6X,A3,1X,A4)
      GO TO 610
      END
```

APPENDIX B

HYPOTHETICAL EXAMPLE TO ILLUSTRATE USE OF FORTRAN PROGRAM

The electrical system shown in figure 13 will be used to illustrate how the FORTRAN program is used. The three major components, identified as units 1, 2, and 3 are interconnected by six cables (101 to 106). The cables terminate in connectors (J1 or J2) or terminal boards (TB-1, TB-3). In all, there are 14 conductors, each with two terminations and a shield over cable 101. The conductor information was listed on data sheets shown in figures 14 and 15, and data cards were key punched accordingly.

The card file for the wire lists is organized as shown in figure 16. The following brief explanation of the key cards will clarify their function:

(1) The deck of cards comprising the FORTRAN program (appendix A) or the shorter binary deck is in front.

(2) The title card, figure 17(a), provides the title of the program plus any information the author may wish to include in the heading such as a distribution list, revision information, limitations as to use of the printout, etc. A 78-character field is available for use in the heading which is automatically printed at the top of each page. The first two characters in the heading, at the extreme left of the card, are reserved to specify the run option to the computer. These two spaces are punched with either a zero (or blank), 1, or 2. Table II describes the choice of options.

(3) Following the title card, a Headings card (fig. 17(b)) is inserted to call out the column headings under CHARACTERISTICS. The headings used for the Brayton engine (VOLTS, AMPS, FREQ, and AWG) are optional and can be modified to suit the individual application.

(4) This deck of cards (CHARACTERISTICS) lists all conductor data except FUNCTION.

(5) The card with an asterisk (*) in the first column signals the end of the CHARACTERISTICS deck.

(6) The following deck comprises the FUNCTION information for the individual conductors. Each card in this deck is keyed to its counterpart by the UNIT and SIGNAL NO.

(7) The final asterisk card signals the end of data to be fed to the computer.

The printout of figure 18 was obtained by running the data cards of figure 16 through the computer. Option 02 was selected for this run to illustrate the subharness routine and the wiring tabulation. Page 1 of the printout calls out the three subharnesses that may be fabricated individually to make up the complete harness. At the top of page 2 of the printout is the run option as well as all the other information punched on the title card. On the same page under CHARACTERISTICS the optional subheadings punched on the card of figure 17(b) are printed out.

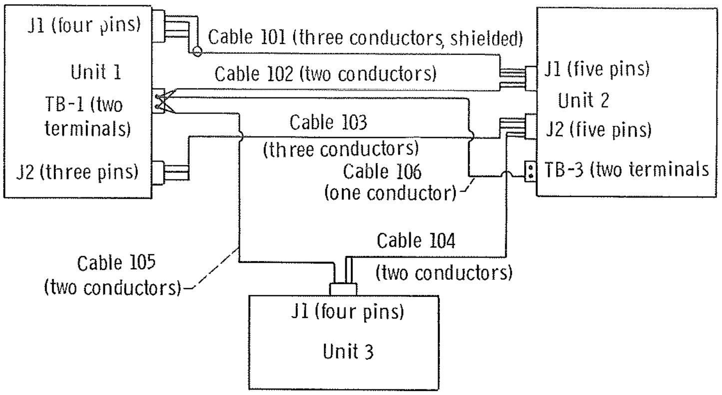


Figure 13. - Electrical system block diagram.

TITLE HYPOTHETICAL SYSTEM

PROJECT NUMBER

ANALYST

SHEET 1 OF 2

STATEMENT NUMBER | CONT | FORTRAN STATEMENT | IDENTIFICATION

FROM				X CABLE X	TO				X CHARACTERISTICS			
UNIT X	SIG X	CONN X	PIN X	NO X	UNIT X	SIG X	CONN X	PIN X	VOLTS X	AMPS X	EREQ X	AWG
1	1	J1	A	101/4	2	1	J1	A	120	12	400	14
1	2	J1	B	101/4	2	2	J1	B	120	12	400	14
1	3	J1	C	101/4	2	3	J1	C	120	12	400	14
1	4	J2	A	103/3	2	6	J2	A	+28	18	DC	10
1	5	J2	B	103/3	2	7	J2	B	COMM	10	DC	10
1	6	J2	C	103/3	2	8	J2	C	-28	8	DC	10
1	7	TB1	1	102/2	2	4	J1	D	120		400	16
1	8	TB1	2	102/2	2	5	J1	E	120		400	16
1	9	TB1	1	105/2	3	1	J1	A	120		400	16
1	10	TB1	2	105/2	3	2	J1	B	120		400	16
2	9	J2	D	104/2	3	3	J1	C	+28		DC	16
2	10	J2	E	104/2	3	4	J1	D	-28		DC	16
1	11	TB1	1	106/1	2	11	TB3	2	120		400	16
1	12	J1	D	101/4	2				GND			

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Figure 14. - Characteristics data sheet.

TITLE HYPOTHETICAL SYSTEM | PROJECT NUMBER | ANALYST | SHEET 2 OF 2

STATEMENT NUMBER | CONT | FORTRAN STATEMENT | IDENTIFICATION

CIRCUIT FUNCTION/REMARKS	UNIT	SIG
POWER OUTPUT TO UNIT 2 PHASE A	1	1
POWER OUTPUT TO UNIT 2 PHASE B	1	2
POWER OUTPUT TO UNIT 2 PHASE C	1	3
DC POWER INPUT FROM UNIT 2 (POS)	1	4
DC POWER INPUT FROM UNIT 2 (NEUT)	1	5
DC POWER INPUT FROM UNIT 2 (NEG)	1	6
VOLTAGE SENSING, PHASE A	1	7
VOLTAGE SENSING, PHASE B	1	8
VOLTAGE SENSING, PHASE A	1	9
VOLTAGE SENSING, PHASE B	1	10
PHASE A REFERENCE	1	11
SHIELD	1	12
POWER INPUT FROM UNIT 1, PHASE A	2	1
POWER INPUT FROM UNIT 1, PHASE B	2	2
POWER INPUT FROM UNIT 1, PHASE C	2	3
VOLTAGE SENSING, PHASE A	2	4
VOLTAGE SENSING, PHASE B	2	5
DC POWER OUTPUT TO UNIT 1, POS 28V	2	6
DC POWER OUTPUT TO UNIT 1, NEUTRAL	2	7
DC POWER OUTPUT TO UNIT 1, NEG 28V	2	8
VOLTAGE SENSING, POS 28V.	2	9
VOLTAGE SENSING, NEG 28V.	2	10
PHASE A REFERENCE	2	11

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Figure 15. - Function data sheet.

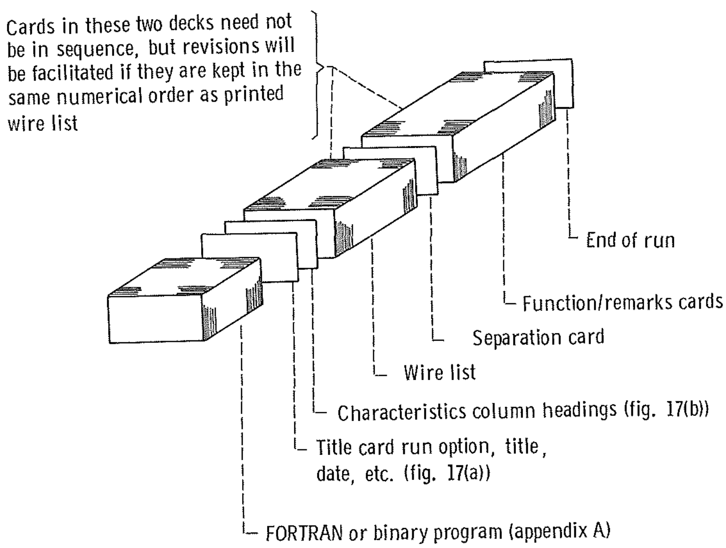
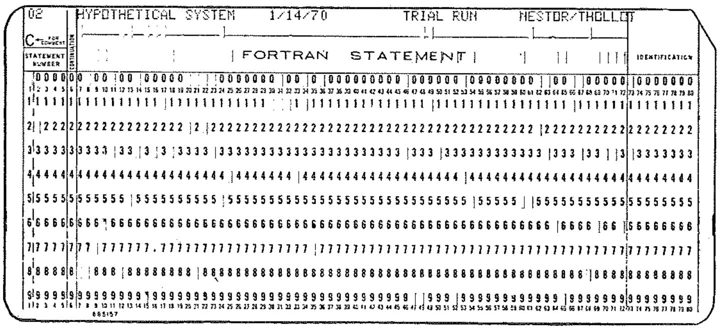
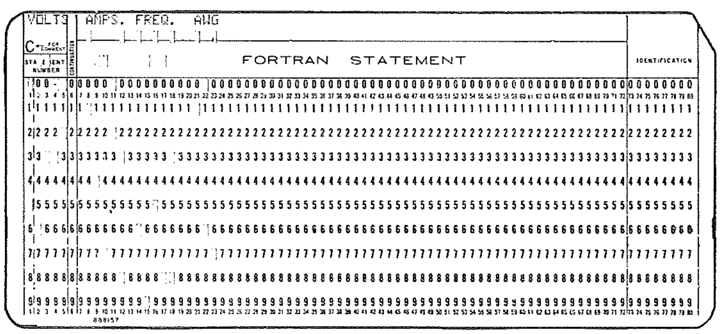


Figure 16. - Organization of card file for wire list tabulation.



(a) Title and run option.



(b) Characteristics.

Figure 17. - Headings cards.

TABLE II. - LIST OF AVAILABLE OPTIONS FOR PRINTOUT OF THE WIRE LIST

Run option		Computer printout
Column 1	Column 2	
0	0	UNIT/SIGNAL NO. sequence, with inversion of FROM and TO data (This option prints out both terminations of each conductor in alpha-numerical sequence.)
0	1	UNIT/SIGNAL NO. sequence, without inversion of FROM and TO data (This option prints out only the origin of each conductor in sequence. Destination of each conductor will print out only on the same line as the origin.)
1	0	UNIT/CABLE NO. sequence with UNIT/SIGNAL NO. inversion
1	1	UNIT/CABLE NO. sequence without UNIT/SIGNAL NO. inversion
2	0	UNIT/SIGNAL NO. sequence with UNIT/SIGNAL NO. inversion (All columns are blank except UNIT, CONNECTOR, PIN. Useful for continuity measurement, resistance, and insulation tests.)
2	1	UNIT/SIGNAL NO. sequence without UNIT/SIGNAL NO. inversion (Similar to 2-0.)
0	2	Subharness Routine (Printout is in the same format as in option 0-0, but tabulation is preceded by a listing of all the individual subharnesses into which the list may be separated. Each subharness may be fabricated as a separate unit for individual installation to complete the electrical system. See example in fig. 18.)

```
UNUSED CORE                                   13027 THRU  14025


LIST CONTAINS  28 TERMINATIONS
Q00000  1   J1      2   J1
Q00000  1   J2      2   J2
TB0000  1   TB1     2   J1
TB0000  1   TB1     3   J1
Q00000  1   TB1     2   TB3
TB0000  1   J1      2
TB0000  2           1   J1
Q00000  2   J1      1   J1
Q00000  2   J1      1   TB1
Q00000  2   J2      1   J2
Q00000  2   J2      3   J1
Q00000  2   TB3     1   TB1
Q00000  3   J1      1   TB1
Q00000  3   J1      2   J2

SUB HARNESS   1        UNIT-CONN* TO *UNIT-CONN
                          1 J1          2 J1
                          2 J1          1 J1
                          2 J1          1 TB1

SUB HARNESS   2        UNIT-CONN* TO *UNIT-CONN
                          1 J2          2 J2
                          2 J2          1 J2
                          2 J2          3 J1
                          3 J1          1 TB1
                          3 J1          2 J2

SUB HARNESS   3        UNIT-CONN* TO *UNIT-CONN
                          1 TB1         2 TB3

SUB HARNESS   4        UNIT-CONN* TO *UNIT-CONN
                          2 TB3         1 TB1
```

```
 0 2      HYPOTHETICAL SYSTEM   POWER AND CONTROL HARNESS

*          FROM          *CABLE*              TO            *    CHARACTERISTICS     *                                         *
*UNIT. SIG . CONN . PIN *NUMBR* UNIT . SIG . CONN . PIN *VOLTS .AMPS..FREQ.. AWG *      CIRCUIT FUNCTION/REMARKS           *
.........................................................................................................................................
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*  1 .   1 . J1    . A   *101/4*  2   .   1 . J1    . A   *  120 .  12 . 400 .  14 * POWER OUTPUT TO UNIT 2, PHASE A        *
*  1 .   2 . J1    . B   *101/4*  2   .   2 . J1    . B   *  120 .  12 . 400 .  14 * POWER OUTPUT TO UNIT 2, PHASE B        *
*  1 .   3 . J1    . C   *101/4*  2   .   3 . J1    . C   *  120 .  12 . 400 .  14 * POWER OUTPUT TO UNIT 2, PHASE C        *
*  1 .   4 . J2    . A   *103/3*  2   .   6 . J2    . A   *  +28 .  18 .  DC .  10 * DC POWER INPUT FROM UNIT 2 (POS)       *
*  1 .   5 . J2    . B   *103/3*  2   .   7 . J2    . B   * COMM .  10 .  DC .  10 * DC POWER INPUT FROM UNIT 2 (NEUT)      *
*  1 .   6 . J2    . C   *103/3*  2   .   8 . J2    . C   *  -28 .   8 .  DC .  10 * DC POWER INPUT FROM UNIT 2 (NEG)       *
*  1 .   7 . TB1   . 1   *102/2*  2   .   4 . J1    . D   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE A               *      DJP CP
*  1 .   8 . TB1   . 2   *102/2*  2   .   5 . J1    . E   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE B               *      DJP CP
*  1 .   9 . TB1   . 1   *105/2*  3   .   1 . J1    . A   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE A               *      DJP CP
*  1 .  10 . TB1   . 2   *105/2*  3   .   2 . J1    . B   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE B               *      DJP CP
*  1    11 . TB1   . 1   *106/1*  2   .  11 . TB3   . 2   *  120 .     . 400 .  16 * PHASE A REFERENCE                      *      DJP CP
*  1 .  12 . J1    . D   *101/4*  2   .     .       .     *  GND .     .      .    * SHIELD                                 *
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*  2 .      .       .    *101/4*  1   .  12 . J1    . D   *  GND .     .      .    *                                         *
*  2 .   1 . J1    . A   *101/4*  1   .   1 . J1    . A   *  120 .  12 . 400 .  14 * POWER INPUT FROM UNIT 1, PHASE A       *
*  2 .   2 . J1    . B   *101/4*  1   .   2 . J1    . B   *  120 .  12 . 400 .  14 * POWER INPUT FROM UNIT 1, PHASE B       *
*  2 .   3 . J1    . C   *101/4*  1   .   3 . J1    . C   *  120 .  12 . 400 .  14 * POWER INPUT FROM UNIT 1, PHASE C       *
*  2 .   4 . J1    . D   *102/2*  1   .   7 . TB1   . 1   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE A               *
*  2 .   5 . J1    . E   *102/2*  1   .   8 . TB1   . 2   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE B               *
*  2 .   6 . J2    . A   *103/3*  1   .   4 . J2    . A   *  +28 .  18 .  DC .  10 * DC POWER OUTPUT TO UNIT 1, POS 28V     *
*  2 .   7 . J2    . B   *103/3*  1   .   5 . J2    . B   * COMM .  10 .  DC .  10 * DC POWER OUTPUT TO UNIT 1, NEUTRAL     *
*  2 .   8 . J2    . C   *103/3*  1   .   6 . J2    . C   *  -28 .   8 .  DC .  10 * DC POWER OUTPUT TO UNIT 1, NEG 28 V*
*  2 .   9 . J2    . D   *104/2*  3   .   3 . J1    . C   *  +28 .     .  DC .  16 * VOLTAGE SENSING, POS. 28V.             *
*  2 .  10 . J2    . E   *104/2*  3   .   4 . J1    . D   *  -28 .     .  DC .  16 * VOLTAGE SENSING, NEG. 28V.             *
*  2 .  11 . TB3   . 2   *106/1*  1   .  11 . TB1   . 1   *  120 .     . 400 .  16 * PHASE A REFERENCE                      *
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*     .     .       .    *     *       .     .       .    *       .     .      .    *                                         *
*  3 .   1 . J1    . A   *105/2*  1   .   9 . TB1   . 1   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE A               *
*  3 .   2 . J1    . B   *105/2*  1   .  10 . TB1   . 2   *  120 .     . 400 .  16 * VOLTAGE SENSING, PHASE B               *
*  3 .   3 . J1    . C   *104/2*  2   .   9 . J2    . D   *  +28 .     .  DC .  16 * VOLTAGE SENSING, POS. 28 V             *
*  3 .   4 . J1    . D   *104/2*  2   .  10 . J2    . E   *  -28 .     .  DC .  16 * VOLTAGE SENSING, NEG. 28V              *

*01* UNIT05, EOF.                                                     REC=  00000 FIL=  00002
```

Figure 18. - Wire list using option 02.

The wire list prints out all the conductor information in alpha-numerical sequence starting with UNIT 1, SIGNAL 1, and continues through to the last conductor, UNIT 3, SIGNAL 4. In all, there are 28 lines of wiring information printed out for the 14 conductors including the shield. If option 0-1 were used instead, the inversion feature would be omitted and only 14 lines of information would appear for the 14 conductors.

In the column at the extreme right on page 2, DUP CP (duplicate connector and pin) point out that terminal board TB-1 has more than one conductor terminating on pins 1 and 2 and may be in error. Examination of figure 13 shows that there are actually two conductors connected to each of the two terminals of TB-1 and, therefore, this is not an error.

In the same manner, if DUP US appears in the right-hand column, it indicates a duplication of unit and signal numbers which should also be verified for possible error.

It may also be noted that the shield on Cable 101 (unit 1, signal 12) runs to unit 2 but is not terminated at that end. It, therefore, appears again under the unit 2 listing as the first line since it lacks a signal, connector, and pin number, as well as the function information. These omissions signal that a connection is missing. In this case, the omission is intentional; however, all such omissions are similarly identified as possible wiring errors.

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