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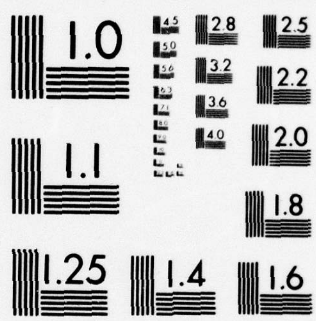

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RPV ELECTRIC POWER SYSTEM STUDY
Phase II: Hot Bench Mockup Development

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The RPV Electric Power Study explores ways for exploiting technology and resolving critical issues affecting the electrical subsystems of remotely piloted vehicles. The objective is to define electrical components and system concepts that offer significant cost, weight and performance improvements over present day systems. Phase I is an assessment of technologies capable of benefitting RPV electrical systems. Phase II develops a plan to transfer viable technologies into RPV systems.

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The Phase II approach is to first develop a complete picture of the needs, requirements and constraints on a laboratory hot bench mockup. After considering concept alternatives and related design factors, a modular concept is selected that is adaptable to all classes of RPV. Preliminary designs of a mockup for each of the four classes of RPV are described, that is:

- Advanced multi-mission RPV,
- High-altitude long endurance RPV,
- Mini RPV,
- Tactical expendable drone system (TEDS).

A mockup development plan is presented for each RPV class including a schedule, budgetary estimate of labor and material costs, list of components and a list of manufacturers capable of developing those items requiring development. Also included is a guide for developing test programs for RPV electrical systems.

PREFACE

This document is a technical report for the second phase of a two-phase study entitled "RPV Electric Power System Study; Phase 2: Hot Bench Mockup Development". The work was performed by the Aerospace Division of Teledyne Ryan Aeronautical, San Diego, California under Air Force contract No. F33615-76-C-2069.

The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio 45433, by Mr. Duane Fox (POP-2) Project Engineer.

The Principal Investigator was Frederic Miller. Also contributing significantly to the work was Lou Pico, Advanced Systems.

This manuscript was released by the author in August 1978.

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SECTION I

INTRODUCTION

1.1 BACKGROUND

This report concludes a two-phase study of ways of exploiting technology and resolving the critical issues affecting the electrical systems of future RPVs (remotely piloted vehicles). The Phase I effort (Reference 1) assessed the capability of current and developing technologies to alleviate RPV electrical problems include lack of adequate generated power, high acquisition and life cycle costs, wiring and interconnect difficulties, poor reliability and maintainability, and excessive complexity, weight, and volume. Another factor was the constant dilemma designers face in trying to satisfy military specifications and standards that are not written for RPVs.

The first phase defined electrical components and system architectures that will offer significant cost and performance improvements over present RPV systems. This includes acquisition and life cycle costs, reliability, maintainability, weight and volume.

The scope of the study is limited to four classes of RPV:

1) Advanced multi-mission tactical RPV (ARPV)
2) High altitude, long endurance RPV (HALE)
3) Mini-RPV
4) Tactical Expendable Drone System (TEDS)

The scope implicitly eliminates targets and cruise missiles from consideration. However, the range of RPV classes is broad enough that little generality is lost by their exclusion. The conclusions apply largely to them also. The study also limits consideration to the next generation of RPV. This implies projecting available "off-the-shelf" technology into the 1983 - 85 time period.

1.2 PROGRAM OBJECTIVES AND SCOPE

As the sequel to the above Technology Assessment, the objective of the Phase 2 effort is to develop plans for developing hot bench mockups for demonstrating the capabilities of advanced RPV electrical system technology as recommended in Phase 1. The plans encompass a preliminary design of a hot bench mockup, the manpower, schedule, and preliminary estimates of costs for both the individual component developments and the overall mockup, and a list of potential alternative vendors for components requiring additional development.

1. Miller, F. L., "RPV Electric Power System Study, Phase 1 Technology Assessment", AFAPL-TR-78-38

The purpose of the hot mockup, in addition to demonstrating technology, is to establish laboratory techniques to verify predicted performance, limitations, and constraints and to discover unforeseen problems which may require further development. The mockup will serve as a test bed for evaluating future concepts and components and for demonstrating the value of tailoring standards and specifications for RPVs. It will operate in the laboratory environment at AFAPL.

1.3 METHOD OF APPROACH

The method of approach to develop a plan is indicated in the work flow diagram of Figure 1. The Phase 2 work starts by defining the mockup in terms of requirements, conceptual approaches, and a recommended preliminary design. This task includes developing overall requirements from the Phase I results and from the laboratory facilities capabilities, interfaces, available space, and method of operation (see Section 3). The design considerations are discussed in Section 4.1. The recommended approach is described in Section 4.2. Since some of the Phase I concepts require further development, capable vendors are identified as potential sources. Then two plans are developed. One is a plan for developing and fabricating the hot bench mockups (Section 5.2). The other is a plan for testing and demonstrating RPV electrical systems (Section 5.3).

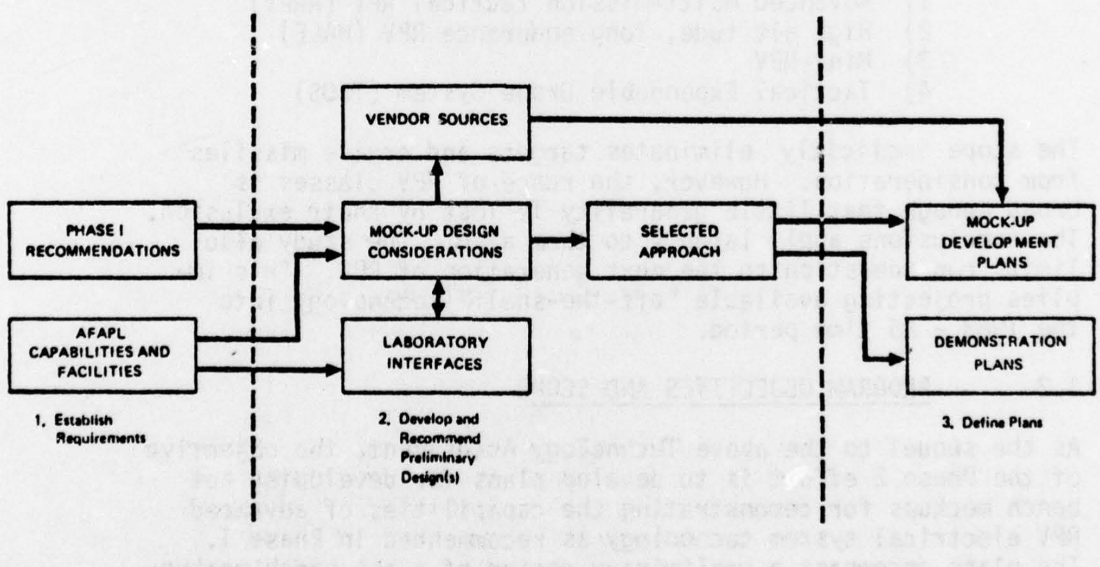


Figure 1. Phase II Work Flow Diagram

SECTION II

SUMMARY

2.1 OVERVIEW

The overall study addresses the problems and technology applications in RPV electrical power systems. Today's systems are relatively old off-the-shelf hardware that is becoming inadequate for the tasks and is causing operational difficulties in performance, maintenance, and life cycle costs. The primary objective of the study is to define the available and developing technologies that can be exploited to resolve the problems and provide significant cost and performance improvements over present day systems. Some specific problems caused by the off-the-shelf design philosophy are the lack of adequate generated power, interconnection difficulties, reliability and maintainability problems such as associated with batteries, and high life cycle costs. A secondary objective is weight and volume improvements.

The study is carried out in two phases. The first phase, reported in Reference 1, assesses the capabilities of available and developing technologies in alleviating the problems and deficiencies in current RPVs and for optimizing future RPVs. The second phase, reported in this volume, develops a plan to establish laboratory techniques to demonstrate and verify the feasibility of the technology applications derived in Phase I. This section summarizes the results of the Phase 2 effort. The Phase 1 summary has been reproduced and included for easy reference and to provide continuity.

2.2 PHASE 2 SUMMARY

The Phase 2 effort was carried on in three parts: (1) completing the mockup requirements, (2) developing a recommended concept, and (3) defining the development and demonstration plans. The requirements include those of the RPV electrical systems to be demonstrated (for each of the four classes) and those of the laboratory facilities, in terms of interfaces, capabilities, limitations, space, operating procedures, and desirable characteristics. The facilities comprise three generator drive stands, load banks, data acquisition and processing system, and the laboratory area. The most desirable characteristics of a hot bench mockup are that it be adaptable to all RPV classes, modular, provide ready access, easy to modify and maintain, portable or easily relocatable, simple, and relatively inexpensive.

The selected configuration is neither an airframe shell nor a mockup. Since this approach offers little benefit to concept demonstration and test and would provide little utility and flexibility as a tool. Instead it consists of a series of modular boards that attach to an expandable frame, which can be either wall-mounted or free standing. The number of boards needed depends on the RPV class. Each board is 3 feet wide and 2 to 4 feet high, and it is made of aluminum sheet. The set of connectors that provides the interface to the laboratory power load, control, and data acquisition subsystems would be common to all classes of RPV. A small system could be mounted on one or two boards. A large system would be mounted on three (or more) boards, for example: one for regulation, power conditioning, and feeder bus control, the second for load distribution and control, and the third for loads. System boards and blanks can be easily stored. The adaptability of the concept allows its use for systems other than RPV, such as cruise missiles and manned aircraft. Therefore, it can provide considerable utility for AFAPL applications.

2.3 PHASE 1 SUMMARY

The Phase 1 report summary is reproduced here in its entirety as a ready reference to help provide continuity with the Phase 2 effort.

The scope of Phase 1 encompasses all aspects of electric power systems: generation, control, conversion, distribution, and interfaces. The scope is limited to four classes of RPV: (1) advanced tactical multi-mission RPV (ARPV), (2) high altitude, long endurance (HALE) RPV, (3) Mini-RPV, and (4) tactical expendable decoy system (TEDS). Four preliminary tasks lay the groundwork for the analytical class studies, which (1) establish a basis for projecting future electrical requirements, (2) define the most critical problem areas in RPVs today and potentially into the future, (3) review the applicability of military specifications and standards to RPV, and (4) survey available and developing technology that would be most suitable for RPV use in the 1983 - 85 time period.

Candidate electrical power systems are evaluated for each of the four RPV classes using a method of applying relative weights to the five most significant system parameters: (1) physical characteristics (weight and volume), (2) performance, (3) reliability, (4) maintainability, and (5) life cycle cost. PRICE and PRICE L are used to compare relative acquisition and life cycle costs. The results of the analyses indicate that the best architecture for the electrical system varies with each class of RPV. The ARPV class prefers either low voltage (28 volts) or high voltage (270 volts) DC over either constant or variable speed fixed-frequency AC systems; a wild frequency AC approach is a possible alternative.

The HALE class clearly prefers a hybrid wild frequency AC/DC system, where 28VDC has little preference over 270VDC. The AC section supplies primarily the payload. Since the engine runs at nearly constant RPM at altitude when the payload is operating, the directly-driven generator supplies power at nearly constant frequency. Furthermore, the payloads are primarily avionics, which easily tolerate the sort of frequency changes involved. This hybrid approach results in the simplest, lightest, and least expensive system architecture. It requires the least power conversion.

For the TEDS class (and its close relative, the cruise missile), simplicity is of paramount importance to weight, volume, reliability, and cost. The concept that best meets the criterion is a wild frequency AC system that depends on inherent regulation. The basic operational concept of TEDS (and cruise missile) requires that the engine run at 100% RPM at all times. To a directly driven generator, the engine is a constant speed drive. By specification and actual field experience, such engines run within a fraction of a percent of a nominal value. Furthermore, a rare-earth permanent magnet synchronous generator has excellent inherent voltage regulation, e.g., seven percent droop from no load to 5KW full load in a 1.5 pound generator running at 60,000 RPM (about 2000 Hz line frequency). The concept requires conversion and regulation only within the avionics suite itself for circuit applications and about 100 watts for the flight control actuators (rare earth PM motors help here too).

Mini-RPVs are not compatible with AC systems because of the small size and wide speed range of the reciprocating engines. High voltage DC offers no advantage. Therefore, a 28 volt DC system is the only practical choice. The difficulty experienced in Mini-RPVs has not been technology, but the availability of suitable components. Ongoing development is easing that situation.

In each class (except Mini-RPV), an existing system representative of the class was selected as a baseline against which four candidate systems could be compared. In all cases, the better candidate systems showed significant improvement in weight, volume, cost, and other factors when compared to the baseline.

Interestingly high voltage DC, which is being considered by some for manned aircraft, does not provide significant benefits for RPV. One reason is that lighter gage wire does not save as much weight in a smaller RPV. Another is that some components become larger at higher voltages; e.g., the battery and main line contactors. Unfortunately one compensates for the other, so that a 270V system weighs about the same (or perhaps even more) as a 28V system.

Considerable benefits can accrue to high voltage wild frequency systems and for line frequencies greater than the conventional 400 Hz for those systems where engine speeds do not vary widely. Future RPV are expected to have few, if any, loads that are sensitive to higher frequencies. Similar to the TEDS case, inherent regulation may be adequate for other applications, thus simplifying the system noticeably. Higher frequencies allow smaller magnetics, a significant weight contributor. Main line current interruption is also simpler for AC than DC.

The electrical sub-system of each class benefits from higher levels of integration with the propulsion and avionics subsystems. Optimizing power extraction from the engine remains a difficult task where an engine is used in several applications. The ARPV and HALE RPV are expected to have a central digital avionics processor and a data bus, both of which would be shared by the electrical system. This greatly reduces control wiring and logic since control and power management would be done in software. A separate electrical power data bus is unwarranted. TEDS and Mini-RPV would not have a data bus, but they will have central microprocessors, which would also be shared by the electrical system for control and management. In both cases, control and some distribution would be done via fiber optics and flat wire or printed circuit cable. Solid state or hybrid solid state/ mechanical contact switching would be used. RPV have always used remote power controller concept (albeit very simple), since no one is available in flight to replace a fuse or reset a circuit breaker.

Rare earth permanent magnets and newer high temperature insulation combined in generators and actuators benefit all systems to some degree. The Mini-RPV is least benefited, because the components are already small and performance is not critical. TEDS electrical system weight is cut by 55 percent, due either directly or indirectly to rare earth PMs. Other benefits are higher power (generator or actuator), better regulation, and it won't demagnetize. Its cost is still higher than other materials and components, but the difference is diminishing as production of rare earth PM material increases.

Review of Military Specifications and Standards that are applied to RPV re-confirms the Teledyne Ryan (and ARINC) position that a RPV Design Handbook is needed to help the designer tailor military specifications to specific systems. However, our position has shifted slightly to recommend a separate handbook for each class (or appropriate grouping) to avoid the unwieldy bulkiness of a single handbook.

The following areas have been identified as having sufficient payoff potential to warrant further work to either exploit developing technology or to ease current and future problems in RPVs:

- **Generate a series of RPV-class design handbooks for tailoring military specifications and standards**
- **Continued exploitation of rare-earth PM materials in RPV size generators and actuators, including regulation techniques that are compatible with PM generators.**
- **Develop hybrid multi-purpose technologies, such as starter-generators, AC/DC generators, other segmented generators for multiple voltages, and multimode emergency or auxiliary (air turbine) power units in RPV-compatible sizes.**
- **Exploit the potential of inherently regulated, high speed, high and wild frequency electrical power.**

- Exploit newer interconnection techniques, such as flat wires, printed circuit cables, and fiber optics.

- Exploit the potential for sharing the avionics data bus and/or central processor for electrical system control and power and redundancy management. This includes development of smart interface units for data bus terminals, where a microprocessor can exert local control.

- Develop hybrid solid state/mechanical contact line contactors.

- Continue development of battery systems which can adequately maintain battery condition and accurately monitor status.

SECTION III

REQUIREMENTS

3.1 PROBLEM STATEMENT

As the previous sections stated, the objective of this phase of the study is to develop a plan to establish laboratory capabilities and techniques for testing and demonstrating advanced technologies and electrical power system concepts. The first task in this work is to develop a complete statement of the problem. To do this, a number of factors must be considered. In addition to the requirements growing out of the advanced technologies and system concepts defined in Phase I, the factors include ensuring compatibility and proper interfacing between the RPV mockups and the laboratory, developing a set of desirable mockup characteristics, and defining the desirable outputs of the overall system. This requires adequately described lab facilities and capabilities as well as RPV mockups.

The following characteristics would be desirable in an RPV mockup:

1) Be adaptable to a wide variety of EPS of all RPV classes, from mini through HALE, plus cruise missiles
2) Occupy as little floor space as is practical
3) Be portable or easily re-locatable
4) Use available commercial or military hardware to minimize cost
5) Provide ready access to the subject system for operation, test, measurement, maintenance, and change
6) Be simple, inexpensive, easy to change, modify, reconfigure, enlarge, or reduce
7) Have modular configuration in terms of shelves, trays, boards, or whatever means are used for mounting equipment with common interfaces for data acquisition, test system control, power inputs, etc. to make the bench as adaptable as possible

A desirable objective is to have a single adaptable hot bench that can be used for any of the four classes of RPV rather than having four different mockups.

Design of a compatible mockup must take into account the following factors:

1) Capabilities, constraints, and method of operation of the existing facility. This includes the generator drives, load banks, data acquisition and

processing system, and available electrical power

2) Physical layout of the facility for potential bench locations, in terms of available space and proximity to pertinent laboratory equipment
3) Interfaces with the existing facilities and equipment: mechanical, electronic, and electrical

For example, the facilities at AFAPL are geared to testing the relatively large 400 Hz AC electrical systems that are normally found in manned military aircraft. RPV systems are typically 28 vdc or wild frequency greater than 400 Hz and have much lower power capacity systems. Therefore, the facilities must be adapted somewhat to handle these systems.

As desirable outputs, the test bench would provide the capability to:

1) Demonstrate and verify the feasibility of advanced technology and system concepts for future RPV
2) Evaluate the dynamic performance and power quality of systems and/or components; perform comparative analyses
3) Analyze transient effects and electromagnetic compatibility in a limited sense
4) Evaluate fault detection and protection techniques; investigate failure effects
5) Perform reliability testing and analysis
6) Identify technical areas that would benefit from further development

The following two sections will describe the AFAPL facilities and review the Phase 1 recommendations, respectively, to further develop the requirements information base.

3.2 AFAPL ELECTRICAL SYSTEM TEST FACILITY

This section describes in summary form the AFAPL test facilities and capabilities as they relate to integrating with and operating a RPV hot bench mockup.

The electrical power system test facility has been configured to test the conventional 115V/208V 400 Hz systems normally used in manned military aircraft. The facility consists of the generator drive stands, load bank, and data acquisition and processing system, and the laboratory space.

Laboratory Space

The laboratory floor plan is sketched in Figure 2. The available floor space is divided into five areas: 1) fabrication work area, 2) generator drive room, 3) control room, 4) load bank room and 5) system test area. The latter area is where the RPV mockup would be located; the available floor area is approximately 1650 square feet. Normal laboratory power is 120/208V, 60 Hz and 400 Hz, single and three phase.

Generator Drive Stands

Three identical generator drive stands are located within the generator sound-isolation room, as indicated in Figure 3. A 350 horsepower D.C. electric motor powers each stand, which also has two counter-rotating generator pads. The speed ranges, and drive characteristics are listed in Table 1. 3:1 speed increasers are available for the drives. Interconnect panels located next to each stand provide access to the control room and load banks. Additional cable access can be provided between generators and test systems via six 6-inch diameter holes in the generator room wall at the floor level.

A torque measurement device is available which can be mounted on the drive stand to determine the power input to the generator. A microprocessor-based speed control system in the control room controls each drive motor to stop, start, control speed, and monitor drive operation. The control system interfaces with the Digital Test System. The drive stands have air and oil cooling provisions for generators under test.

The ceiling is approximately nine feet high, and the clear areas are unobstructed from floor to ceiling. The areas marked "miscellaneous motors, pumps, pipes, etc." could accept a table or work bench, if desired. The room has a light-duty overhead crane that will travel from the drive pads to the raised floor area and the double doors.

Control Room

The control room adjoins the generator drive room, and it is air conditioned. It contains the control consoles for the generator drives and load banks. It also contains the digital data acquisition and processing system. A sketch of the control room floor plan is shown in Figure 4.

Load Banks

Five identical remotely-controlled load banks are installed in

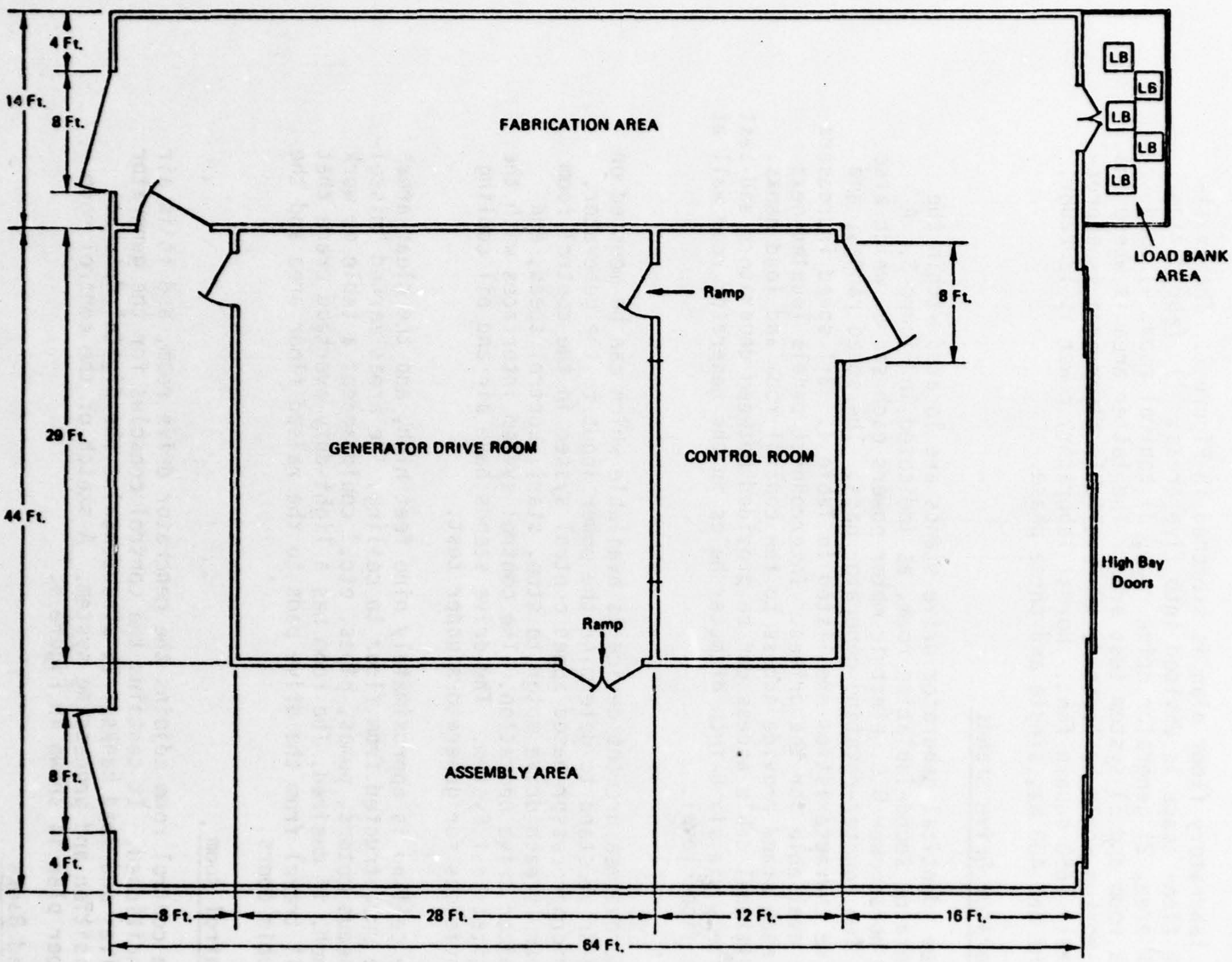


Figure 2. Laboratory Floor Plan

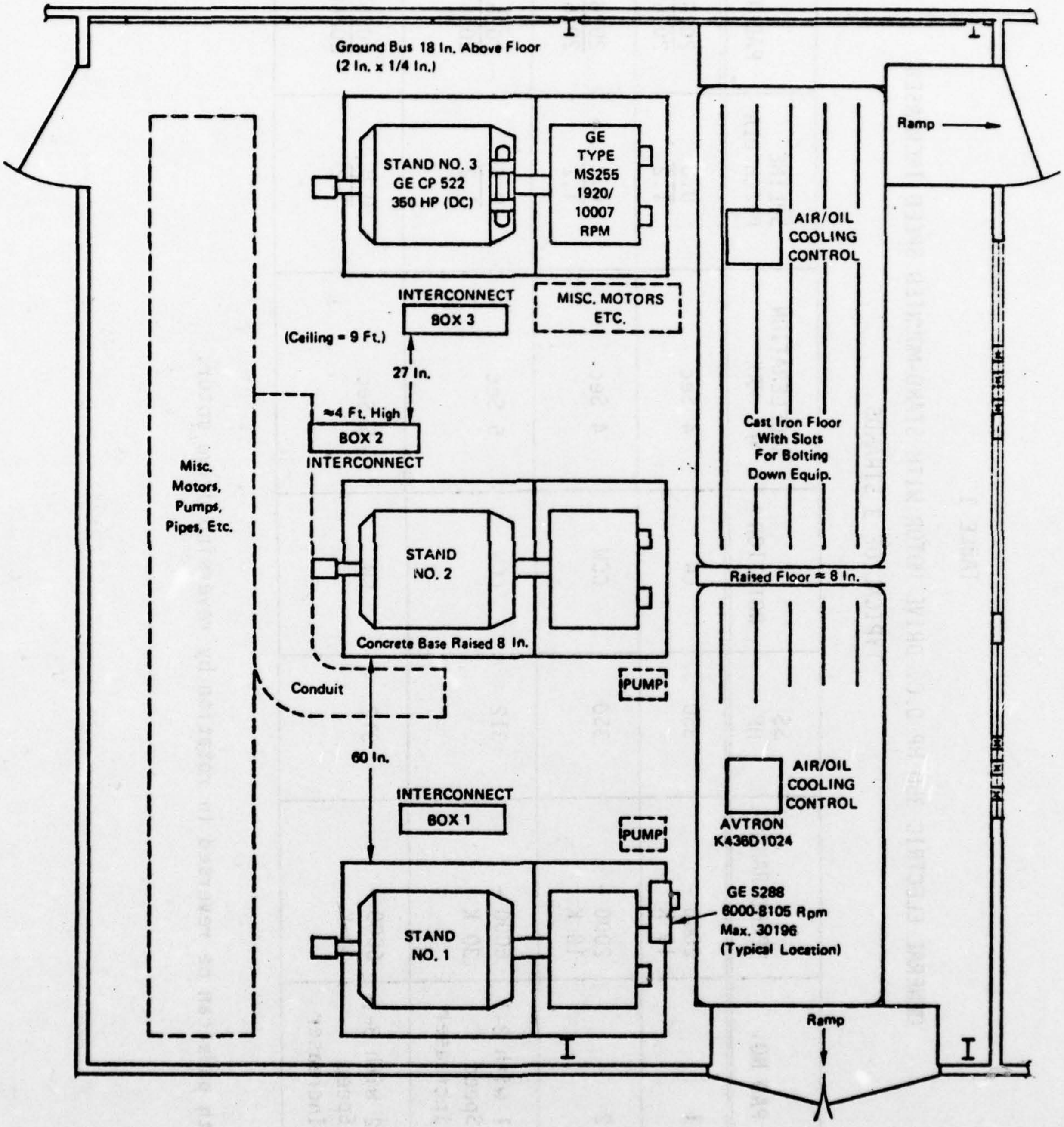


Figure 3. Generator Drive Room

TABLE 1

GENERAL ELECTRIC 350 HP D.C. DRIVE MOTOR WITH STAND-MOUNTED SPEED INCREASER

TYPICAL OF 3 STRANDS

PAD NO.	SPEED RANGE	SS HP	ROTATION *	ACCELERATION θ MAX	SPLINE PITCH DIA	PAD TYPE
1	2000 - 10 K	350	CW	4 Sec	0.8 / 1.2	20262 / 20266
2	2000 - 10 K	350	CCW	4 Sec	0.8 / 1.2	20262 / 20266
1 with 3-1 Speed Increaser	6000 - 30 K	312	CCW	5 Sec	0.8 / 1.2	20262 / 20266
2 with 3-1 Speed Increaser	6000 - 30 K	312	CW	5 Sec	0.8 / 1.2	20262 / 20266

*Both pads can be reversed in rotation by reversing drive motor.

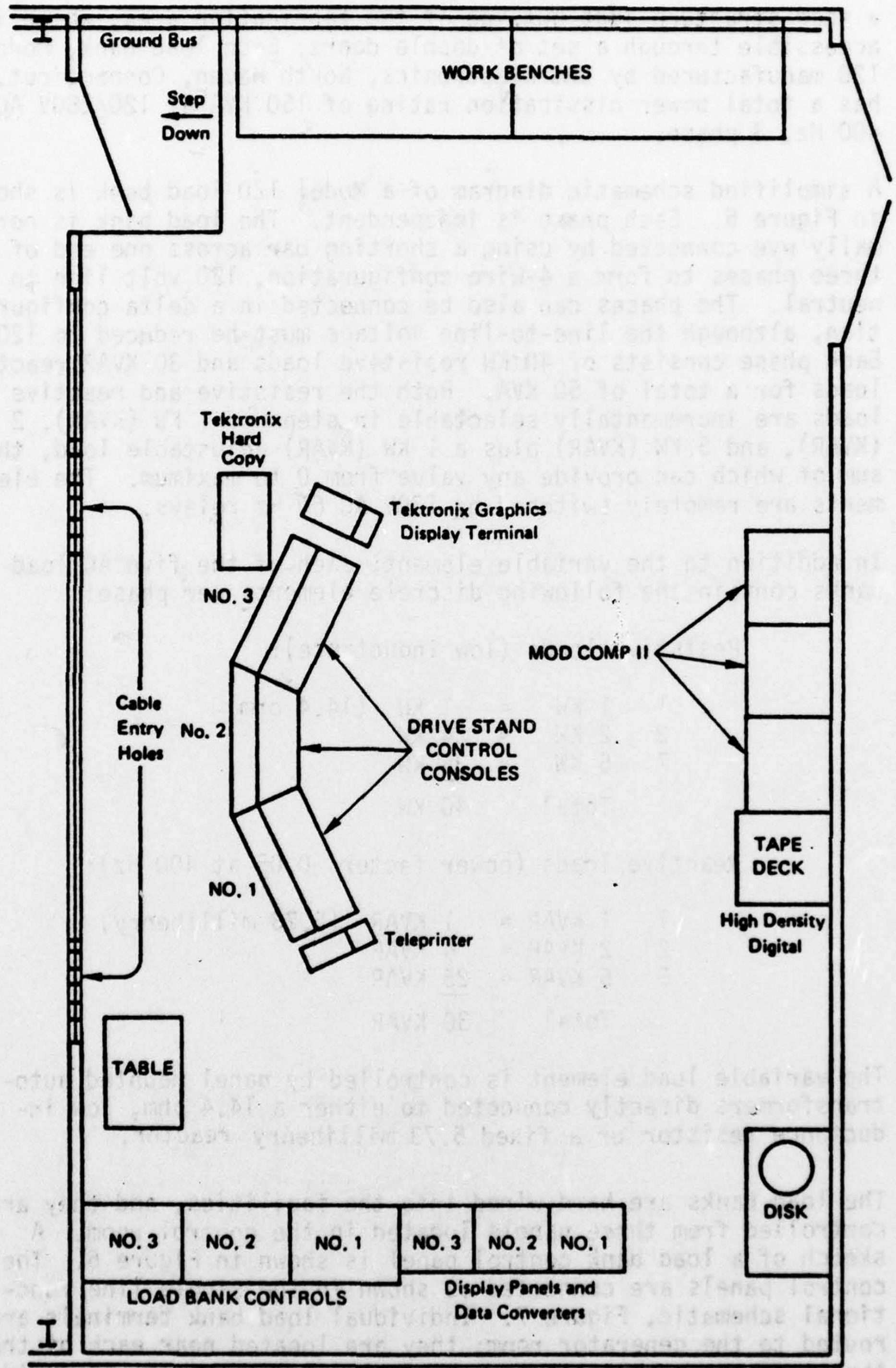


Figure 4. Control Room Floor Plan

a shed structure just outside of the fabrication area, which is accessible through a set of double doors. Each load bank, Model 120 manufactured by UMC Electronics, North Haven, Connecticut, has a total power dissipation rating of 150 KVA at 120/280V AC, 400 Hz, 3 phase.

A simplified schematic diagram of a Model 120 load bank is shown in Figure 5. Each phase is independent. The load bank is normally wye connected by using a shorting bar across one end of the three phases to form a 4-wire configuration, 120 volt line to neutral. The phases can also be connected in a delta configuration, although the line-to-line voltage must be reduced to 120V. Each phase consists of 40 KW resistive loads and 30 KVAR reactive loads for a total of 50 KVA. Both the resistive and reactive loads are incrementally selectable in steps of 1 KW (KVAR), 2 KW (KVAR), and 5 KW (KVAR) plus a 1 KW (KVAR) adjustable load, the sum of which can provide any value from 0 to maximum. The elements are remotely switched by 120V AC 60 Hz relays.

In addition to the variable element, each of the five AC load banks contain the following discrete elements per phase:

Resistive loads (low inductance):

1	1 KW	=	1 KW	(14.4 ohm)
2	2 KW	=	4 KW	
7	5 KW	=	35 KW	
	Total		40 KW	

Reactive loads (power factor 0.05 at 400 Hz):

1	1 KVAR	=	1 KVAR	(5.73 millihenry)
2	2 KVAR	=	4 KVAR	
5	5 KVAR	=	25 KVAR	
	Total		30 KVAR	

The variable load element is controlled by panel mounted autotransformers directly connected to either a 14.4 ohm, low inductance resistor or a fixed 5.73 millihenry reactor.

The load banks are hard wired into the facilities, and they are controlled from three panels located in the control room. A sketch of a load bank control panel is shown in Figure 6. The control panels are connected as shown in the single line functional schematic, Figure 7. Individual load bank terminals are routed to the generator room; they are located near each of the three generator test stands. Control panel authority is divided,

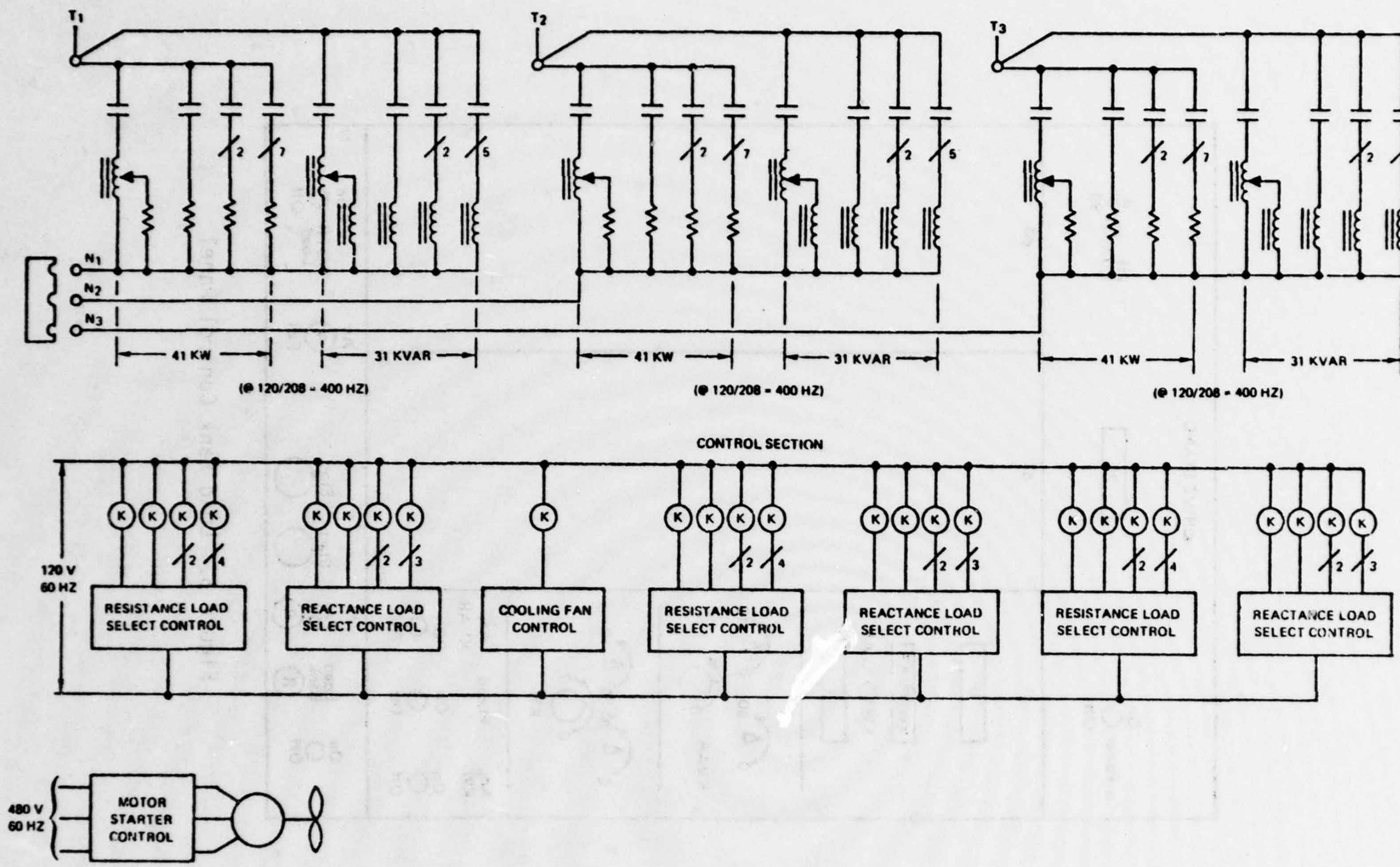


Figure 5. UMC 7456 Load Bank, Single Line Functional Schematic

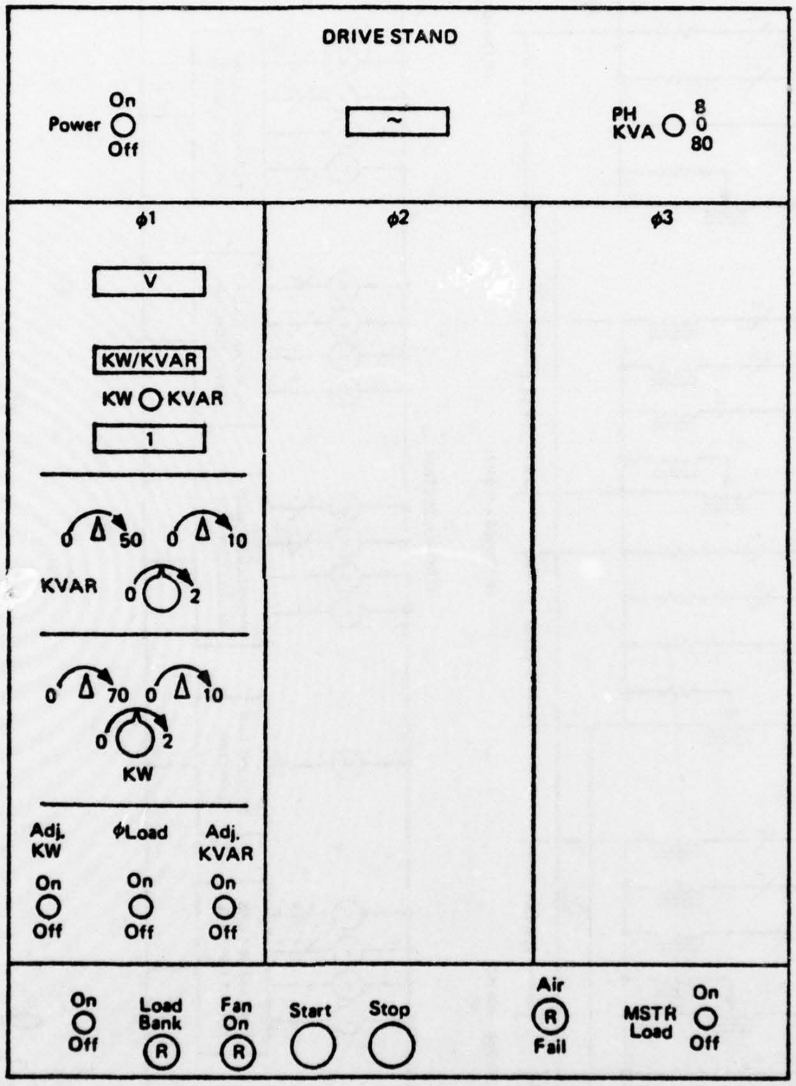


Figure 6. Load Bank Control Panel

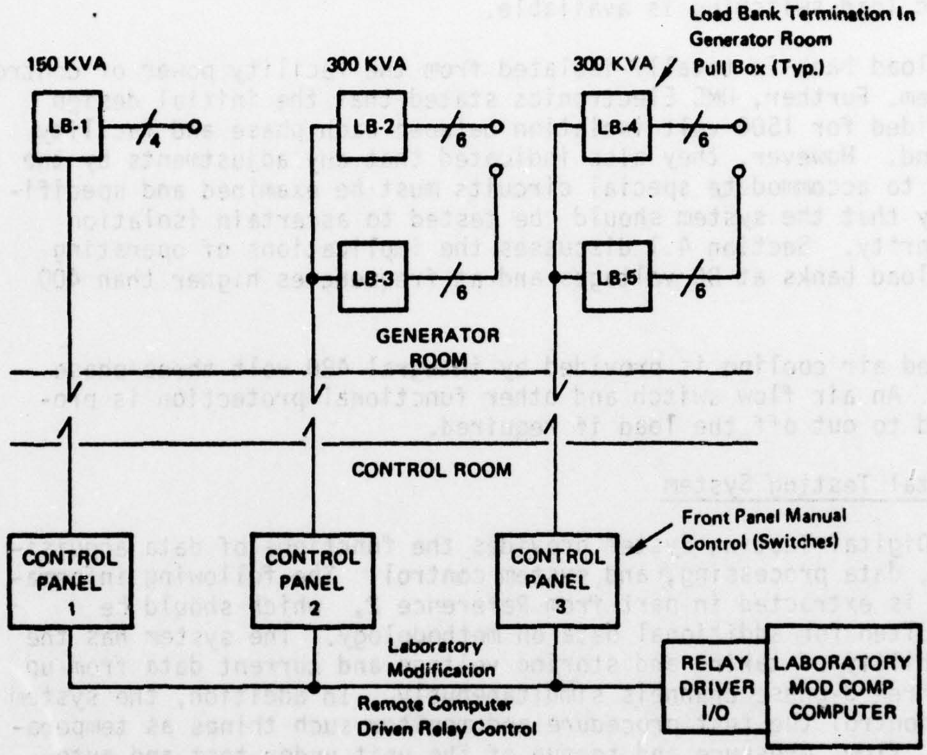


Figure 7. General Load Bank Interconnect of AFAPL Development Lab

such that one panel controls one 150 KVA load bank, and the remaining two control panels each control two 150 KVA load banks. These two control panels are wired such that identical steps are switched into each of the load banks. However, only one 1 KW adjustable load is connected in each dual bank setup. The control panels have been modified to interface with the MODCOMP computer in the Digital Testing System. Therefore, either manual or automatic load switching is available.

The load bank is totally isolated from the facility power or control system. Further, UMC Electronics stated that the initial design provided for 1500 volt isolation between each phase and facility ground. However, they also indicated that any adjustments by the user to accommodate special circuits must be examined and specifically that the system should be tested to ascertain isolation integrity. Section 4.1 discusses the implications of operating the load banks at DC voltages and at frequencies higher than 400 Hz.

Forced air cooling is provided by integral 480 volt three-phase fans. An air flow switch and other functional protection is provided to cut off the load if required.

Digital Testing System

The Digital Testing System provides the functions of data acquisition, data processing, and system control. The following information is extracted in part from Reference 2, which should be consulted for additional data on methodology. The system has the capability of taking and storing voltage and current data from up to three 3-phase channels simultaneously. In addition, the system can control the test procedure and monitor such things as temperature, flow, pressure and torque of the unit under test and automatically terminate the test in the event of a malfunction.

The digital test system consists of the following major components: MODCOMP II computer, Sangamo Sabre IV High Density Digital Tape Drive (HDDT), 18 isolated analog to digital (A/D) converters, generator drive stand controller, and timing and interface electronics. A simplified block diagram of the system is shown in Figure 8.

The system has four basic modes of operation: 1) A/D converters to computer memory (disk or core) data acquisition, 2) A/D converters to HDDT drive data acquisition, 3) HDDT drive to computer disk for analysis of data previously collected, and 4) computational mode for general purpose computation and program development. Data points are collected and stored one sixteen-bit word at a time. Data points may be collected from any A/D

2. Caputo, E. J., "Aircraft Electrical System Testing and Data Reduction Using Digital Techniques", NAECON 78

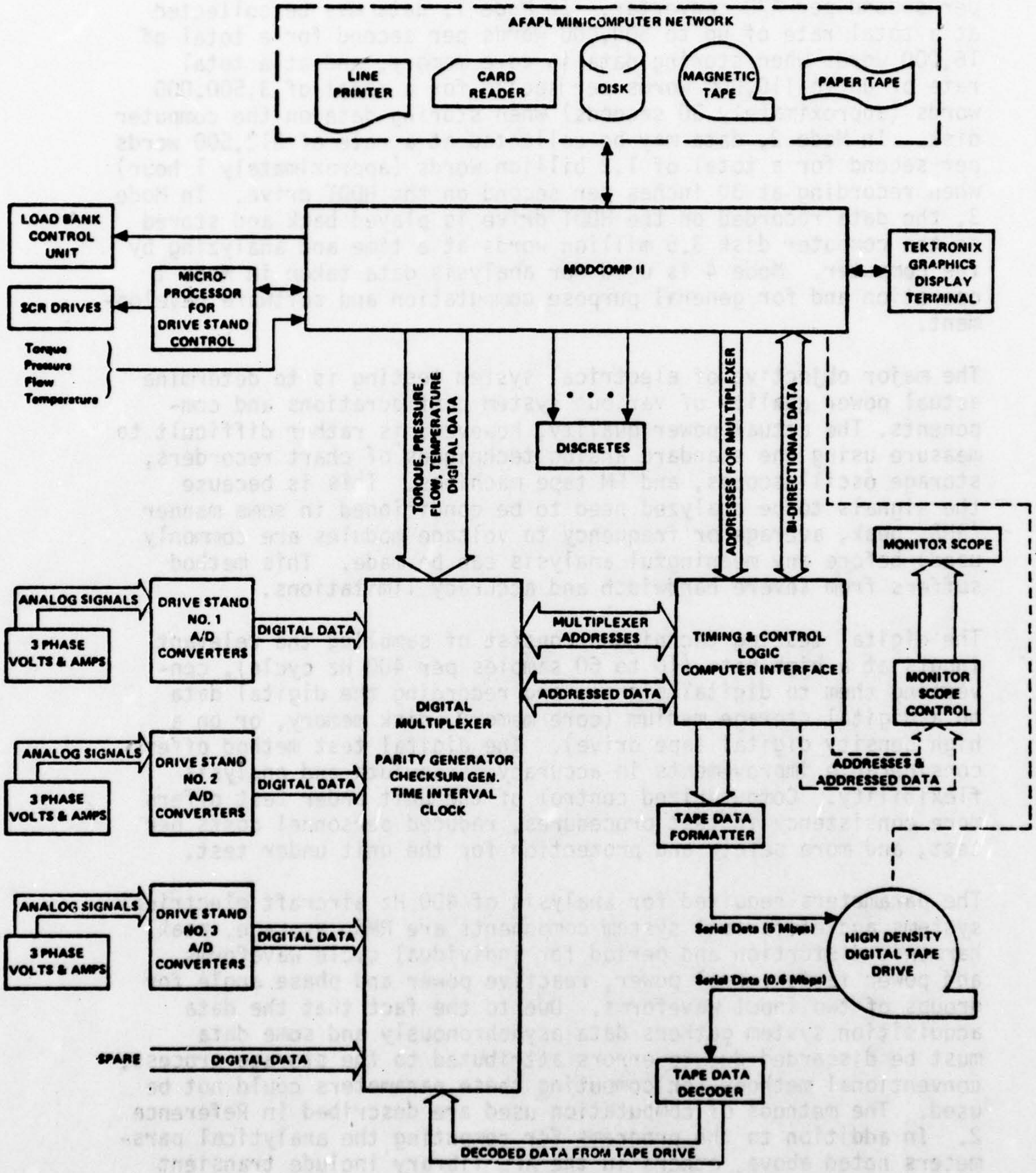


Figure 8. Digital Testing System

converter (in any order) at up to 100,000 data points (words) per second per A/D converter. In Mode 1, data may be collected at a total rate of up to 500,000 words per second for a total of 16,000 words when storing data in core memory, and at a total rate of up to 110,000 words per second for a total of 3,500,000 words (approximately 30 seconds) when storing data on the computer disk. In Mode 2, data may be collected at a rate of 312,500 words per second for a total of 1.2 billion words (approximately 1 hour) when recording at 30 inches per second on the HDDT drive. In Mode 3, the data recorded on the HDDT drive is played back and stored on the computer disk 3.5 million words at a time and analyzing by the computer. Mode 4 is used for analysis data taken in Mode 1 operation and for general purpose computation and software development.

The major objective of electrical system testing is to determine actual power quality of various system configurations and components. The actual power quality, however, is rather difficult to measure using the standard analog techniques of chart recorders, storage oscilloscopes, and FM tape machines. This is because the signals to be analyzed need to be conditioned in some manner (RMS, peak, average or frequency to voltage modules are commonly used) before any meaningful analysis can be made. This method suffers from severe bandwidth and accuracy limitations.

The digital testing techniques consist of sampling the relevant inputs at a high rate (10 to 60 samples per 400 Hz cycle), converting them to digital signals and recording the digital data on a digital storage medium (core memory, disk memory, or on a high density digital tape drive). The digital test method offers considerable improvements in accuracy, bandwidth and analysis flexibility. Computerized control of the unit under test offers more consistency in test procedures, reduced personnel costs per test, and more safety and protection for the unit under test.

The parameters required for analysis of 400 Hz aircraft electrical systems and electrical system components are RMS, average, peak, harmonic distortion and period for individual cycle waveforms, and power factor, real power, reactive power and phase angle for groups of two input waveforms. Due to the fact that the data acquisition system gathers data asynchronously and some data must be discarded due to errors attributed to the storage process, conventional methods for computing these parameters could not be used. The methods of computation used are described in Reference 2. In addition to the programs for computing the analytical parameters noted above, others in the APL library include transient analysis, time cutout/trip curves, and efficiency.

The digital testing system in use at AFAPL has proven to be very effective in analyzing steady state and transient performances of AC electrical system components. Due to the fact that each cycle (of the 400 Hz signals) can be analyzed individually, a capability to analyze transients very accurately was achieved. The integration of the testing function with analysis function using the MODCOMP II computer allows for analysis of test results immediately following each test. Analyses done by the computer allow test data to be presented in a variety of formats as desired by the test engineers.

3.3 RPV EPS CANDIDATES REVIEW

3.3.1 Introduction

This section reviews the EPS candidate selected in Phase 1 as being the best architecture for each class. Each of the four classes of RPV studied imposes slightly different requirements on a hot test bench, in terms of available bench space, the input power waveform, power loads, interfaces, and data and control needs.

The space requirements are based on the assumption that the regulator/power control unit is located near the generator, which is on a drive stand, and is separate from the remainder of the system. The question of hot bench requirements then addresses the remaining portion of a system, consisting of the distribution and control, stored energy, loads, and intersystem interface elements. The space needed to mount components is addressed in the Section 4 as part of the design considerations in selecting an approach to mockup design. The components required are also listed in Section 4. The list includes the central data processor and data bus components which were considered part of the avionics system during the Phase 1 analysis, but they must be included in a hot bench design.

3.3.2 ARPV LVDC System

The candidate LVDC (low voltage DC) system would generate 10 KW of MIL-STD-704 power regulated at 27.5 volts. The generator is a 30,000 to 40,000 RPM, solid rotor, rare earth magnets, air cooled machine that is either pad mounted or integral with the engine. The accompanying power control unit (PCU), which can be integral with the generator or separately mounted nearby, rectifies and filters the wild frequency AC output of the brushless generator and regulates the generator voltage at 27.5 volts.

Generators using samarium cobalt magnets are presently in use in the Tomahawk cruise missile with a 4 KW rating and integral PCU. The proposed unit for the FIREBRAND is a 7 KW unit in a ram air turbine, and 10 KW and larger units have been designed.

Sm Co generators can be made smaller than conventional generators. This plus a generator speed of 30,000 to 40,000 RPM or higher, permits a weight reduction of approximately 30% over a standard 8,000 RPM machine. Permanent magnet generators are also brushless, which improves their high altitude characteristics and the overall MTBF.

Figure 9 shows a LVDC system as it might apply to an ARPV utilizing the high speed, samarium cobalt generator with its PCU. Monitor and control of the electrical power system is by the avionics computer via the data bus into the remote terminal unit and its interface unit for control of the solid state switchgear.

The solid state switchgear can be two types, one simply a switch, the other a current limiting switch or circuit breaker. The power feeder and distribution wire weights and volumes were determined by use of conventional round wire and conventional connectors. The control wiring between the remote terminal unit and the power controllers uses flat wires to minimize weight and volume and fiber optics to minimize EMI susceptance.

3.3.3 HALE RPV AC/DC System

The AC/DC system envisioned is a combination of the VSVF (variable speed, variable frequency) and LVDC systems, although any of the AC systems and HVDC (high voltage DC) would also serve. The YQM-98A system is a successful example of such a hybrid. The ovjective is to minimize the amount of power conversion required for the various loads therby productin the simplest possible system. Therefore, those loads that can use the VSVF power directly, such as poyloads, core avionics, and fuel pumps would do so without conversion. This could represent 50 to 95% of the total load. Those loads which require DC, such as flight control actuators, or are frequency sensitive, such as cooling blowers, would use DC thereby sharing a common conversion at the generator.

The AC/DC system is shown schematically in Figure 10. Note that while the DC outputs of the engine-driven and air turbine motor driven generators can be paralleled, the AC outputs cannot. Recent developments, such as the hybrid PM/EM or flux-shunt regulator, allow regulating the AC and DC generators independently where both AC and DC loads require close regulation.

3.3.4 MINI-RPV

The generalized architecture is similar to that of the Navy STAR Mini-RPV, described in detail as an example in subsequent paragraphs, but with a higher capacity generator supplying 1500 watts

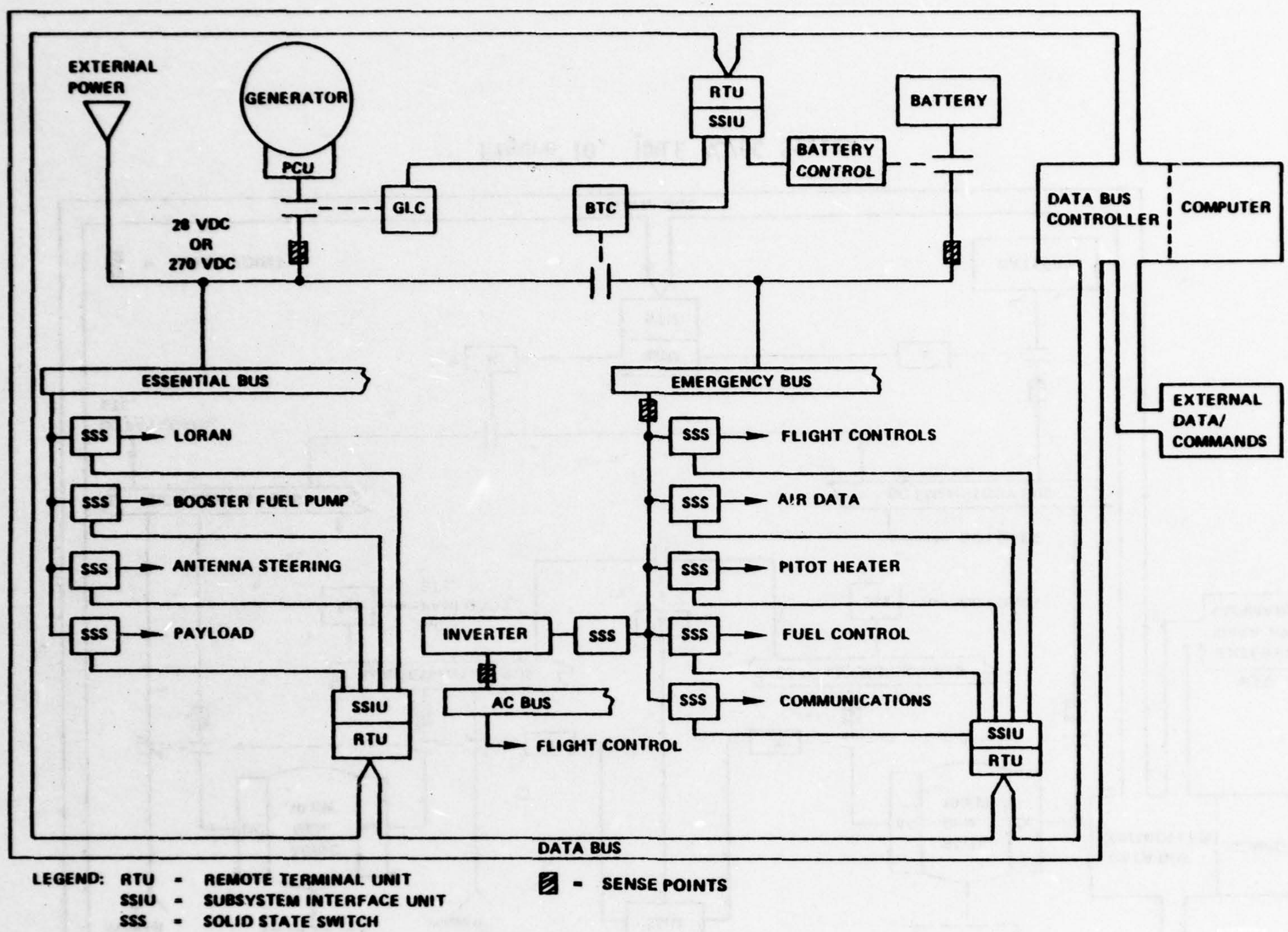


Figure 9. ARPV LVDC/HVDC

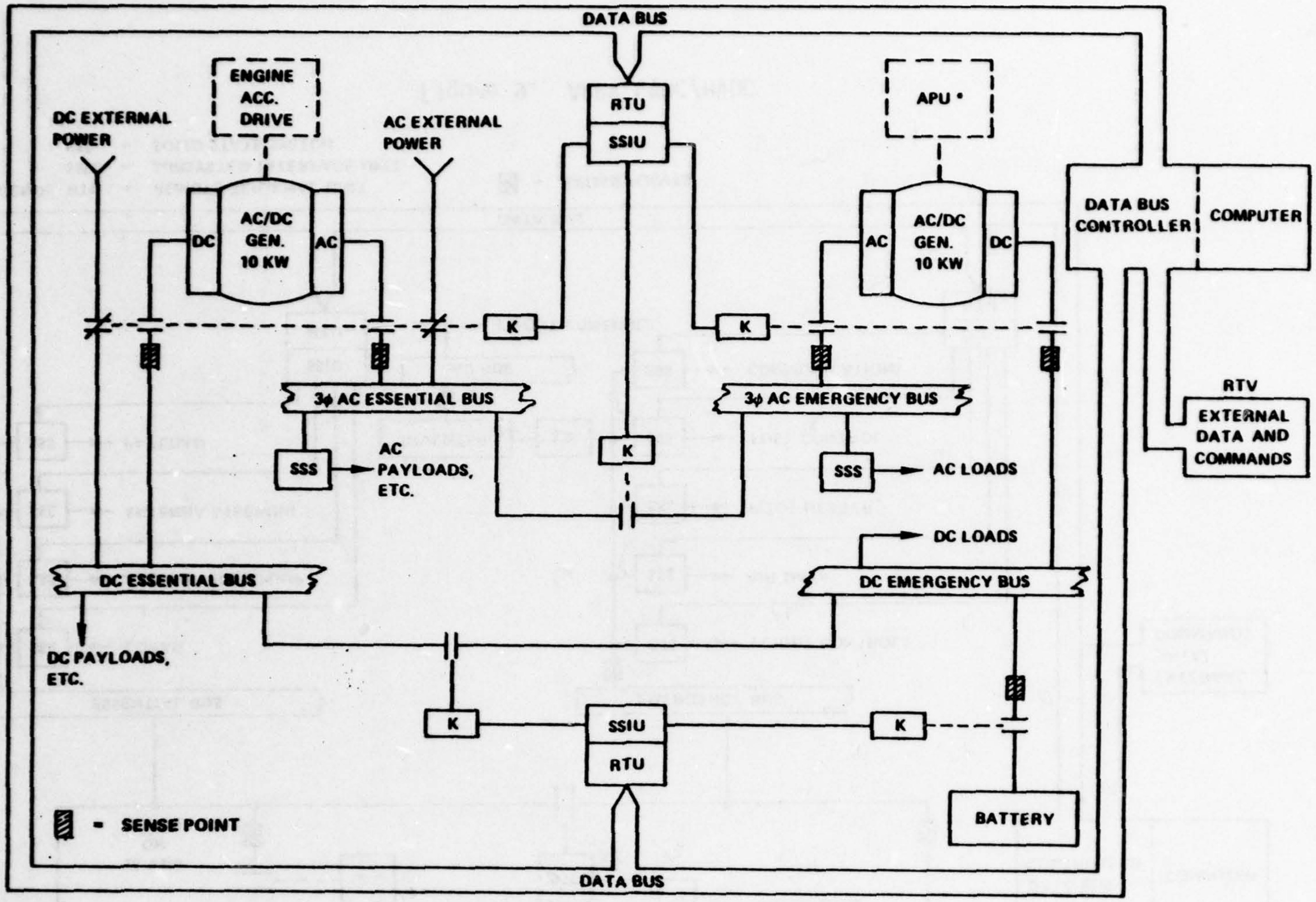


Figure 10. HALE AC/DC System

or more at 27.5 VDC. Because the Mini-engine has a relatively low output shaft speed, a speed increaser may be required for some generators; the belt drive used in the STAR system is such an example. A simplified schematic is shown in Figure 11.

Several candidate generators are available such as a flux-switch generator and a permanent magnet (SmCo) alternator. The major difference between these two machines is that the flux-switch generator has an electromagnetic field, which is also used for regulation, while the PM alternator, which has no means of controlling the field, uses a series switching regulator. These approaches provide comparable overall performance.

To save weight, size, and cost, the voltage regulator is combined with the rectifier. If the regulator-rectifier is made an integral part of the generator the need for shielding the power leads is eliminated.

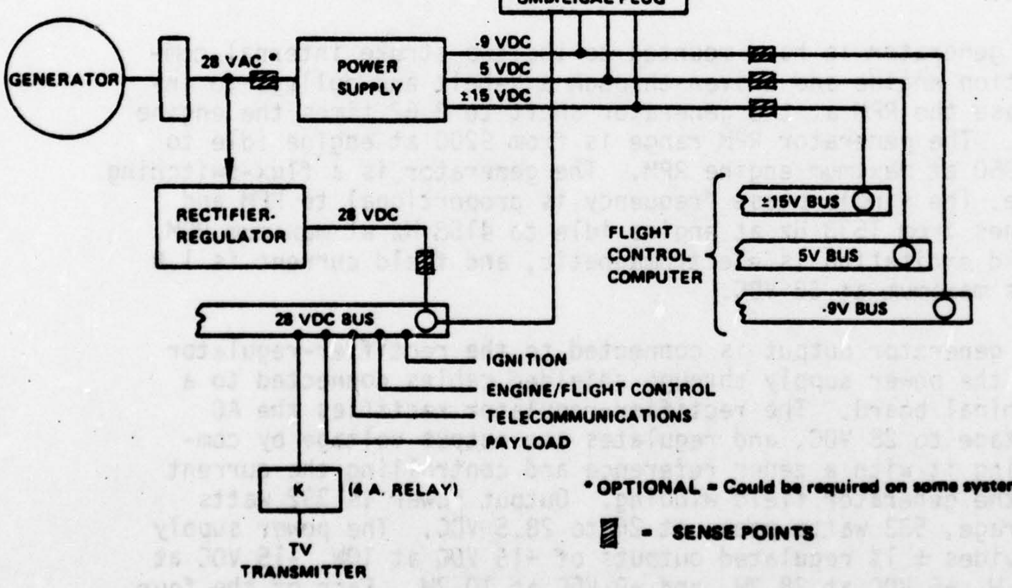


Figure 11. MINI-RPV LVDC Without Boxes (Single Output)

However, additional generator volume in a crowded engine compartment commands a high premium, and the environment is severe. A preferred solution is to locate the rectifier-regulator outside the engine compartment, even though power lead shielding is needed.

Utilization equipment often requires voltages other than that supplied by the generator. These can be obtained in various ways: a) by a power supply within the utilization equipment, b) by a multi-output generator, or c) by a central power supply that could be a separate unit or a part of the regulator rectifier.

The electrical system used on the STAR Mini-RPV consists of a belt driven AC generator, a rectifier-regulator, a regulated avionics power supply, a power distribution assembly, and the distribution wiring. The power distribution assembly consists of a 4 amp relay to switch 28 VDC power to the video transmitter payload. Power is distributed from a central terminal board to the various loads using conventional interconnecting wire.

The generator is hard-mounted to the two-stroke internal combustion engine and driven through a V-belt and pulleys to increase the RPM at the generator shaft to 2.62 times the engine RPM. The generator RPM range is from 9200 at engine idle to 24,950 at maximum engine RPM. The generator is a flux-switching type. The single phase frequency is proportional to RPM and ranges from 1533 Hz at engine idle to 4158 Hz at maximum RPM. Field excitation is electromagnetic, and field current is 1.8 amps maximum at 28 VDC.

The generator output is connected to the rectifier-regulator and the power supply through shielded cables connected to a terminal board. The rectifier-regulator rectifies the AC voltage to 28 VDC, and regulates the output voltage by comparing it with a zener reference and controlling the current in the generator field winding. Output power is 392 watts average, 533 watts peak, at 26 to 28.5 VDC. The power supply provides ± 1% regulated outputs of +15 VDC at 10W, -15 VDC at 8.6 W, +5 VDC at 28.2W, and -9 VDC at 10.3W. Each of the four voltages are derived from individually secondary windings of a transformer whose primary is connected to the generator AC output.

External power for system checkout prior to engine start is provided via an umbilical connector. Power and return lines for each of the 5 systems voltages are connected directly to the outputs of the vehicle power supplies at a central terminal board. This same terminal board serves as a distribution point for the vehicle loads. A bias resistor in the regulator supplies the initial generator field excitation from the main 28 VDC bus, which is energized from ground power at the time of engine start. Once the engine RPM is high enough for the generator to sustain system loads, the external power supplies are switched off in the ground support equipment, and the umbilical plug removed in preparation for launch.

No battery was required in the power system because survival of the vehicle was contingent upon engine-on net recovery, as compared to glide/engine-off-parachute recovery modes typical of other RPVs. Size and weight constraints prohibited addition of a battery which would power the essential systems until net recovery in the event of generator, rectifier-regulator, or power supply failure. A small battery to fire the pyrotechnics for parachute deployment was employed in the flight test vehicles, wherein a parachute system replaced the payload during initial test flights.

3.3.5 TEDS VSVF System

The VSVF system shown in Figure 12 is similar to a LVDC system, except that conversion of the generator output is deferred to the load areas. Transmitting 240 VAC allows using lighter gage feeder wires and smaller line contactors than 28 VDC. Neither voltage nor frequency of the generator output is regulated. Since the TEDS engine is expected to operate at a single throttle setting (100% RPM), then frequency variation throughout the flight would be negligible. For example, the Harpoon engine specification calls for the engines to operate at a nominal maximum RPM ± 3/4 percent. Field experience shows the variation to be ±0.3 percent actual. Therefore assuming a single throttle setting, the system would behave as a constant frequency in area of 2000 to 4000 Hz (for 4 and 8 poles respectively). Such frequencies are low enough to not cause excessive feeder line reactance for the relatively short lines in a TEDS and high enough to allow very small transformers in the power converters.

While the line frequency is essentially constant, voltage variations due to load changes (such as cycling the payload) will change the voltage/frequency ratio. The voltage droop in the referenced SmCo generator when cycling a 3 KW payload would be about 4%. The magnetics would have to be designed to allow for such variations. However, at the frequencies involved, the magnetics are very small, and a 4% increase in size would be insignificant.

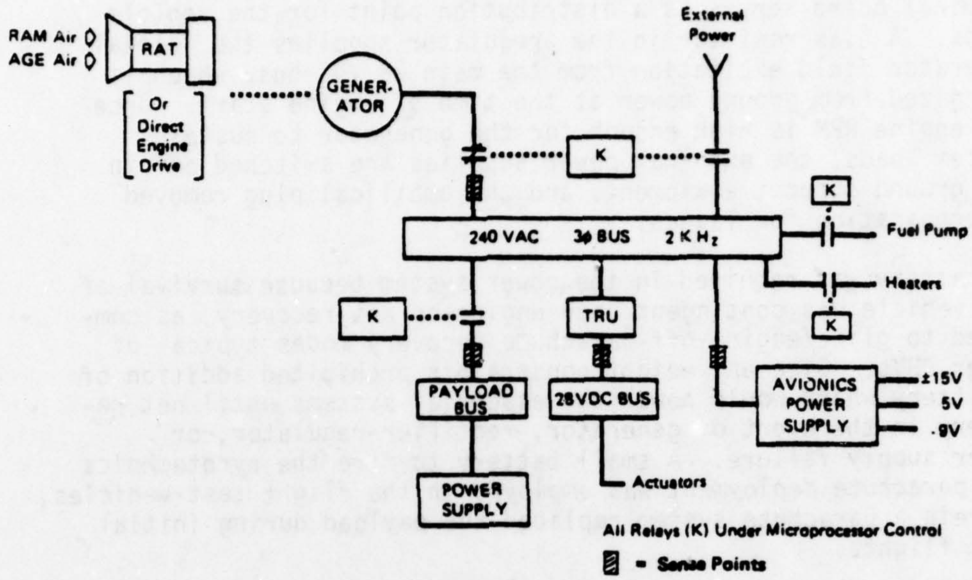


Figure 12. TEDS VSVF System Without Boxes

If future TEDS mission scenarios should call for a second throttle setting, such as 92% or 95% for example, then generator voltage and frequency will change together and at approximately a constant ratio. Such a change by itself would have no more effect on power supplies, TRUs, and heaters than in the previous DC case, since the primary effect is in the voltage change. DC motors, i.e., flight control actuators, would similarly not be affected. AC motors would run slower, of course. The only AC motor envisioned in a TEDS vehicle would be a fuel pump and possibly a cooling fan. Changing speed proportional to engine speed is an ideal situation for a fuel pump. However, a cooling fan would have to be sized for the lowest expected frequency to ensure adequate air flow. Hence it would be slightly larger than for a fixed frequency case.

3.4 CONCLUSION

This review of the recommended RPV systems concludes the summary of material that impacts the design of hot bench mockups in one way or another. The information forms the basis for developing mockup designs, which is discussed in the next section.

SECTION IV

EPS MOCKUP DESIGN

4.1 DESIGN CONSIDERATIONS

4.1.1 Introduction

The preceding section provided a necessary information base for designing RPV electrical hot bench mockups. However, the data raises additional questions and issues which must be resolved before a design can be completed. In addition to the basic design issue of selecting a design configuration, questions remain such as:

1) How to include the central data processor, software, and data bus (in two classes), which the electrical subsystem shares with the avionics, and how much development is involved?

2) How well does the existing load bank, which was designed for 115 VAC 400 Hz power, perform at RPV voltages: DC and frequencies of 2K Hz to 5K Hz? Are actual loads better than simulated loads?

3) What are the approximate costs and schedules associated with the various classes of mockups (estimated to a degree of confidence that would allow planning and decision making on potential future programs)?

4) Other issues, including availability of DC power, how to approach EMI testing, and transient testing in DC systems.

This section will discuss these areas to clear the way for describing the selected concept.

4.1.2 Mockup Design Alternatives

Mockups are built to help understand, observe, and evaluate proposed system behavior under reasonable approximations to actual conditions. Therefore the mockups are fabricated to reasonably replicate the design under consideration. This technique offers to the mockup visitor a vicarious bond to the experiment and/or equipment, such that one can readily associate to the experiment and relate to an actual installation. Construction techniques involved in replication often utilize production drawings and where possible actual production or final installation structural hardware. The inaccessibility and difficult working space associated with and usually found in the actual installation is carried forward to the mockup tool. Additionally, costs associated with such detailed replication can be excessively high for the actual experimental value received.

Quite naturablly, mockups constructed for the specific purpose of investigating human factors response to control placements or actuations must closely duplicate the installation to satisfy the intended operation. For evaluating conceptual electrical system performance, however, this attention to esthetic replication is unnecessary.

The key characteristics of an RPV electrical system hot test bench are accessibility, small size, and ease of reconfiguration. This is necessary to simplify the inevitable hardware changes. Also, as alluded to above, hot bench mockups were usually structured to replicate in its entirety the physical airframe of a system as well. Construction was generally completed on a plywood "skinned" slab which represented a realistic vehicle ground plane by virtue of the copper or aluminum sheet. This completed structure required a relatively large laboratory space.

A review of the existing APL facilities indicates that much of the necessary equipment, interconnecting wiring, and isolation afforded by that installation is suitable and ready for use. The question arises as to the best physical location of the hot bench. The mockup must be designed for the available space and structure. The maximum weight of all components, including mounting hardware, must be known to assure that floor loading and/or wall loading is within the allowable limits prescribed by the building code. While this task is not extensive, sufficient engineering must be expended to assure that the building walls and floors are not overloaded.

Several locations within the laboratory area were considered. The mezzanine, the generator room, and the areas of wall space and room areas outside of the generator room concrete block enclosure. Locating mockups on the generator room exterior wall minimizes the use of floor space, although it restricts location flexibility. Using a rollaway dolly platform provides location flexibility, although it requires more floor space than a wall-mounted system.

The mockup design approach that best meets the requirements intuitively calls for the use of modular elements or panels. An example of this approach is indicated in Figure 13. It offers the user the ability to readily change from one setup to another, ready access to all components, simple inter-module wiring, low cost, and a means of reducing overall storage requirements. The question immediately arises as to the optimum configuration of the modules in terms of size, number, orientation, material, and means of mounting. Panel sizes considered ranged from 4 ft. by 12 ft. to 2 ft. by 3 ft. Number was obviously inversely proportional to size. Orientation was either horizontal or vertical; one configuration had panels that laid horizontally in operation and rotated to the vertical for storage when not in use. Materials considered insluded metal-clad wood, honeycomb, and reinforced aluminum sheet. Mounting means included being fixed to a frame or bench, hinged horizontally or vertically, and combinations.

A variety of frame structures and associated components can be supplied from commercial construction and warehouse equipment manufacturers. Such systems have fixed structures or supports within which the location of shelves, racks, and panels can be varied and adjusted as needed. One vendor, in particular, offers a support and column design which is used as the standard for this discussion. The key attribute of this particular design is that the "keyhole slots" for mounting racks and shelves are shaped such that the removal forces are not as great if conventional keyhole designs were used.

Whatever mounting configuration is selected, it must be capable of supporting the total weight of any electrical system candidate. While the tare weights of a small system panel, including connectors, terminal blocks, and mounting supports could approach 30 pounds, the total weight with all installed equipment to be evaluated could reach 150 pounds. Expanding this example to a complete system (worst case assumptions) indicates that the mounting mechanism would have to accommodate at least four panels per column. Accordingly, the final design selection must include the capability to support a 1000 pound static load plus any dynamic working forces associated with connecting and disconnecting various components and adjustments. Most of the commercial catalog item rack frames and systems are specified at 15,000 pounds minimum, which is well over the minimum dynamic requirements. Therefore, any manufacturer's design could be selected with considerable safety.

Although the use of 1/4 - inch or 1/8 - inch thick aluminum plate or sheet would simplify overall component mounting board construction, other concepts are available. Aluminum-skinned plywood or sheet foam has been successfully used with structural mockups. This approach is lighter than using a solid plate, the metal skin can be used as the ground plane, and it is low in cost. Unfortunately, compression of the wood, or foam filler, when mounting through-bolts or studs for electrical return paths can introduce a relaxed joint such that eventually the contact resistance increases and high resistance ground returns are formed. This must be avoided in laboratory designs, and therefore the approach is not recommended.

Another alternate is to use light gauge material sheet stock, 0.090 or 0.060 inches thick. The panel weight would be considerably reduced with minimum compression of through-bolt electrical joints. Additional stiffening would be required however, by beading, riveting of angles or some similar positive action. Unless stiffening

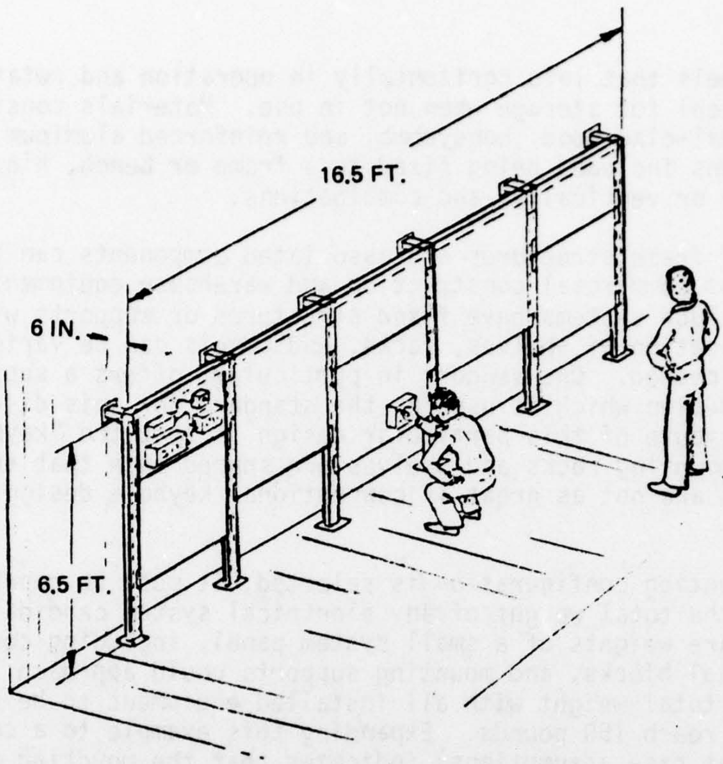


Figure 13. Modular Mockup Wall Mount

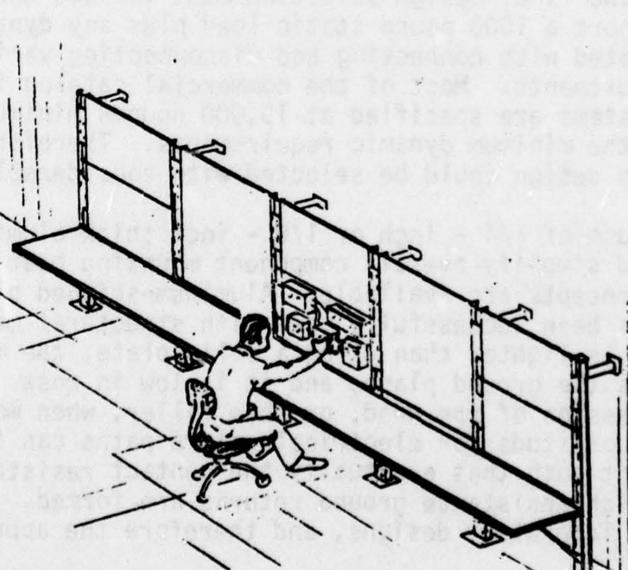


Figure 14. Wall Mount With Tray

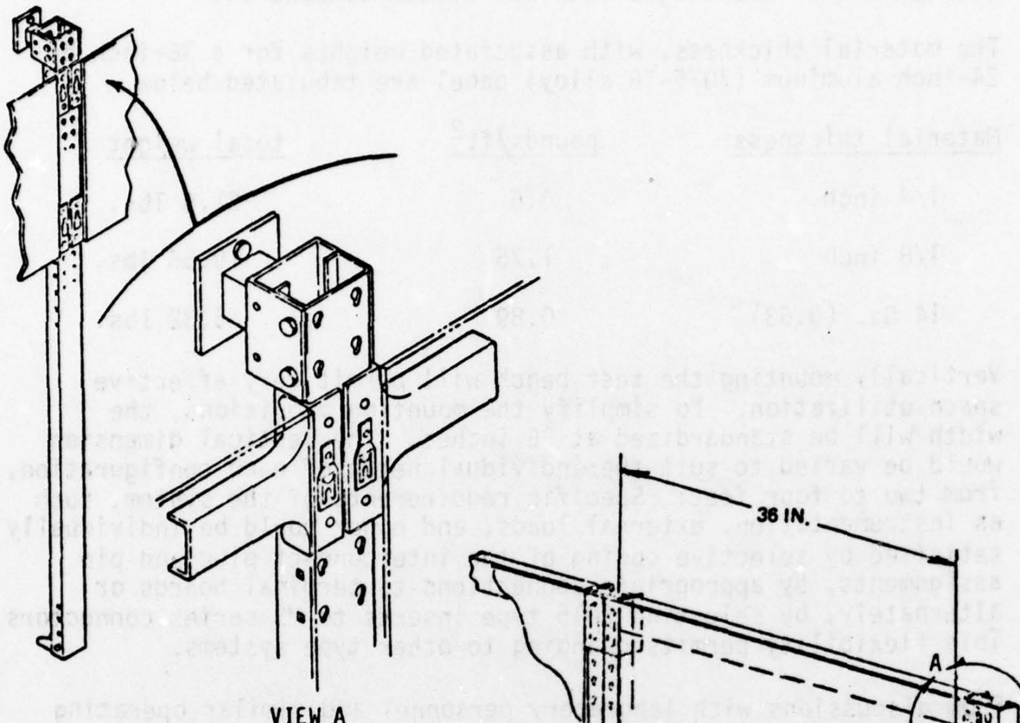


Figure 15. Panel Attachment

were added, severe panel deflection and distortion would be encountered when mounting electrical system components.

The material thickness, with associated weights for a 36-inch by 24-inch aluminum (7075-T6 alloy) panel are tabulated below.

Material thickness	pounds/ft^2	total weight
1/4 inch	3.6	21.6 lbs.
1/8 inch	1.76	10.56 lbs.
14 Ga. (0.63)	0.89	5.32 lbs.

Vertically mounting the test bench will permit very effective space utilization. To simplify the mounting provisions, the width will be standardized at 36 inches. The vertical dimension would be varied to suit the individual needs of each configuration, from two to four feet. Specific requirements of the system, such as instrumentation, external loads, and power could be individually satisfied by selective coding of the interconnect plug and pin assignments, by appropriate connections to terminal boards or alternately, by selecting 5015 type inserts to MS series connectors. This flexibility permits changing to other type systems.

From discussions with laboratory personnel and similar operating experience in the laboratory environment, we conclude that the most practical approach is to bolt a standard mounting column (floor feet attached) to the wall using a six to ten-inch spacer, as indicated in Figure 14. Horizontal column spacing must accommodate the selected standard panel dimension and the support column width. A column spacing of 38-1/2 inches permits 36 inch wide panels to be used. Raw stock aluminum plate and sheet are furnished in both 36-inch by 96-inch and 48-inch by 96-inch dimensions. Accordingly simple shearing from a 36-inch wide stock material can economically provide the necessary panels.

Figure 15 illustrates an individual panel mounting procedure, and it shows a method to accommodate rapid interchangeability. A wall surface 6.5 feet high would provide ample space. The operator viewing angle from a distance of four feet can accommodate all mounting and panel details. Additionally, an operator in a squatting position has working access to the lowest panels, although this position would rarely be used.

Alternatives to the fixed wall emplacement must also be considered. An obvious variation is to simply exchange the wall mount for a floor mounted portable pedestal. In this configuration, frame columns are supported by angled braces and mounted on a rolling platform, as indicated in Figure 16. In this manner, the equipment could be more easily moved to various locations throughout the facility. Another advantage is that both sides of the panels are accessable for mounting components thereby reducing the overall panel space needed. Conversely, access to the more rigid interconnects, (generator outputs and simulated load circuits) might not be as easily accommodated. In a large installation with high current and power capacity, tie-ins to the main system might become unweildy, and the conductor flexibility and weights might detract from the intended free standing rollaway approach.

Figure 17 is included to indicate the flexibility of a wall mounted swing-out installation. Both sides of the panel are accessible for mounting components, thereby reducing the panel area needed. The panels can be folded flat against the wall when not in use. This approach requires less wall space than the first method described, which uses contiguous single-sided panels; this may be a moot point, however. Since the panels are closer together, interpanel wiring can be slightly more compact. However, the overhang moment can cause high wall loads, which must be evaluated for a particular installation.

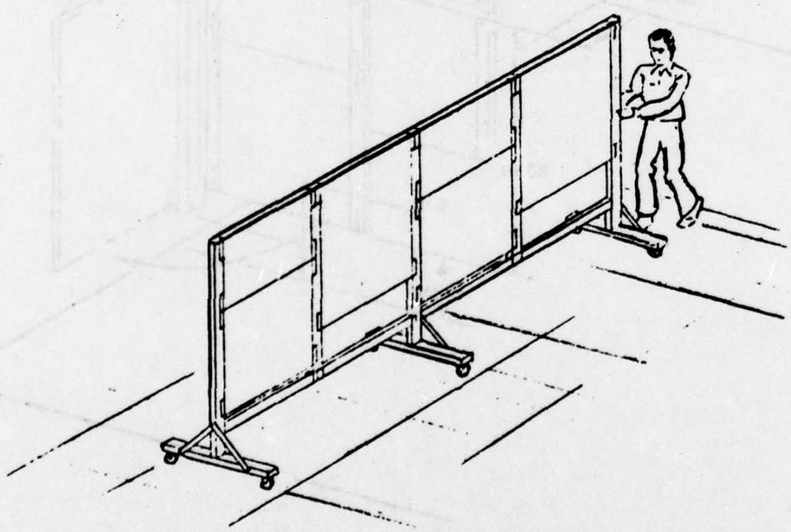


Figure 16. Rollaway Mockup

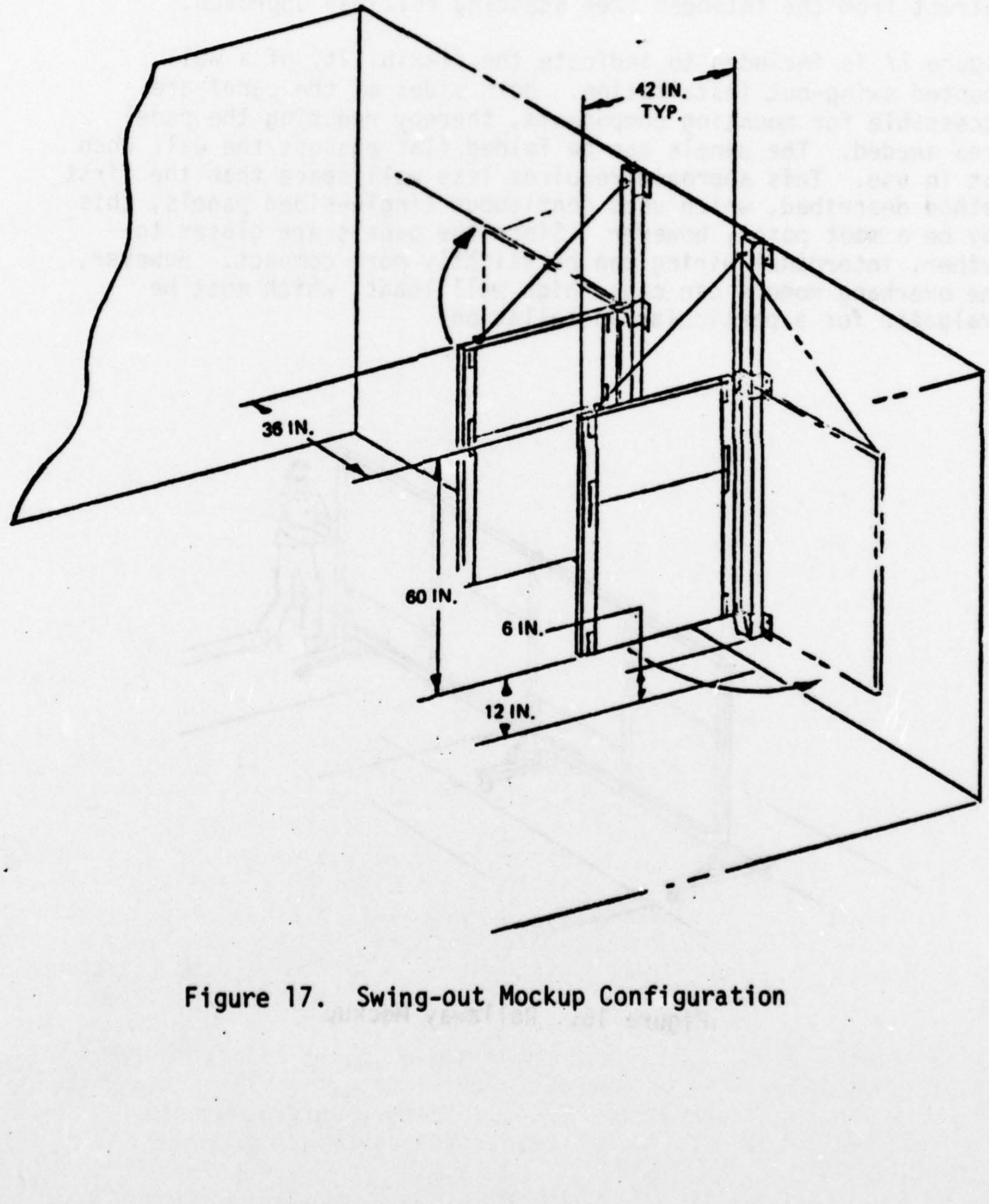


Figure 17. Swing-out Mockup Configuration

A number of vehicle system configurations could be under active investigation at any time. With the expected relatively low costs of each panel section, a practical approach would be to include several panels and store unused ones rather than to tear down each panel following test. Additionally, because of the many system types that would be under test or investigation, several system types might be in varying state of buildup and/or testing at any one time. The storage requirements would include interconnecting cables for each type system and any special hardware items under test. The cabinets should accommodate up to 8 standard panels, (3 foot widths and varying height, up to 4 feet). Expected unloaded panel weights are 14.3 pounds per linear foot width, (28.06 pounds for a 2 foot high panel and 38.6 pounds for a 4 foot high panel). Components would be in addition to these weights. Accordingly, fully loaded panel storage weights could approach several hundred pounds.

The various vendors use different attaching mechanisms. The Interlake Inc. assembly, which is used as the example for this discussion, uses a single support arm, which mates with the keyhole frame. Each arm, which are used in pairs, weighs 2.5 pounds. These can be bolted to the aluminum panel for both mounting and stiffening. The total weight is then:

Aluminum panel, 1/8 inch thick, 36 in x 24 in	10.5 lbs
Top support arm set (right and left)	5.0 lbs
Bottom support arm set (right and left)	5.0 lbs
Misc. fixed hardware, bolts, terminals etc.	7.5 lbs
Total fixed weight	28 lbs

The Interlake system is widely stocked throughout the United States, is low cost, and provides the modularity necessary for a flexible installation. The approximate costs of a 5 bay (6 column) installation would be:

3 rack frames,	P/N LF15-24084	$41.00	$123.00
6 rigid wall fix,	P/N LA 0602-R1	$ 5.00	$ 30.00
16 pair support arms	P/N LIA 9060	$11.25 pair	$180.00
	Total rack frame expenditures		$333.00

This example assumes that the laboratory initially establishes an operating complement of 8 component mounting boards.

While the benefit of using catalog hardware is its availability, minor adjustments to these items would be helpful. Specifically in the matter of the rack frame, the Interlake LF-15-24084 frame provides a 1-5/8 x 3-inch dual column frame, having an overall height of 84 inches. The keyhole slots in the rack frame are spaced 2 inches apart, thereby permitting the beam assembly heights and positions to have two-inch increments. Inasmuch as a full rack frame is unnecessary, these frames could be cut in two lengthwise at the site.

The 1-1/2" by 3-inch column can individually support up to 15,000 pounds; six columns would be used for one 5-bay installation and thereby support up to 90,000 pounds, well over any weight restrictions that could be envisioned for this, or any future study applications. The family of aluminum mounting plates used in this installation, again, would have common dimensions in width, with height being a variable sized to accommodate the hardware required for the particular system under test.

In summary, the benefits of this approach over a conventional vehicle replicated installation include:

1) Exceptional access to all components and wiring

2) Reasonable replication of the installation as regards to wiring lengths, component orientation, and system protection elements

3) Considerably less bulk than with conventional three-dimensional replicas

4) Ground plane provided by the aluminum mounting plate, individually bonded to the structure and the facility ground bus.

5) Simplified storage of all mockup boards. A bank of test boards could be configured and stored until needed.

6) Very low initial and follow on costs. The rack is a multi-sourced production item. The standard mounting panel, a readily fabricated item.

7) Interfaces to the system are provided by standard pin assignments.

8) Components mount vertically as in a typical airborne installation.

4.1.3 Microprocessors and Data Busses

The Phase 1 study concluded that future electrical systems would be software controlled, and they would share the avionics central processor and data bus where one is used. These elements were not counted as part of the electrical during the Phase 1 analyses, but they must be included in any mockup designs. What are the implications?

Electrical power control and monitor software is very simple, consisting of level sensing and boolean logic, as compared to complex multi-function avionics software. Other related software functions that would be included are an event programmer, to simulate a mission programmer, and possibly test functions. These functions would easily fit within microprocessor capabilities. Such a computer need not be flightworthy. A more effective approach would be to use a general purpose microprocessor that could provide more utility as a laboratory tool and could be used on more than one system.

One of the key items to a successful program is to demonstrate the feasibility of the selected design concept and yet stay within the overall time and cost constraints. Accomplishing this objective means minimizing design and fabrication time, hardware costs and lead time, new software development, and de-bug and integration time.

The recommended approach uses available off-the-shelf commercial equipment to synthesize new generation concepts. The marketplace has available a significant amount of hardware that can be utilized. Foremost in availability and maturity is the Intel multi-microprocessor equipment, which permits substantially all hardware to be obtained off-the-shelf and provides both hardware and software development support. Others include Texas Instruments, Motorola, National Semiconductor, ...

The Intel single board computer (SBC) products, for example, configured in conjunction with auxiliary equipment, provide the building blocks for implementing breadboard systems of any capability required by RPV systems as well as for many manned aircraft electrical systems. The SBC uses the 8080 microprocessor, various types of memory and input/output resources, and an arbiter. Card racks with system bus mother-boards are expandable to accommodate many modules. Existing logic analyzer and in-circuit emulator capability simplifies development and checkout. Availability of a real time multi-tasking operating system and higher order language (HOL) software simplifies software development. Selection of a particular microprocessor system should take into account the systems being used by other WDL laboratories on related programs. The purpose is to optimize compatibility and data exchange.

The technology to implement a multiplexed data bus to meet MIL-STD-1553A has reached the point where modules to build 2-chip systems are now in limited production. Therefore this element of an ARPV or HALE RPV system mockup has left the "development required" category and gained "off-the-shelf" status. Circuit Technology Inc., Farmingdale, N.Y., produces a hybrid line transceiver, CT 1231, and Harris Semiconductor Products, Melbourne, Florida, produces a Manchester encoder-decoder, HD-15530. Figure 18 indicates how these modules would be used in a typical system. The line coupler may be a transformer for a two-wire system or a light emitting diode and detector for a fiber optic system. The subsystem interface unit functions are application dependent. They include serial-to-parallel data conversion and buffer, data control logic stored in a read-only memory or programmed logic array module, discrete and analog data conversion, and signal conditioning. The engineering time now required is approximately one month for design, one month for fabrication and checkout, plus hardware delivery time. Other manufactures are also developing hybrid circuits for the data bus functions, some of which are expected to enter production in the near future. Several companies have developed hybrid circuit modules for their own use, such as Hughes Semiconductor; whether these devices will also become available is unknown.

4.1.4 Load Banks

Through the cooperation of UMC Electronics, internal workings of the load bank were investigated. Initially, we were concerned that the existing load bank equipment, contactors, switches, reactors, resistors and wire could not tolerate the dissipation and arcing conditions associated with alternate system voltages. Several contactors used in this existing design are no longer catalog items; further, no DC or tungsten load ratings or data are available for any of these contactors. The relay manufacturer indicates that the contact areas and air gaps used in these old designs generally comply with the recommended practice of today's applications. Nonetheless, an actual load test using the proposed system operating values is recommended to verify the contactor and other load bank characteristics when operating the voltages, currents, and frequencies of non-400 Hz systems.

The 1 KW/KVAR variable loads, both resistive and reactive, are controlled by autotransformers located in the control panels. The autotransformers are the limiting element in high frequency operation. Unfortunately, most standard autotransformers have a frequency limit of about 2000 Hz. Above 2000 Hz, the hysterisis losses increase dramatically resulting in excessive core losses. Therefore, the present equipment could be used up to 2000 Hz and left switched out at higher frequencies. The discrete load values would provide realistic resolution for lab use.

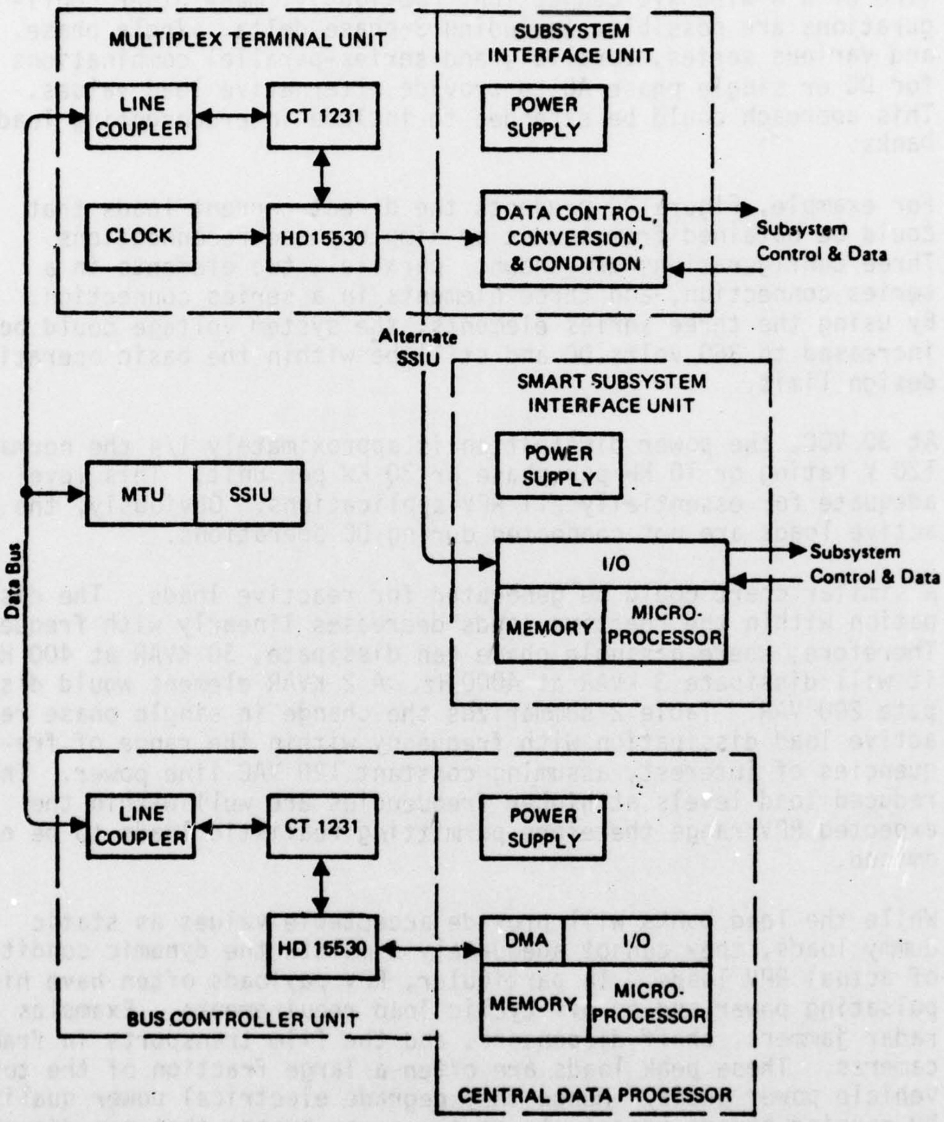


Figure 18. Data Bus Implementation

The load banks are wired such that the outputs of each phase (resistive and reactive) are brought out independently, as indicated in Figure 19. Normally, one end of the three phases in a load bank are connected by a shorting bar to form the neutral line of a 4-wire wye connection. Obviously, many other configurations are possible, including 3-phase delta, single phase, and various series, parallel, and series-parallel combinations for DC or single phase AC to provide alternative load values. This approach could be extended to include interconnecting load banks.

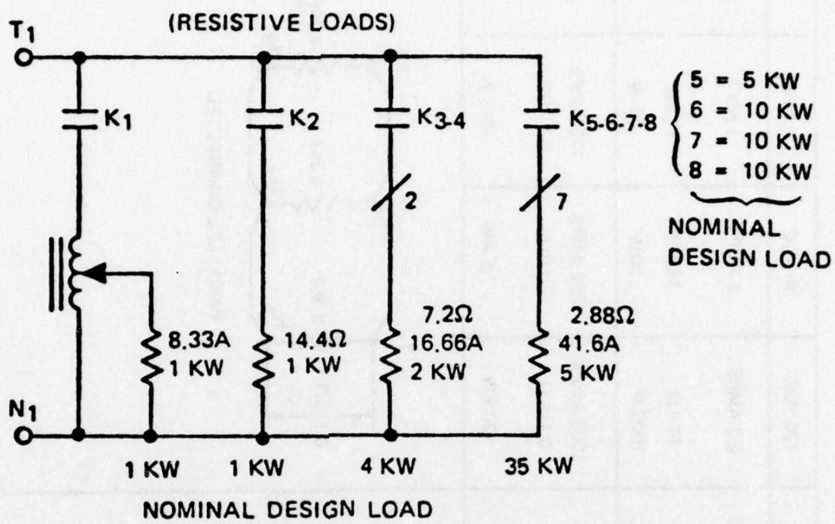
For example, Figure 20 presents the direct current loads that could be obtained from a unit by simple phase reconnections. Three configurations are shown: parallel, two elements in a series connection, and three elements in a series connection. By using the three series elements, the system voltage could be increased to 360 volts DC and still be within the basic operating design limit.

At 30 VDC, the power dissipation is approximately 1/4 the normal 120 V rating or 10 KW per phase or 30 KW per unit. This level is adequate for essentially all RPV applications. Obviously, the reactive loads are not connected during DC operations.

A similar chart could be generated for reactive loads. The dissipation within the reactive loads decreases linearly with frequency. Therefore, where a single phase can dissipate, 30 KVAR at 400 Hz, it will dissipate 3 KVAR at 4000 Hz. A 2 KVAR element would dissipate 200 VAR. Table 2 summarizes the change in single phase reactive load dissipation with frequency within the range of frequencies of interest, assuming constant 120 VAC line power. The reduced load levels at higher frequencies are well within the expected RPV range therefore permitting realistic loads to be examined.

While the load banks will provide acceptable values as static dummy loads, they cannot adequately simulate the dynamic conditions of actual RPV loads. In particular, RPV payloads often have high pulsating power and on-off cyclic load requirements. Examples are radar jammers, chaff dispensors, and the film transports in frame cameras. These peak loads are often a large fraction of the total vehicle power needs. Hence they degrade electrical power quality by causing severe transients on the power busses that can disrupt computers or other avionics components or even the primary electrical power regulators and conditioners.

The relatively high costs of airborne qualified equipments and lack of availability, however, restricts their general adoption. A more practical approach is to substitute a composite dummy load controlled by a simple clock and switching network connected to



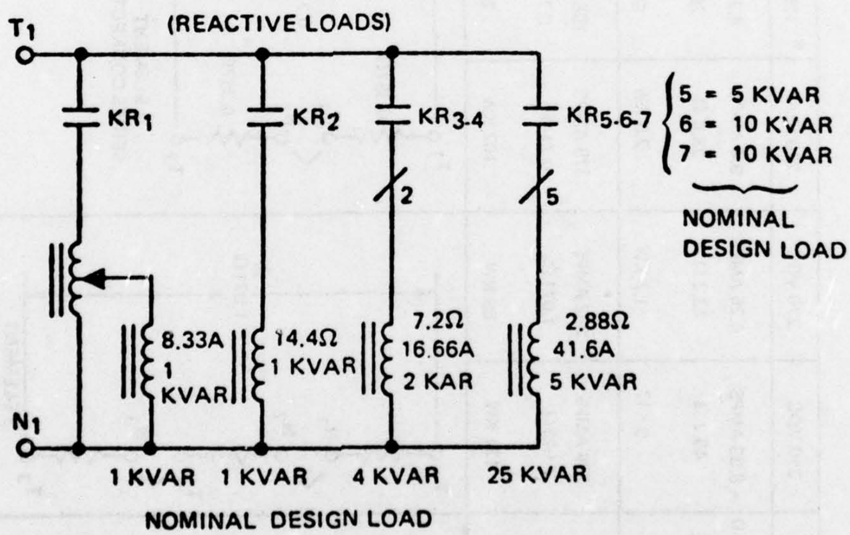
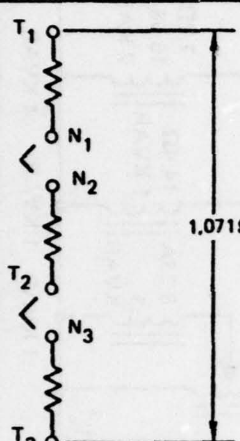


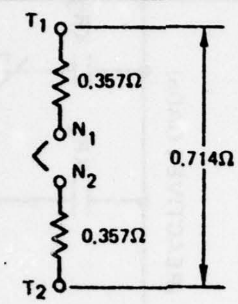
Figure 19. Individual Phase Load Bank Characteristics

TERMINAL VOLTS	360 VDC	270 VDC	270 VDC	120 VDC	120 VDC	30 VDC	+15V	+5V
MIN INCREMENT LOAD	8.33 AMPS	6.25 AMPS	9.4 AMPS	4.2 AMPS	8.3 AMPS	2 AMPS	1 AMP	0.35 AMP
MAXIMUM EFFECTIVE RESISTANCE	43.2 Ω	43.2 Ω	28.8 Ω	28.8 Ω	14.4 Ω	14.4 Ω	14.4 Ω	14.4 Ω
POWER DISSIPATION	3 KW	1.7 KW	2.5 KW	500 W	1000 W	60 W	15 W	1.8 W
MAXIMUM LOAD	336 AMPS	252 AMPS	378 AMPS	168 AMPS	1008 AMPS	252 AMPS	125 AMPS	42 AMPS
MINIMUM EFFECTIVE RESISTANCE	1.071 Ω	1.071 Ω	0.714 Ω	0.714 Ω	0.119 Ω	0.119 Ω	0.119 Ω	0.119 Ω
POWER DISSIPATION	121 KW	68 KW	102 KW	20 KW	120 KW	7.5 KW	1875 W	210 W

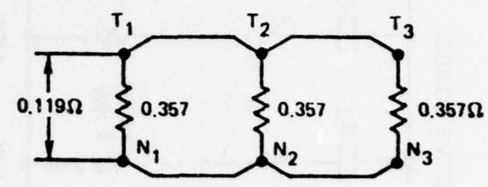
CIRCUIT CONFIGURATION



3 ELEMENT SERIES CONNECTED



2 ELEMENT SERIES CONNECTED



PARALLEL CONNECTED

Figure 20. Series and Parallel Phase Connections

TABLE 2

SINGLE PHASE REACTIVE LOAD AS A FUNCTION OF FREQUENCY

f	w	L	XL	I	MAX. NUMBER OF LOADS	SECTION	TOTAL
400	2513	5.73187×10^{-3}	14.4	8.33A	X2 =	2 KVAR	51.4 KVA
		2.86594×10^{-3}	7.2	16.67A	X2 =	4 KVAR	@ 0.8 pf
		1.14775×10^{-3}	2.88	41.67A	X5 =	25 KVAR	31 KVAR
							(41 KW)
1 KHz	6283	TYP	36.01	3.33A	X2 =	800 VAR	20 KVA
							@0.8 pf
			18.0	6.67A	X2 =	1.6 KVAR	12.4 KVAR
							(16 KW)
			7.2	16.67A	X5 =	10 VAR	
2 KHz	12566	TYP	72.03	1.67A	X2 =	400 VAR	10.28 KVA
							@0.8 pf
			36.01	3.33A	X2 =	800 VAR	6.2 KVAR
			14.4	8.33A	X5 =	5 KVAR	(8.2 KW)
4 KHz	25132	TYP	144.06	0.83A	X2 =	200 VAR	4.15 KVA
							@0.8 pf
			72.03	1.67A	X2 =	400 VAR	3.1 KVAR
			28.85	4.16A	X5 =	2.5 KVAR	(4.1 KW)

simulate the high repetition rate switching and in-circuit characteristics of the real vehicle loads. This would save considerable money and eliminate scheduling of high value equipments. Characteristics of the switching mechanism must tolerate high voltage transients that would be expected from rapid load switching of high power circuits. Figure 21 illustrates a comparatively simple mechanization of this type of load device. The primary purpose of simulated loads is to evaluate electrical system performance during severe and worst case conditions and to insure that the complete RPV system will function satisfactorily under all conditions.

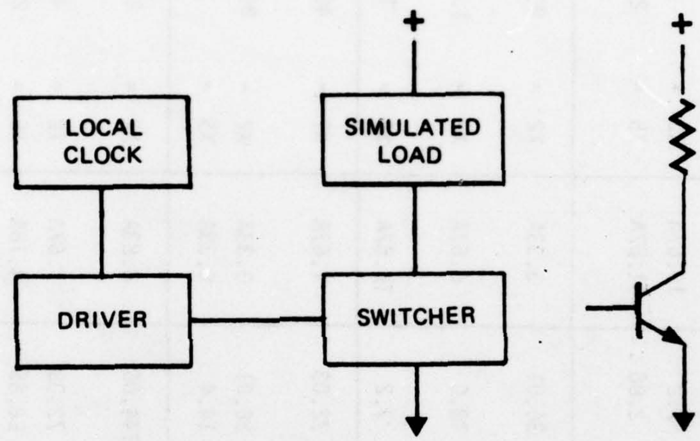


Figure 21. Simulating Pulsed Loads

4.1.5 Cost Considerations

The cost data used in the planning estimates are based on the PRICE data generated in the Phase I studies with some adjustments and augmentation. PRICE (described briefly in Appendix A of the Phase I report, Reference 1 is an empirical parametric model that has been developed for performing trades, sensitivity, and comparative cost studies and for developing budgetary cost and schedule estimates for planning purposes. Except for a few unusually highly calibrated situations, the data produced by PRICE are not used for firm estimates.

PRICE encompasses development costs up to and including system integration and limited documentation. It does not include software or subsequent performance testing and evaluation. Therefore, the cost of these functions must be added.

While the candidate evaluation data, assumptions, and ground rules are consistent within each class, they are not consistent between classes. For example, the ARPV class was analyzed first. The system design philosophy included packaging control and distribution components collectively within three boxes, a holdover approach from the baseline BGM-34C system. The boxes include the umbilical distribution box, power relay control box, and the main power control box. The non-recurring and production costs of the boxes is a large fraction of the overall system cost. The subsequent treatment of the other three classes eliminated the approach as being unnecessarily expensive and complex and used instead a simpler distributed packaging concept. The difference is especially evident in comparing the ARPV and HALE RPV development costs as indicated in Table 3. For planning purposes, the development costs for the three boxes are deleted from the ARPV costs.

In all of the future electrical systems, performance monitoring, control logic, and redundancy management is presumed to be done in software. In the ARPV and HALE RPV classes, the data bus is assumed to be part of the avionics suite and, therefore, its cost is not charged against the electrical system. For the planning estimate to be complete, the cost and schedule of an appropriate (although simple) central microprocessor, software logic, and a data bus must be included, as is discussed in Section 4.1.3.

The Mini-RPV and TEDS analyses assumed that appropriate generators, regulators, and power supplies would be available, based on components currently in development. Therefore, very little non-recurring development cost was assigned. Such an assumption has little affect on a comparative analysis as long as it is used consistently for all candidates within the class. However, the assumption may not be valid when planning for a specific technology demonstration system. Therefore, as a conservative measure, a development cost that is considered representative of non-recurring design for a generator, regulator, and power supply is included in the Mini-RPV and TEDS planning estimates, as indicated in Table 4. To provide an estimate of material costs, the average system production cost, as estimated by PRICE, is doubled. This approach approximates moving back along the learning curve to a quantity of one.

Finally arriving at a reasonable approximation to the cost to develop and demonstrate a system mockup requires justifying the PRICE data with probable costs from generator/regulator manufacturers based on their recent historical experience with similar components. The vendors that we contacted were pleasantly consistent in their projections. Their corroboration helps support the projected revised cost estimates listed in Table 5. These estimates are the basis for the task breakdowns given in Section 5.2.

TABLE 3

SUMMARY PHASE I PRICE COST DATA FOR DEVELOPMENT AND PRODUCTION

COST ELEMENT	ARPV LVDC		HALE AC/DC		MINI-RPV LVDC		TEDS VSVF	
	AVERAGE		AVERAGE		AVERAGE		AVERAGE	
	DEV	PROD	DEV	PROD	DEV	PROD	DEV	PROD
Generator	136	0.41	153	2.56(2)	2	2.1	10	9.80
Power Control Unit	114	1.43	113	4.12(2)			85	0.52
Regulator/Rectifier					included		included	
Power Supply					1	1.27	1	1.23
Battery	10	0.97	26	2.10				
Inverter	74	1.87						
Buy Group	1	1.49	7	7.06	-	0.05	1	0.93
Integration	38	0.56	53	1.08	8	0.11	23	0.26
Power Relay Control Assembly	9	0.41						
Main Power Control Box	177	10.07						
Umbilical Distribution Box	244	12.55						
Power Distribution Assembly					3	0.07		
SYSTEM TOTALS	703	29.77	252	16.92	14	3.60	120	13.74
QUANTITY OF VEHICLES		1000		50		1500		5000

Dev. = Development Cost

Avg. Prod. = Average Production Cost

Costs in thousands of dollars, CY77

(2) indicates two units required

TABLE 4

NORMALIZED PHASE I COST DATA FOR DEVELOPMENT AND PRODUCTION

COST ELEMENT	ARPV LVDC		HALE AC/DC		MINI-RPV LVDC		TEDS VSVF	
	AVERAGE		AVERAGE		AVERAGE		AVERAGE	
	DEV	PROD	DEV	PROD	DEV	PROD	DEV	PROD
Generator	36	0.41	53	2.56(2)	20	2.1	25	1.0
Power Control Unit	114	1.43	113	4.12(2)				
Regulator/Rectifier					(included)			
Power Supply					10	1.27	10	1.23
Battery	10	0.97	26	2.10				
Power Distribution Assembly					3	0.07		
Buy Group	1	6.0	7	7.06	-	0.05	1	0.93
Integration	38	0.56	53	1.08	8	0.11	23	0.26
SYSTEM TOTALS	199	9.37	252	16.92	41	3.60	59	3.94

Dev. = Development Cost

Avg. Prod. = Average Production Cost

Costs in thousands of dollars, CY 77 basis

(2) indicates two units required

TABLE 5

REVISED COST DATA FOR SYSTEM MOCKUP DEVELOPMENT AND TEST

COST ELEMENT	ARPV LVDC		HALE AC/DC		MINI-RPV LVDC		TEDS VSVF	
	DEV.	MAT'L.	DEV.	MAT'L	DEV.	MAT'L	DEV.	MAT'L.
Generator	25	8	25	16	20	4	25	8
Power Control Unit	60	4	60	8				
Regular/Rectifier					(included)			
Power Supply					10	2.5	10	2.5
Controller/Data Bus (1)	16	4	20	10	12	3	14	3
Battery	10	2	26	4				
Power Distribution Assembly					3	0.2		
Buy Group	1	12	6	14	-	0.1	1	2
Integration	38	1	53	2	18	0.2	23	0.5
Test	40		60		25		30	
Technical Reports	30		40		20		20	
SYSTEM TOTALS	230	31	290	54	110	10	123	16

Dev. = Development Cost

Mat'l. = Material Cost

Costs in thousands of dollars, CY77 basis

(1) includes central microprocessor, software, and data bus, where one is used.

4.1.6 Other Considerations

In addition to the more significant factors discussed in the previous sections, several lessor factors are worth mentioning.

The laboratory does not have 28 VDC power available. Therefore it must be supplied either by a transformer/rectifier/regulator operating from normal 400 Hz or 60 Hz lab power or by driving the RPV system generator itself as a DC source. The level of DC power needed is generally on the order of 1-10 KW, which is a relatively small value. Therefore the preferred approach is to provide a small 28 VDC supply rather than depend on running the RPV system generator for power. This power would normally be used for check-out and maintenance.

The Digital Testing System performance is more than adequate for 400 Hz systems. However its performance will be reduced for 4000 Hz systems, expecially where many data channels are needed. The number of samples per cycle is a tenth that available at 400 Hz. Therefore, the number of available data channels may have to be reduced in some instances to obtain an adequate sampling rate for transient and higher harmonic data.

4.2 RECOMMENDED APPROACH

4.2.1 Summary

This section presents the recommendations for the RPV hot bench design based on the requirements, available facilities, alternatives, and design considerations discussed in the preceding sections. After summarizing the recommendations, the ARPV mockup will be described as a detailed example, because it has the highest priority of the four RPV classes. The remaining classes will then be summarized briefly, since the details will be the same according to our concept of a common approach. Included in the description of each mockup is a schematic, panel layout, list of components with part numbers, and a list of components requiring development with potential developers.

The recommended hot bench design employs a wall-mounted frame on which aluminum circuit panels are mounted contiguously in a vertical array, as indicated in Figure 22. The panels are a standard 36-inch width with a height variable from 12 to 48 inches as needed to suit the application. The vertical location is adjustable in two-inch increments.

The preferred location is on the north face of the wall separating the assembly area from the generator drive stand room, as depicted in Figure 23. This location offers a free standing wall space large enough to accommodate a five bay panel and up to 90 square feet of panel area. The mock-up is outside the generator room and thereby offers reduced ambient noise levels. It is in reasonable proximity to all three generator mounting pads, the interconnection boxes, and the control room. The interconnection boxes provide interfaces to the control room, load banks, and instrumentation. The wall space is located in an area where visitors can easily observe the experiment in progress.

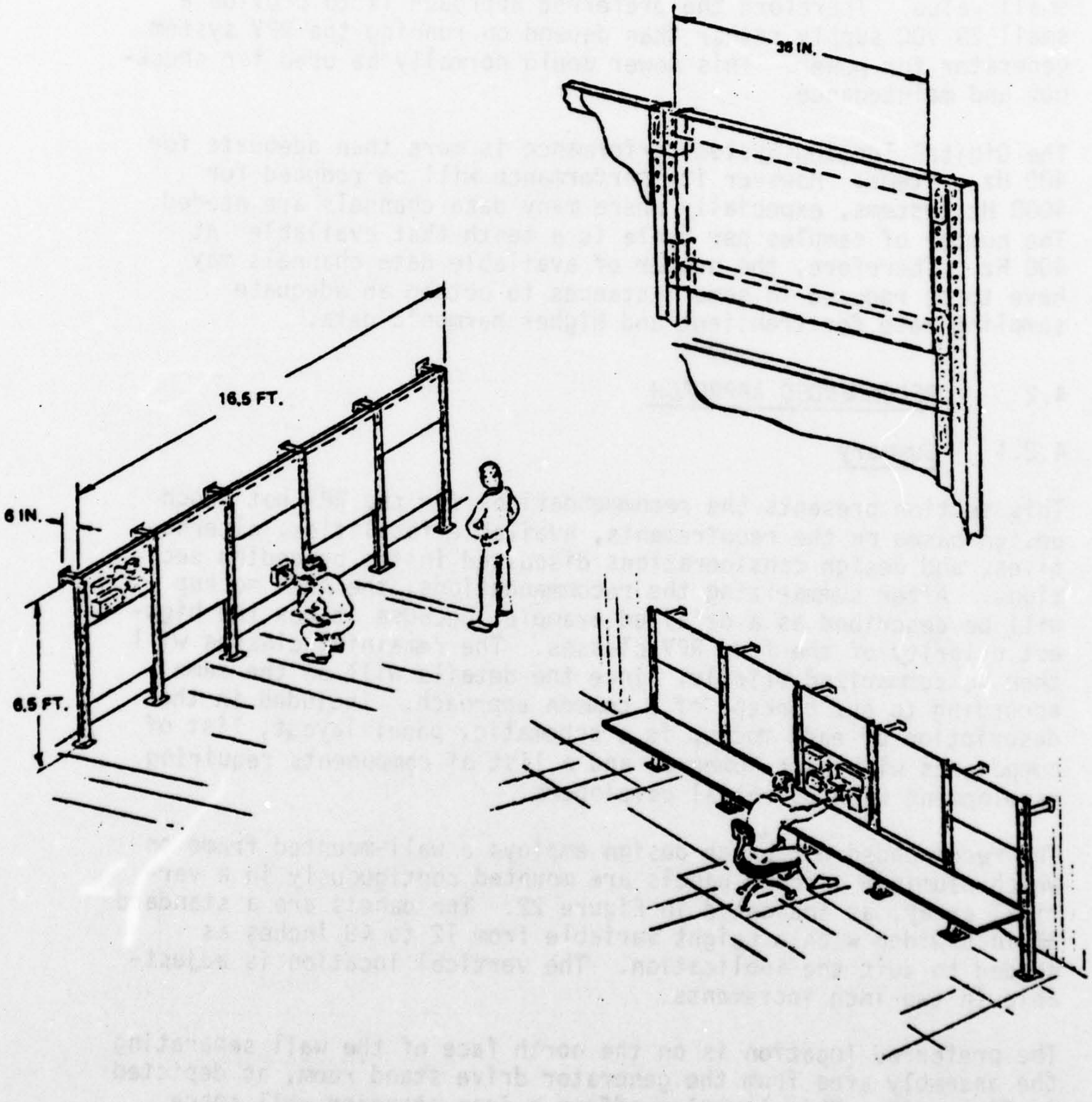


Figure 22. Hot Bench Design Wall Mounted Frame

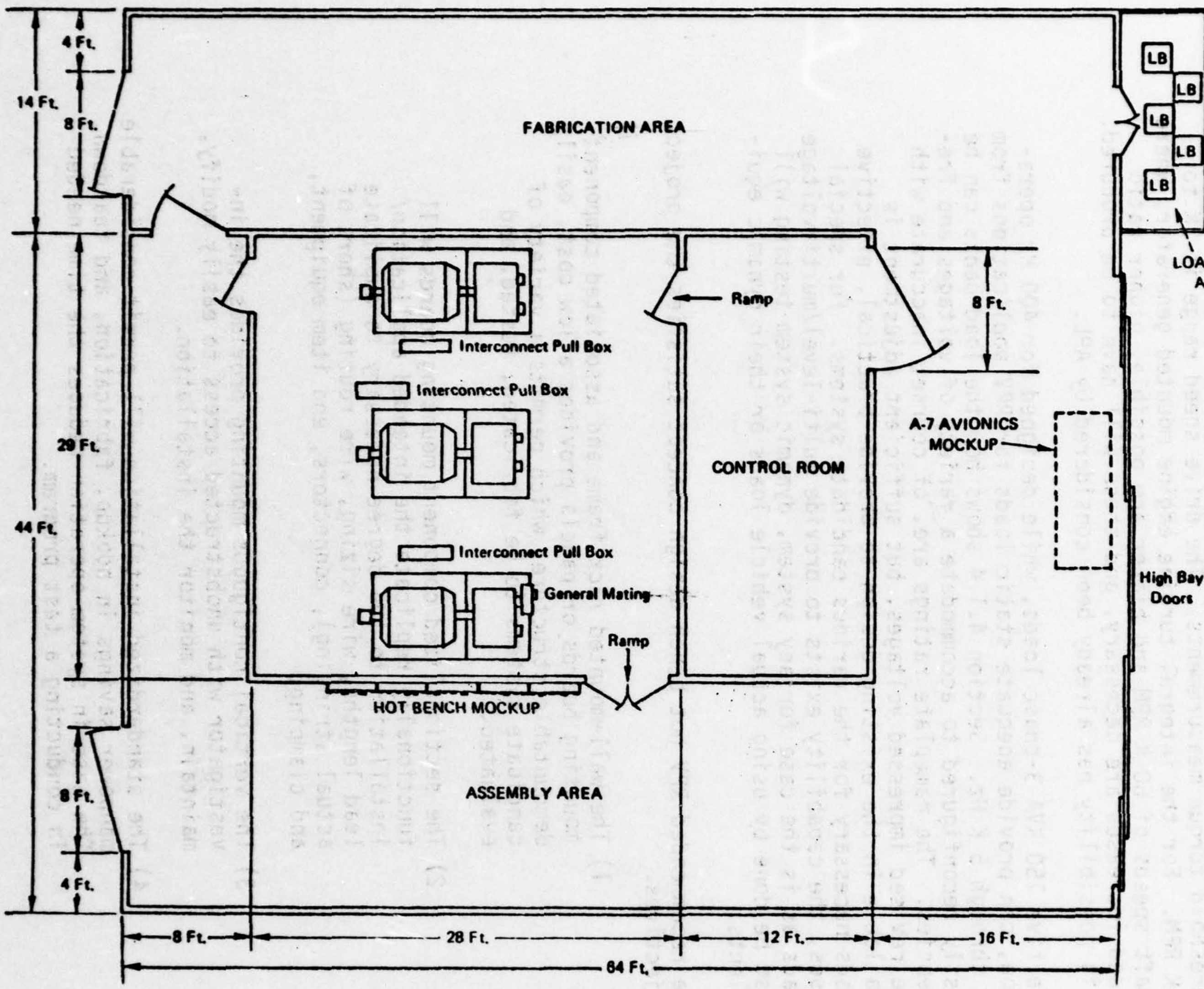


Figure 23. Mockup Location

The existing generator drives can be used as is for most present applications, except for specific examples where integral, engine-mounted generators are being considered. The limitation of the present drives is in the available speed range and the high-threshold torque measurements. The drive speed range is 2K to 30K RPM. For the integral turbine engine mounted generator, where shaft speeds of 60 K RPM and higher are possible, higher ratio speed increases are necessary, and these will have to be procured. This possibility has already been considered by APL.

The five 150 KVA 3-phase loads, while designed for 400 Hz operation, can provide adequate static loads for RPV applications from DC through 5 K Hz. Section 4.1.4 shows how the load banks can be easily reconfigured to accommodate a variety of voltages and frequencies. The nameplate ratings are, of course, inaccurate with the revised impressed voltages, but sufficient adjustment is available in the existing design to provide practical, effective loads necessary for the various candidate systems. For special cases, the capability exists to provide multi-level/multi-voltage loads as is the case for any system, dynamic system testing will best be done by using actual vehicle loads or their dynamic equivalents.

The recommended RPV hot bench design concept satisfies the project objectives.

1) The wall-mounted rack frame and associated component mounting boards or panels provides a low cost, easily demountable structure, which permits a variety of candidate systems to be fabricated, tested, and evaluated.

2) The sectionalized component mounting boards will functionally replicate the intended application/installation to the degree necessary to duplicate lead lengths, wire sizing, wire routing (short of actual stringing), connectors, end item equipment, and clamping.

3) The vertical contiguous mounting provides the investigator with unobstructed access to easily modify, maintain, and monitor the installation.

4) The standardized installation will permit considerable manpower savings in hookup, fabrication, and teardown. The ease in system operation reduces the time needed in conducting a test program.

4.2.2 ARPV Mockup

The Phase 1 effort concluded that a LVDC system is the best approach for the ARPV; Section 3.3 includes a brief description of that system as extracted from the Phase 1 report. Since the ARPV has the highest priority importance of the four RPV classes, we have concentrated on it to develop the recommended hot bench design concept. This required expanding the LVDC design to include additional circuit details as a basis for a mockup layout on the circuit panels. This task was also done for the other three classes. The resulting layouts helped determine the panel space needed, the optimum partitioning for multiple panel systems, and interpanel wiring requirements. Panel space requirements were also estimated for mounting vehicle loads, including the central processor, real or simulated payloads and avionics, and actuators operating into spring loads. These data went into the selection of the 36-inch panel width as being a standard for all panels to establish the common frame configuration.

Therefore the LVDC system shown in Figure 9 has been expanded and re-organized as shown in Figure 24. The two-bus system remains as the standard for RPVs, composed of an essential and an emergency bus. The battery is placed on the emergency bus following purging of extraneous loads. The battery is optimally sized for the return-to-base electrical loads. The avionics system will contain a central microcomputer with a data bus, various flight data sensor packages (simulated), and a surface actuator group. Although the basic vehicle requirements are yet to be precisely defined, we have assumed that a basic return-to-base/recovery backup mechanism will be included. Accordingly this candidate design has incorporated provisions for flight safety vehicle control, a backup communications link with associated interfaces, and a parachute for emergency recovery.

The ARPV equipment is laid out onto three panels: (1) main electrical system control and distribution (Figure 25), (2) avionics loads, including the central microcomputer (Figure 26), and (3) electro-magnetic actuators Figure 25). Panels 1 and 2 are two feet high; panel 3 is one foot high. The generator power control unit is included on the first panel, although it may very well be located separately next to the generator to better approximate line lengths found in an RPV.

The central microcomputer mounted on the avionics load panel consists of a commercial single board computer, power supply, real time clock, and input/output/data bus cards in a standard rack. The RF transmitter and fuel pump are included as examples of optional vehicle equipment that could be used as real loads. These represent electrical noise generators found on all RPV.

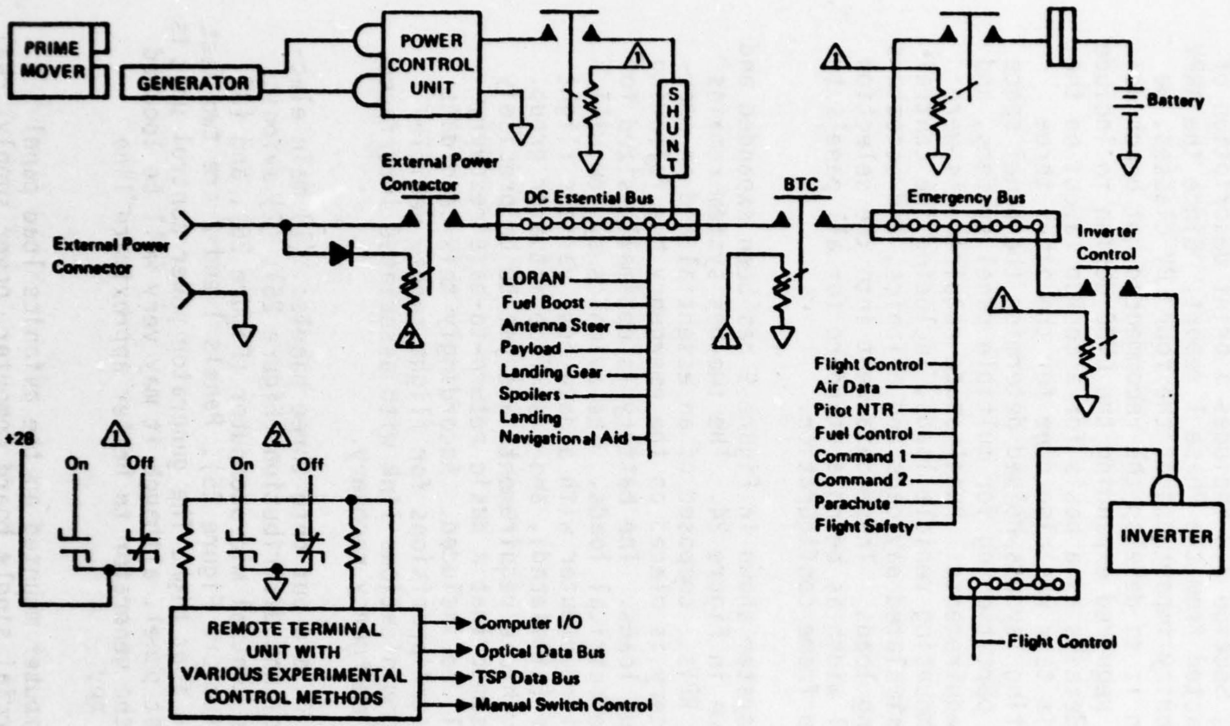
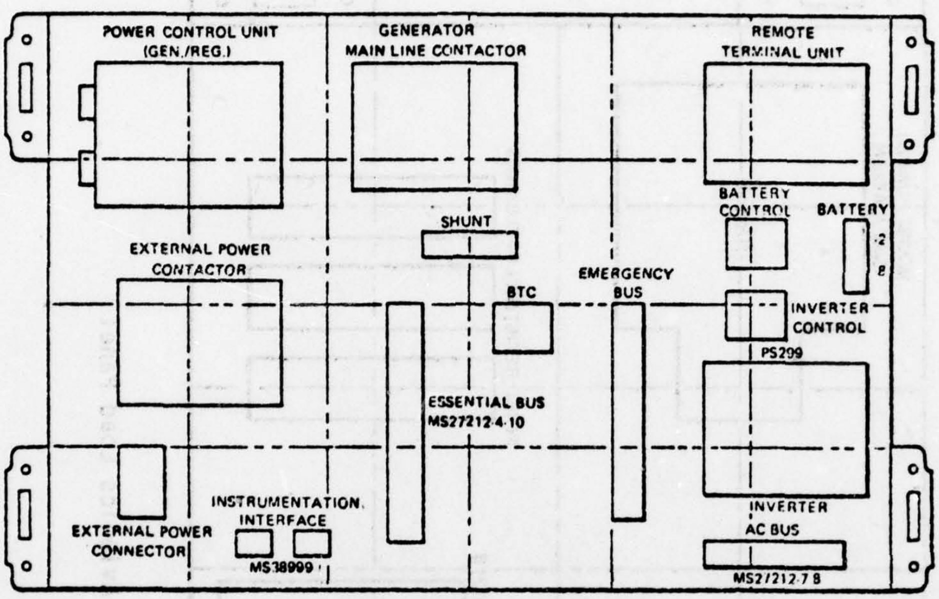
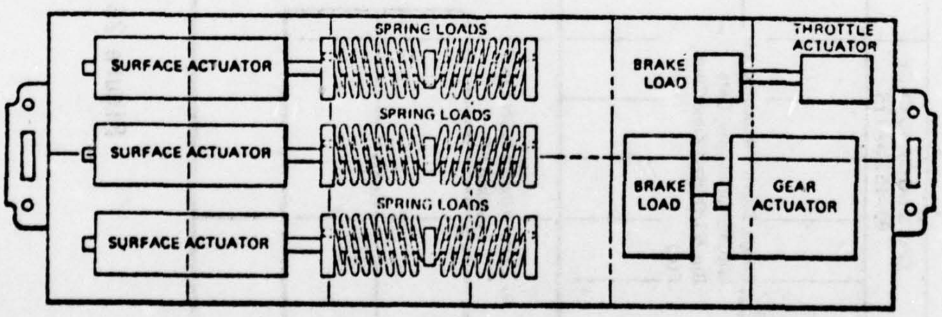


Figure 24. ARPV Mockup Schematic



ARPV LV DC SYSTEM



ACTUATOR LOAD MOUNTING BOARD

Figure 25. ARPV Hot Bench Mockup

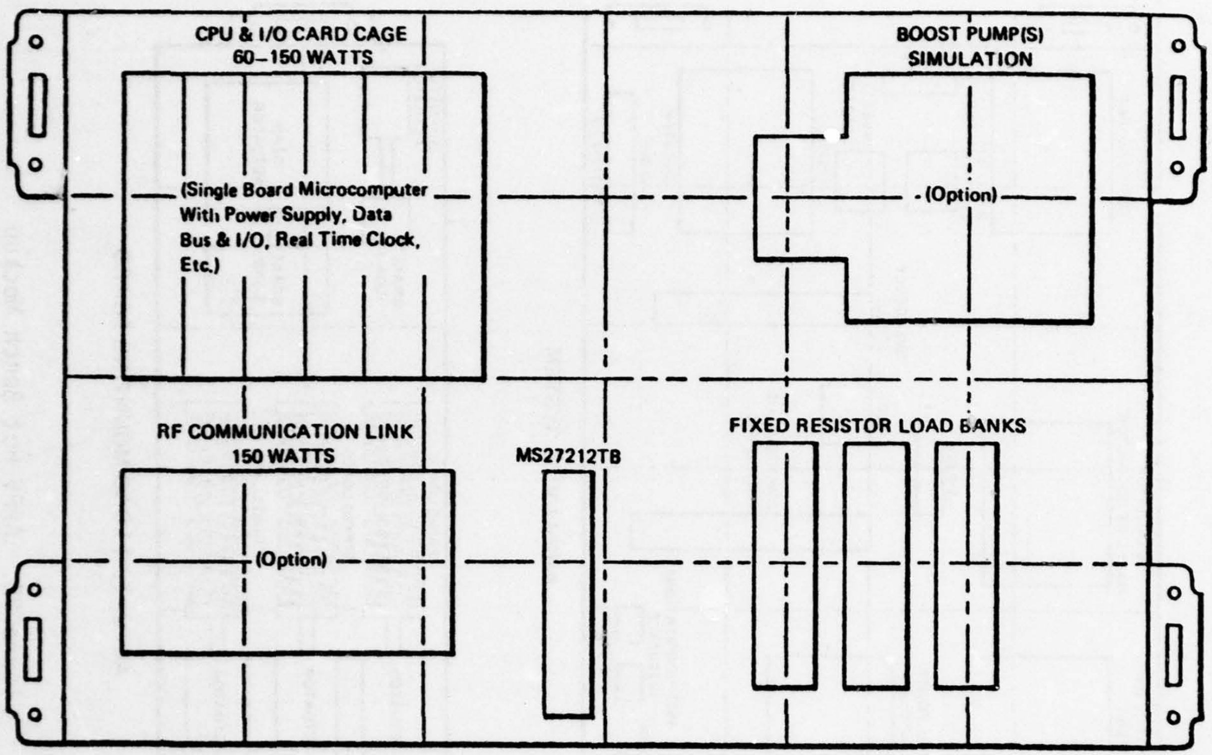


Figure 26. ARPV Avionics Load Panel

The flight control actuators typically possess load switching characteristics which are difficult to duplicate. A component mounting board is assigned to this function. For a larger or more complex ARPV, such as a controlled configured vehicle having multiple actuators, multiple boards could be required.

The interfaces with the generator room, load banks, and control room should be standardized so as to facilitate interchange with other vehicle component mounting boards, i.e., HALE, MINI, TEDS. The instrumentation connectors, power connector(s), and load bank connectors would provide individual circuit coding. Circular connectors having 5015 type inserts and standard MS 27212 terminal strips provide low cost interfaces to the various busses. The hot bench construction will produce lead lengths and separations that approximate those expected in an ARPV.

Checkout of the assemblies would be performed by conventional incremental circuit isolation techniques. Final system tests could then be performed on the rack frame upon installation. Instrumentation checkout is also incremental. However, preassigning channels and wiring interfaces to each component mounting board would permit simple preconnection verification. This would help reduce manpower requirements.

A transformer/rectifier/regulator operating from either 400 Hz or 60 Hz lab power is recommended to provide 28 VDC power to eliminate the nuisance of starting the drive stands until actual generator tests are required. Additionally, much of the conventional system tests could be accomplished with this power source.

Table 6 contains the listing of equipments that are used on the ARPV mockup. Selected items are flagged as also being appropriate to the HALE vehicle equipment listing. As discussed in the next section, one half of the HALE generation and control system could support the ARPV development requirements - or vice versa. Selected items suggested for additional development are listed in Table 7.

TABLE 6

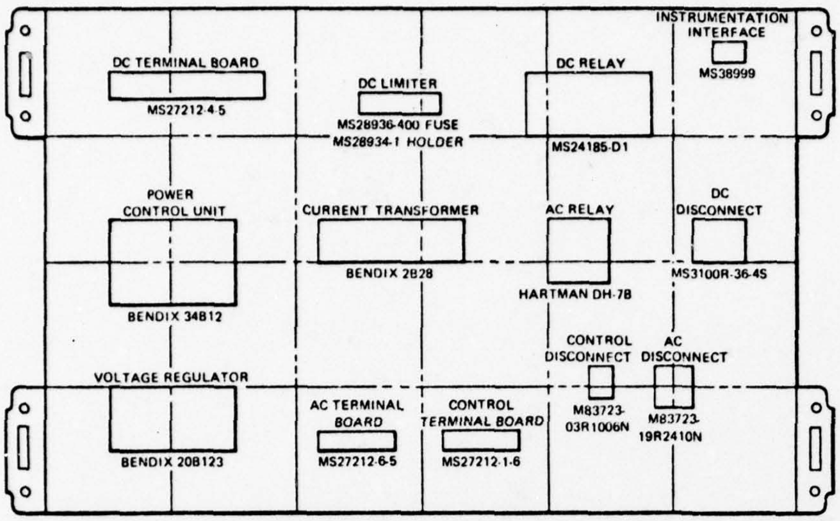
PARTS LIST FOR POWER CONTROL PANEL - ARPV

COMPONENT	VENDOR	P/N	APPROX. COST	APPROX. DELIV.	APPROX. SIZE	APPROX. WT.	APPLI. HALE
Generator	Electro-Kinetics	Similar to EKC 5066	8000.00	32 weeks	Vol 250"^{3}	26 lbs	x
Generator Line Contactor	Hartman	A-751 Type	300.00	16 weeks	7.0 x 5.2 x 3.7	5.9 lbs	x
External Power Contactor	Hartman	A-751 Type	300.00	16 weeks	7.0 x 5.2 x 3.7	5.9 lbs	x
Shunt	---	MS91587-5	50.00	6 weeks	1.8 x 3.2 x 1.4	0.8 lbs	x
Inverter Control Relay	---	MS27400-1	38.00	16 weeks	1.0 x 1.7 x 1.0	0.17 lbs	No
Battery Bus Tie Contactor	---	MS24140-D1	82.10	16 weeks	2.7 x 2.8 x 2.7	0.95 lbs	No
Connector	---	MS3126E-14-5S	7.22	16 weeks	1.50 x 2.0	0.25 lbs	No
Bus Tie	---						
Contactor		MS24182-D1	80.00	16 weeks	3.6 x 2.9 x 3.0	1.15 lbs	No
Battery	Eagle Picher	New	800.00	24 weeks	6.2 x 7.8 x 4.8	16.5 lbs	No
Boards	---	MS27212-2-5	1.16	8 weeks	1.0 x 1.1 x 5.0		No
Terminal		2-4	1.16	8 weeks	1.0 x 1.1 x 4.2		No
		MS27212-2-3	1.1	8 weeks	1.0 x 1.1 x 3.5		No
Inverter	EMP	PS-299	1300.00	13 weeks	7.0 x 5.5 x 4.8	6.5 lbs	No
Power Control Unit	EKC	(Integral with Generator)					

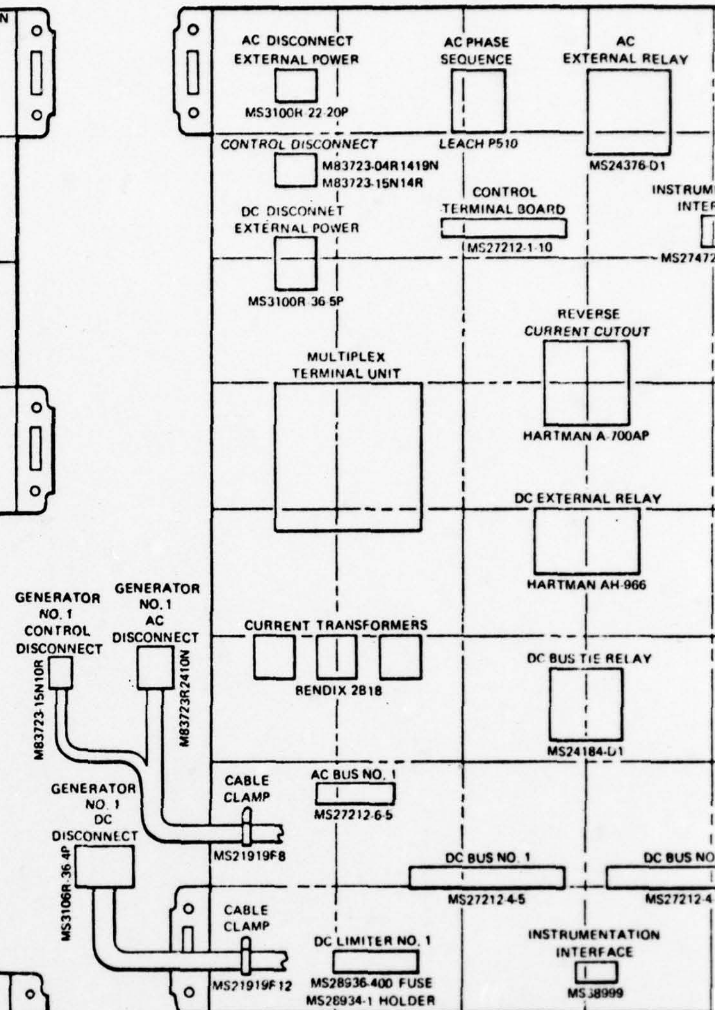
TABLE 7

ITEMS OF DEVELOPMENT INTEREST APPLICABLE TO THE ARPV VEHICLE

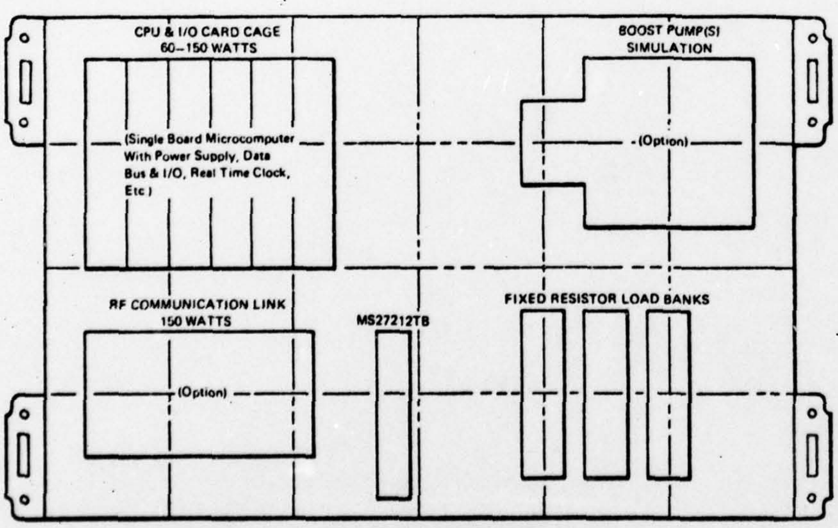
SUBJECT	POSSIBLE VENDORS
Integrated data bus control with electrical power interfaces and control elements	In House (AFAPL-AFAL) TRA SRL Harris Semiconductor
Integral turbine engine driven generators	Continental Lycoming GE Garrett Electro-Kinetics Simmonds Electro Pacific LSI Garrett GE Electro Kinetics
External power/internal power - uninterrupted power transfer methodology	In House (AFAPL-AFAL) TRA SRL
Monolithic voltage regulators and system components	Harris Motorola Texas Instruments ITT National Semiconductor
High efficiency actuator motors	LSI GE Globe Lucas Aerospace Superior Electric
Fibre optic data bus and associated interfaces	Spectronics ITT In House (AFAL) Valtec Hughes Aircraft



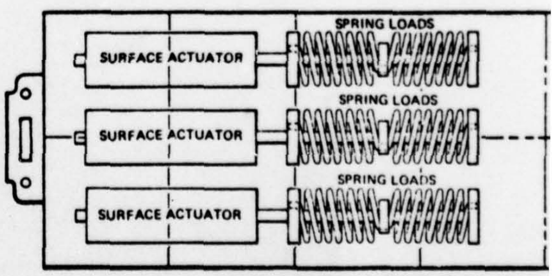
GENERATOR NO. 1 CONTROL HALE (LH)



POWER CONTROL HALE A



AVIONICS LOAD PANEL



ACTUATOR LOAD MOUNTIN

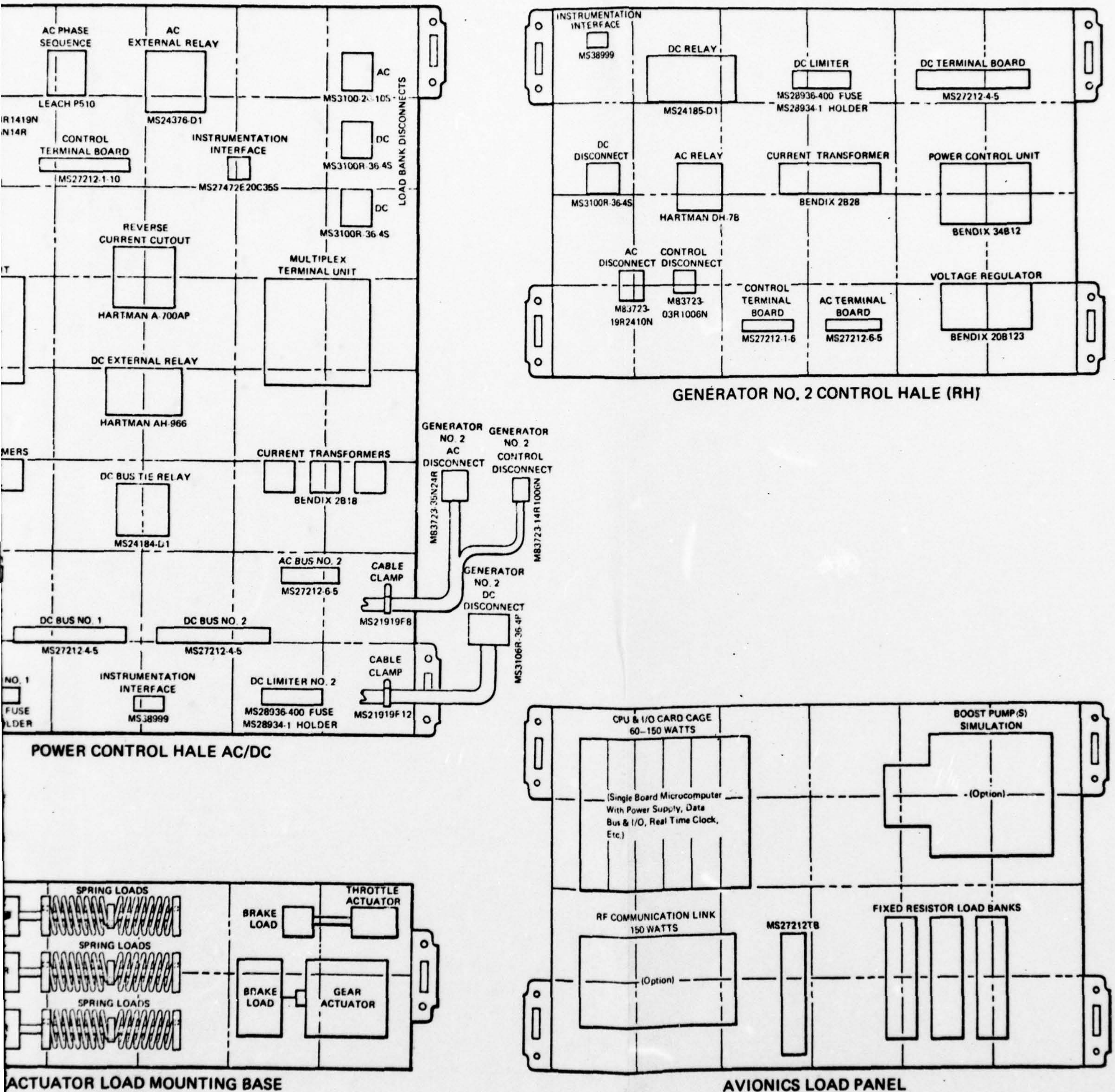


Figure 27. HALE RPV Panel Layouts

4.2.3 Other Class RPV Hot Bench Mockups

HALE RPV

The HALE vehicle is an AC/DC system, having redundant power and utilization equipment. The basic schematic diagram, Figure 10 taken from the Phase 1 report, is in sufficient detail to structure the component panel, Figure 27. The sizing of these boards were made on a trial basis. They consist of dual generator control boards, the power control board, dual avionics load boards (same as Figure 26), and an actuator board. The power control board provides the power bus interfaces to the individual AC/DC generator systems. This board is four feet high; the generator control boards are two feet high.

The component list for the HALE vehicle includes several DC components that are also used with the ARPV vehicle. Accordingly, one half of the HALE system (located on two boards) could also serve as the ARPV mockup. Space utilization would not be efficient; however, full control would be available and only one set of hardware could supply both mockups.

The component list for the HALE vehicle is contained in Table 8. Selected items are suggested for additional development effort, and are contained in Table 9.

MINI-RPV

The Mini class vehicle is a low power system having two viable configurations; a single output generator and a multiple output supply. Both configurations are sized approximately the same thereby permitting either type to be installed on a two-foot high component panel.

Figure 11 represents the single line schematic. Figure 28 shows the Mini component panel with trial placement of the various system elements.

As with all interfaces, standardization of the instrumentation and bus connections permit simple rapid installation and checkout. The component list for the Mini, in either configuration, is contained in Table 10. Selected items are suggested for additional development effort and are contained in Table 11.

TABLE 8

PARTS LIST FOR HALE RPV AC/DC

POWER CONTROL PANEL

COMPONENT (Description)	VENDOR	PART NUMBER	APPROXIMATE COST	DELIVERY
Connector Elec	MIL-C-83723	M83723-14R1006N	7.50 (76)	20 weeks
Backshell - Conn	MIL-C-83723	M83723-15N10R	3.00 (76)	20 weeks
Connector Elec	MIL-C-83723	M83723-24R2410N	60.00 (76)	20 weeks
Backshell - Conn	MIL-C-83723	M83723-35N24R	3.00 (78)	20 weeks
Connector - Elec	MIL-C-83723	M83723-04R1419N	16.00 (Est)	20 weeks
Backshell - Conn	MIL-C-83723	M83723-15N14R	3.00 (Est)	20 weeks
Connector - Elec	MIL-C-5015	MS3106R-36-4P	12.60 (76)	20 weeks
Connector - Elec	MIL-C-5015	MS3100R-36-4S	12.60 (Est)	20 weeks
Connector - Elec	MIL-C-5015	MS3100R-24-10S	12.00 (Est)	20 weeks
Clamp - Cable		MS21919F12	2.00 (Est)	
Clamp - Cable		MS21919F8	2.00 (Est)	
Limiter - Current		MS28396-400	3.00 (Est)	
Holder Limiter		MS28394-1	5.00 (Est)	
Board Terminal		MS27212-4-5	5.00	8 weeks
Board Terminal		MS27212-6-5	7.80	8 weeks
Board Terminal		MS27212-1-10	4.30	8 weeks
Relay		MS24184-01	300.00 (Est)	10 weeks
Relay		MS24376-01	300.00 (Est)	10 weeks
Relay	Hartman	AH-966	400.00 (Est)	10 weeks
Reverse Current Cutout	Hartman	A-700AP	500.00 (Est)	12 weeks
Relay Phase Sequence (Alternate) (Alternate)	Leach Hartman HI-G	P510-E-AB AVR-985 1438-1B	400.00 (Est)	12 weeks
Transformer Current	Dev Item			
Inverter 28 DC to 115 AC	EMP	PS-299	1300.00	90 days ARO

TABLE 8

PARTS LIST FOR HALE RPV AC/DC (Continued)

GENERATOR CONTROL PANEL

COMPONENT (Description)	VENDOR	PART NUMBER	APPROXIMATE COST	DELIVERY
Connector Elec	MIL-C-5015	MS3100R-36-4S	13.00 (Est)	20 weeks
Limiter Current		MS28936-400	3.00 (Est)	
Holder Limiter		MS28934-1	5.00 (Est)	
Board Terminal		MS27212-4-5	5.00	8 weeks
Board Terminal		MS27212-1-10	4.30	8 weeks
Board Terminal		MS27212-6-5	7.80	8 weeks
Relay	Hartman	A-571 (Type) or MS24185-D1	300.00 (Est)	10 weeks
Relay	Hartman	DH-7B	300.00 (Est)	10 weeks
Transformer Control	Development Item			
Generator 20 KW DC 20 KVA AC	Development Item			
Power Control Unit	Dev Item			
Regulator Voltage	Dev Item			
Connector - Elec	MIL-C-83723	M83723-03R1006N	15.10 (76)	20 weeks
Backshell - Conn	MIL-C-83723	M83723-15N10R	3.00 (76)	20 weeks
Connector - Elec	MIL-C-83723	M83723-19R2410N	60.00 (Est)	20 weeks
Backshell - Conn	MIL-C-83723	M83723-35N24R	5.00 (Est)	20 weeks

TABLE 9

ITEMS OF DEVELOPMENT INTEREST APPLICABLE TO THE HALE VEHICLE

SUBJECT	POSSIBLE VENDORS	
Integrated data bus control with electrical power interfaces and control elements.	In House (AFAPL, AFAL) TRA SRL Harris Semiconductor	
Optical data bus and associated interfaces	ITT In House SRL Spectronics	
Integral turbine engine driven generators	Continental Lycomming GE Garrett Electro Kinetics	Simmonds Electro-Pacific LSI Garrett GE Electro Kinetics
High voltage switch gear	GE LSI Bendix Hartman	
Monolithic voltage regulators and system components	Harris Motorola Texas Instruments ITT	
Fibre optic data bus and associated interfaces	Spectronics ITT In House (AFAL) Valtec Hughes Aircraft	

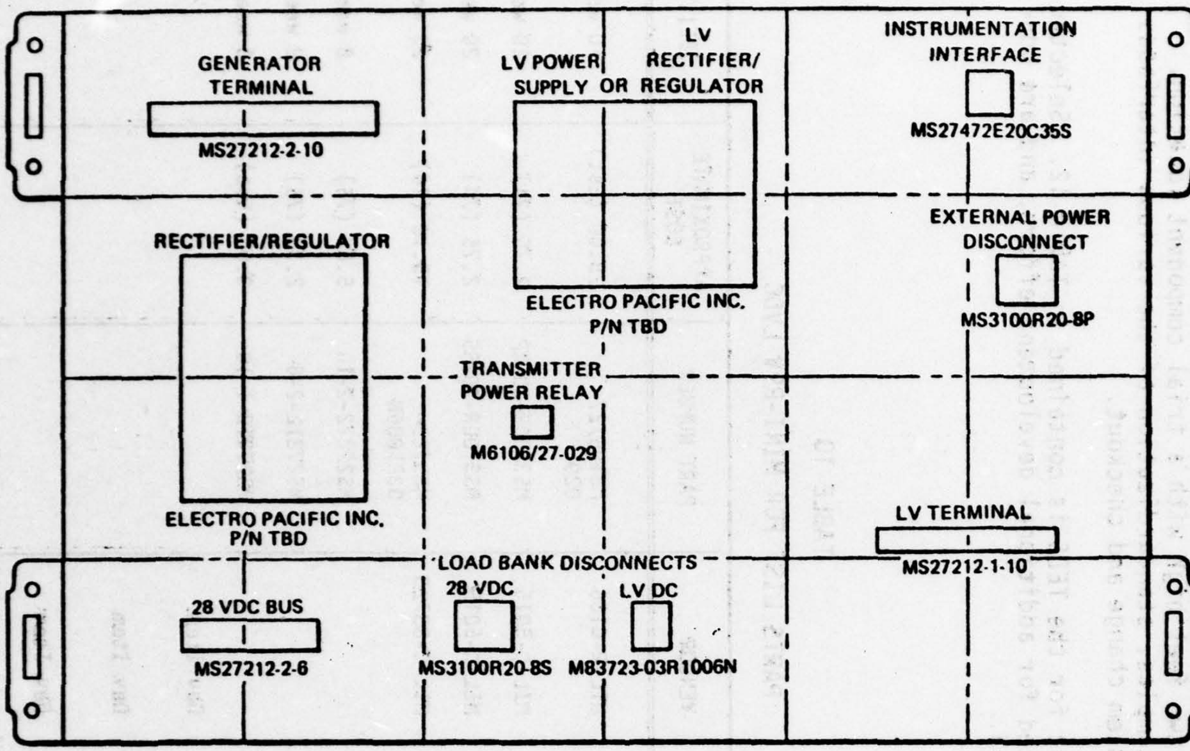


Figure 28. Mini-RPV Panel Layout

TEDS

The recommended TEDS vehicle EPS is the VSVF wild frequency concept. Figure 12 represents a single line schematic of a high voltage transmission, variable frequency system. Figure 29 shows the component panel, two feet high with a trial component location. As in previous examples, standardization of the various interfaces permits rapid system change and checkout.

The component list for the TEDS is contained in Table 12. Selected items are suggested for additional development effort, and are contained in Table 13.

TABLE 10

PARTS LIST FOR MINI-RPV LVDC

COMPONENT (Discrepancies)	VENDOR	PART NUMBER	APPROXIMATE COST	DELIVERY
Relay	MIL-R-6106	M6106/27-029	25.00 (Est)	10 weeks
Connector - Elec	MIL-C-5015	MS3100R-20-8P	2.75 (74)	20 weeks
Connector - Elec	MIL-C-5015	MS3100R-20-8S	2.75 (74)	20 weeks
Connector - Elec	MIL-C-83723	M83723-03R1006N	15.10 (76)	20 weeks
Board Terminal		MS27212-2-10	5.00 (76)	8 weeks
Board Terminal		MS27212-2-6	2.30 (76)	8 weeks
Board Terminal		MS27212-1-10	3.00 (Est)	8 weeks
Rectifier/ Regulator	Dev Item			
Generator 28 VAC	Dev Item			
LV Power Supply	Dev Item			

TABLE 11

ITEMS OF DEVELOPMENT INTEREST APPLICABLE TO THE MINI VEHICLE

SUBJECT	POSSIBLE VENDORS	
High speed reciprocating engine shaft driven generators and associated regulators	Continental Lycomming GE Garrett	Simmonds Electro-Pacific LSI Garrett GE Electro Kinetics
High frequency (4000 Hz) magnetic components, and power supplies	Triad TDC Freq. Technology UTC Abbott Labs	
Monolithic voltage regulators and system components	Harris Motorola Texas Instruments ITT National Semi-Conductor	
High efficiency actuator motors	LSI GE Globe Lucas Aerospace Superior Electric	

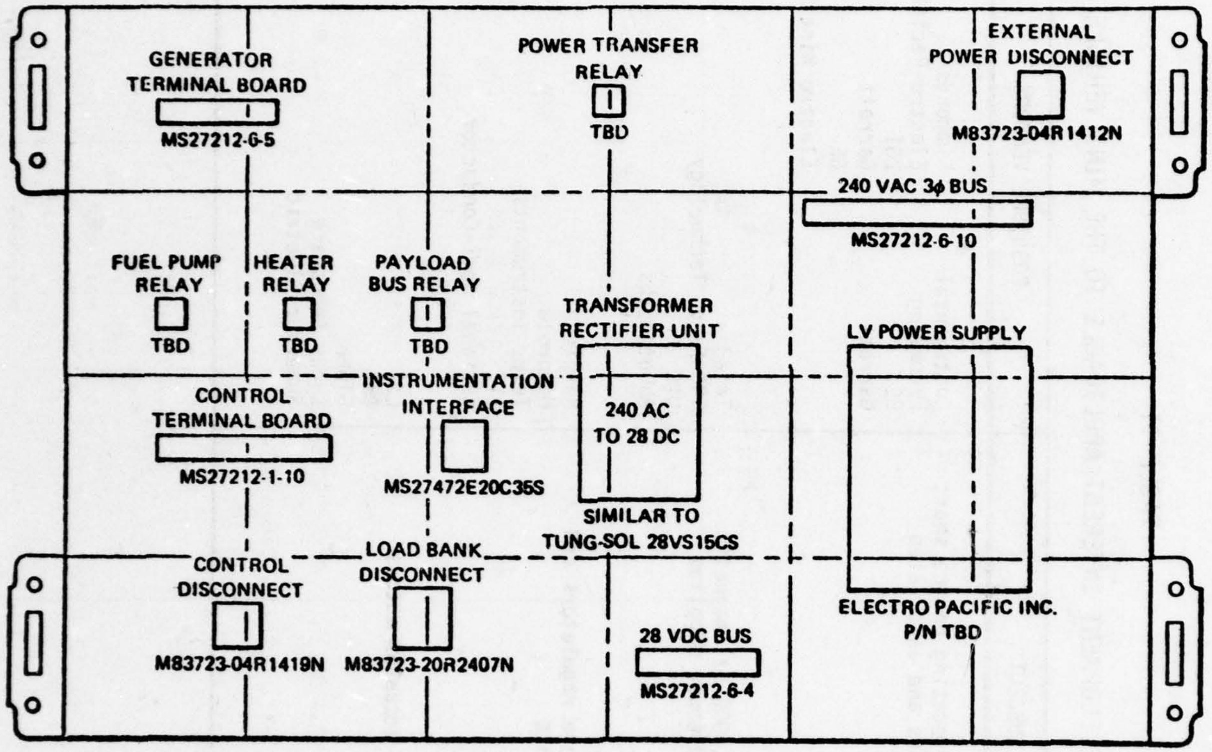


Figure 29. TEDS Panel Layout

TABLE 12

PARTS LIST FOR TEDS VSVF SYSTEM

COMPONENT	VENDOR	PART NUMBER	APPROXIMATE COST	DELIVERY
Connector - Elec	MIL-C-83723	M83723-04R1412N	16.00 (Est)	20 weeks
Connector - Elec	MIL-C-83723	M83723-04R1419N	16.00 (Est)	20 weeks
Connector - Elec	MIL-C-83723	M83723-20R2007N	20.00 (Est)	20 weeks
Board Terminal		MS27212-6-5	5.80 (Est)	8 weeks
Board Terminal		MS27212-6-10	7.00 (Est)	8 weeks
Baard Terminal		MS27212-6-4	5.00 (Est)	8 weeks
Board Terminal		MS27212-1-10	3.00 (Est)	8 weeks
Backshell - Conn		M83723-15N14R	3.00 (78)	20 weeks
Backshell - Conn		M83723-35N20R	3.00 (78)	20 weeks
Transformer Rectifier Unit	Dev Item			
Power Supply Low Voltage	Dev Item			
Relay	Leach	Similar to KC-D2A-022	900.00 (Est)	12 weeks
Relay	Leach	Similar to KDA-D4T-013	75.00 (Est)	12 weeks
Generator 240V 3 Ø Y	Dev Item			

TABLE 13

ITEMS OF DEVELOPMENT INTEREST APPLICABLE TO THE TEDS VEHICLE

SUBJECT	POSSIBLE VENDORS	
Integral turbine engine driven generators	Continental Lycomming GE Garrett	Simmonds Electro-Pacific LSI Garrett GE Electro Kinetics
Hot gas integral turbine driven power supplies (alternate)	Sundstrand TRW LSI Garrett	Electro Kinetics
Long term thermal batteries (5KW 40 minutes)	Sonotone Eagle Picher Catalyst Research Leesona Mooos	
High frequency magnetic components/ power supplies	Triad UTC TDC Freq Tech Abbot Labs	
Monolithic voltage regulators and system components	Harris Motorola ITT Texas Instruments National Semi-Conductor	

SECTION V

DEVELOPMENT AND DEMONSTRATION PLANS

5.1 INTRODUCTION

This section presents the plans for developing and demonstrating RPV electric power systems. The development plan, which is presented first, is based on the approach recommended and described in Section 4.2. The plan has five parts: one for the basic framework that is common to all mockups and one for each of the four classes of RPV.

The subject of testing RPV electrical systems is presented as a guide to developing test plans rather than as a demonstration test as such. The discussion is generic in that it encompasses the types of tests that would typically be performed on any class of RPV. As the specific system to be demonstrated becomes better defined, the test plan can be made specific.

The schedules and material and labor costs associated with the plans were developed from the PRICE runs made during the Phase I study, discussions with vendors, and engineering judgment. The resulting data are adequate for planning purposes, although they lack the supporting details needed to provide firm estimates.

The developmental aspects of the plans are consistent with the results of the Phase I study (Section 2.3), which concludes that major improvements over existing systems in weight, volume, cost, reliability, and maintainability with equal or better performance are attainable without major technology development by using the currently available state of the design art. Therefore, the limited development that is required concerns re-sizing components or adapting technology and design techniques to RPV applications.

5.2 DEVELOPMENT PLANS

The purpose of the Development Plan is to provide planning data for future RPV electric power system programs for technology development and feasibility demonstrations. The planning data are consistent with and based upon the results of the Phase I Technology Assessment study. It therefore encompasses the four classes of RPV: ARPV, HALE RPV, TEDS, and Mini-RPV. Obviously, other classes of vehicles, such as cruise missiles, can also be served by similarity. The Development Plan has five parts to provide planning flexibility. The first part is for the basic mockup framework that is common to and supports all mockups. The basic framework encompasses essentially the common mechanical, electrical, and electronic interfaces between the laboratory facilities and the electric power system mockups themselves. The remaining four parts treat each of the four classes of RPV. Therefore the initial program would consist of the framework plan (part one) plus one of the RPV plans. Once the framework has been completed, the other RPV plans (or cruise missile or manned aircraft plan for that matter) can be implemented as a complete program.

The program schedules presented in Figures 31 through 35 for the development of the five parts are based on the respective system hardware and cost data in Section 4. The development schedules were derived from schedule estimates generated by PRICE analyses in Phase I. These estimates for Mini-RPV and TEDS were augmented slightly to account for estimates from vendors on development items and delivery schedules.

To help develop the program plans, a typical program task flow was developed, shown in Figure 30. The task numbers correlate with those comprising the program schedules. The tasks are described as follows:

Task 1. System Definition. Define the characteristics of the system to be developed in terms of functional, performance and physical requirements; interfaces; constraints; specifications; checkout, test, and maintenance philosophies; and program plans.

Task 2. Detail Design. Design the functional system elements with sufficient detail for procurement, fabrication, checkout, and test; includes hardware and software design for the demonstration system and its support and test.

Task 3. Design Development and Parts Procurement. Design and develop those elements, i.e., hardware components, software, or firmware, that are not considered "off the shelf" and where additional development is needed in areas such as technology application or design technique; procure off-the-shelf system hardware, software support, and test elements.

Task 4. Fabrication and Assembly. Fabricate hardware and develop software elements; assemble and checkout subsystem elements and assemble complete system including data acquisition and test

Task 5. Checkout complete system functions and compatibility.

Task 6. System Test. Test the completed system according to the system test and demonstration plan.

Task 7. Technical Reports. Document the system description, analyses performed, results, and conclusions.

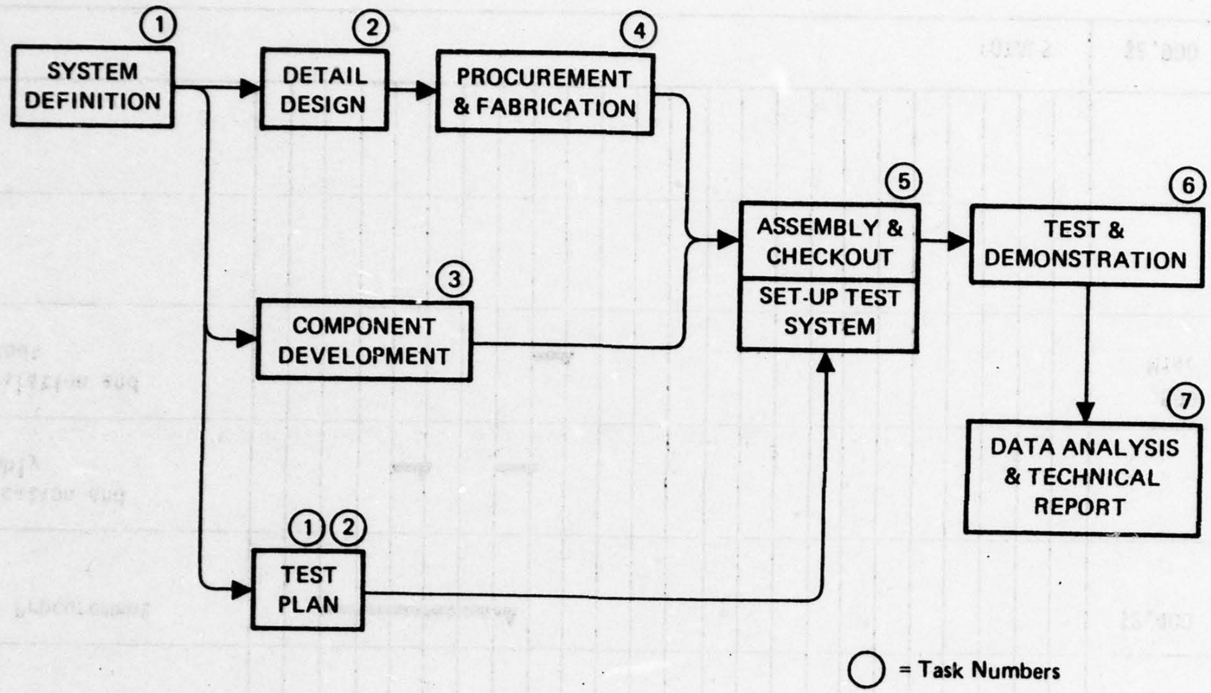


Figure 30. Technology Demonstration Program, Task Flow

TASK	DESCRIPTION	MONTHS OF PROGRAM																								COST	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MATERIAL	LABOR
1	System Definition																										Manhours $4,000
2	Detail Design																										12,000
3	Parts Procurement																									$2,400	6,500
4	Fabrication and Assembly																										8,000
5	Installation and Checkout																									500 Misc	6,000
	TOTALS																									$2,900	$36,500

Figure 31. RPV Electric Power Demonstration System Development Plan, Hot Bench Mockup: Basic Framework

TASK	DESCRIPTION	MONTHS OF PROGRAM																								COST	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MATERIAL	LABOR
1	System Definition																										$10,000
2	Detail Design																										30,000
3	Component Development and Parts Procurement																									$12,000	60,000
4	Fabrication and Assembly																									19,000	40,000
5	System Checkout																										20,000
6	Test and Demonstration																										40,000
7	Data Analysis and Technical Report																										30,000
																									TOTALS	$31,000	$230,000

Figure 32. ARPV Demonstration System Schedule

TASK	DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MATERIAL	LABOR
		MONTHS OF PROGRAM																								COST	
1	System Definition	■	■																								$15,000
2	Detail Design			■	■	■	■																				40,000
3	Component Development and Parts Procurement			■	■	■	■	■	■	■	■															$24,000	65,000
4	Fabrication and Assembly					■	■	■	■	■	■	■														30,000	45,000
5	System Checkout											■	■	■	■												25,000
6	Test and Demonstration															■	■	■	■								60,000
7	Data Analysis and Technical Report																■	■	■	■	■	■					40,000
																									TOTALS	$54,000	$290,000

Figure 33. RPV Electric Power Demonstration System Development Plan for HALE RPV

TASK	DESCRIPTION	MONTHS OF PROGRAM																								COST	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MATERIAL	LABOR
1	System Definition																										$4,000
2	Detail Design																										12,000
3	Component Development and Parts Procurement																									$6,500	28,000
4	Fabrication and Assembly																									3,500	11,000
5	System Checkout																										10,000
6	Test and Demonstration																										25,000
7	Data Analysis and Technical Report																										20,000
																								TOTALS		$10,000	$110,000

Figure 34. RPV Electric Power Demonstration System Development Schedule for Mini-RPV

TASK	DESCRIPTION	MONTHS OF PROGRAM																								COST	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MATERIAL	LABOR
1	System Definition																										$4,000
2	Detail Design																										12,000
3	Component Development and Parts Procurement																									$8,000	35,000
4	Fabrication and Assembly																									8,000	12,000
5	System Checkout																										10,000
6	Test and Demonstration																										30,000
7	Data Analysis and Technical Report																										20,000
																									TOTALS	$16,000	$123,000

Figure 35. RPV Electric Power Demonstration System Development Schedule for TEDS

The length of the schedule for the basic mockup framework, shown in Figure 31, is driven by the delivery schedules for connectors, which currently run from 12 to 16 weeks. The other components can be obtained within a few days to several weeks. Therefore if suitable connectors are already in hand, the schedule could be reduced by three months. This factor may not be important when compared to the delivery schedules for any of the RPV systems.

The length of the development task for each RPV program has been sized to equal the nominal period required to develop a new generator and regulator for an appropriately sized RPV engine using current design and materials technology. Other developmental items of a similar nature may be included, but the generator/regulator development has the longest lead time. Generator development calling for an associated engine development or modification, such as an integral engine generator for an ARPV or a multi-mode APU for the HALE RPV, has not been included. Propulsion related programs tend to be more lengthy and expensive than the ones recommended here; hence they should be treated separately. However such programs can be dovetailed to produce a combined system at a later time.

5.3 TEST PLAN GUIDE FOR RPV ELECTRICAL SYSTEMS

5.3.1 Introduction

This guide is presented to assist in planning a test program for quantitative measurements of an electrical power system. It is not intended as a detailed plan but as a guide to point out differences between manned aircraft and RPVs and parameters which should be considered in RPV testing.

Electrical power systems in RPVs, as with manned aircraft, are evaluated using MIL-STD-704 criteria; hence this document is the most applicable. In some instances, where the avionics have been proven tolerant, voltage excursions can be allowed to exceed the established limits for short periods of time. These instances are evaluated on an individual basis and are the exception instead of the rule.

5.3.2 General Considerations

The prime considerations in an electrical power system test program are power quality and the ability of the EPS to support the loads. The test program on an RPV consists of measuring parameters on DC lines, both generator derived and battery, as well as on AC lines, where in a manned aircraft the considerations deal mainly with AC lines. The following parameters should be considered as they apply to a RPV system:

DC	AC
Voltage	Voltages
Current	Current
Ripple Voltage	Frequency
Ripple Frequency Content	Power
Transients	Transients
	Waveform Distortion
	Phase Balance
	Modulation on Waveforms
	Phase Angle

From the above data the power quality and excess capacity (or deficiency) can be determined.

The types of loads and/or simulation play an important part in the ability to determine the power quality and the ability of the EPS to support the RPV requirements. This will be discussed in greater detail later.

The EPS tests are performed under local ambient conditions. While operation under wide temperature and humidity excursions can affect system performance, the cost of such testing is prohibitive for most RPV systems for the benefits gained. This would certainly be so for concept demonstrations.

Additional test equipment may be required to compliment the digital computer. At the highest sampling rate of 100,000 per second, conversion from analog to digital takes 10 μsec. In a practical aspect, this may be too long to gain sufficient information about a DC transient. Equipment which can capture a transient, give real time analysis, and give it to the computer on request would be a tremendous aid in evaluating an RPV system.

5.3.3 Procedures

Prior to any measurements, a loads analysis is performed to help establish performance evaluation criteria. In this analysis, source and load characteristics are identified. In RPV, sources include batteries, DC generators, AC generators, and inverters. The sources or combination of sources naturally depend on the system.

In the recommended system for the ARPV for example, the sources are a battery, DC generator, and possibly an inverter. The recommended HALE system has a battery and two AC/DC generators. The Mini-RPV system has an AC generator and rectifier - regulator and possibly a battery. The TEDS system power source is a wild frequency generator.

The loads in a system are identified as to their power bus connection, duty cycle (e.g., continuous, 60%, standby and transmit, etc), and current (power) requirements.

Therefore, when the analysis is complete, the sources, their rated capacity, and the total load requirements are known. From these data a test procedure and system demonstration can be formulated.

Using actual loads or a close simulation is very important in testing an RPV system. Some of the loads are non-linear, some reactive, and some resistive. The high switching current or pulsing current levels that are common in RPV payloads usually command a large percentage of the available power budget. This causes variation in power quality and load interactions. In a manned aircraft the effect is also present, but it usually is not as severe. Therefore, in an RPV EPS test, the type of equipment used and the loads it will present should be carefully considered.

Equally important in an RPV is time-history loading. Loads should be energized or de-energized as they would occur in a mission. Where an RPV has multi-configurations, each configuration should be tested since this usually involves major component changes.

The test sequence consists of a simulated RPV mission. The power system is instrumented, the loads (actual or simulated) are installed, and a simulated mission profile is followed. Tests are performed with generators turning at the RPM expected in flight. This requires some knowledge of the installation.

This technique provides a time-history loading of the system and yields information on its ability to support the loads. Equipment does not necessarily have to be energized for the total expected mission time so long as it is sequenced properly. In some cases, equipment will be energized at different times and, due to operational timing, be on simultaneously at some times and not at other times. Where these conditions exist, they must be considered in a test sequence.

5.3.4 Bus/Source Performance

The electrical power system is evaluated by instrumenting each source and/or bus. This involves measurements on a battery bus as well as AC and DC generator derived power. The RPV power distribution usually consists of a main bus, payload bus, and a battery or emergency bus.

ARPV

The ARPV will require mainly DC measurements. Transients, voltage, current, ripple voltage and ripple frequency will be parameters necessary to evaluate this system. DC data will require approximately 8 to 10 channels of data acquisition. Figure 36 indicates where senses points would be located in an ARPV system.

Transients that occur during power change-overs between battery and generator will be of prime importance. With the trend toward computer controlled systems, fast rise-time, short duration (less than 10 milliseconds) transients will create system incompatibilities unless knowledge of the environment exists and precautions are taken. While the capability to measure transients of 400 Hz signals exists, additional laboratory equipment and/or different techniques may be necessary to analyze DC transients.

The battery in this system would be used during recovery. Bus change-over could occur as a result of under voltage or under current sensing depending on system configuration. Data on battery capacity and transient activity during change-over would be required.

The possibility exists that an ARPV may have AC power requirements. In this case in addition to AC voltage and current, parameters such as harmonic distortion, AC transients, etc. would be measured. An additional 2 to 6 channels of data acquisition would be necessary.

HALE RPV

The HALE RPV will require both AC and DC measurements for the recommended hybrid configuration. The evaluation will have to be treated differently from the ARPV. The battery could very well be needed on take-off or landing. Bus change over could occur as a result of current, voltage, or frequency sensing. Battery data, data on transients occurring at bus change over, and voltage extremes must be measured in order to take precautions to preserve computer memory or prevent malfunction.

The AC is a wild frequency, 2 kHz to 5 kHz, requiring a higher sampling rate than that used for 400 Hz. It may be necessary to vary generator RPM during the test sequence to simulate a change in engine RPM that would occur during take off and landing. Eighteen channels of data acquisition (6 DC and 12 AC) would be necessary during a test sequence. Figure 37 shows the recommended sense points.

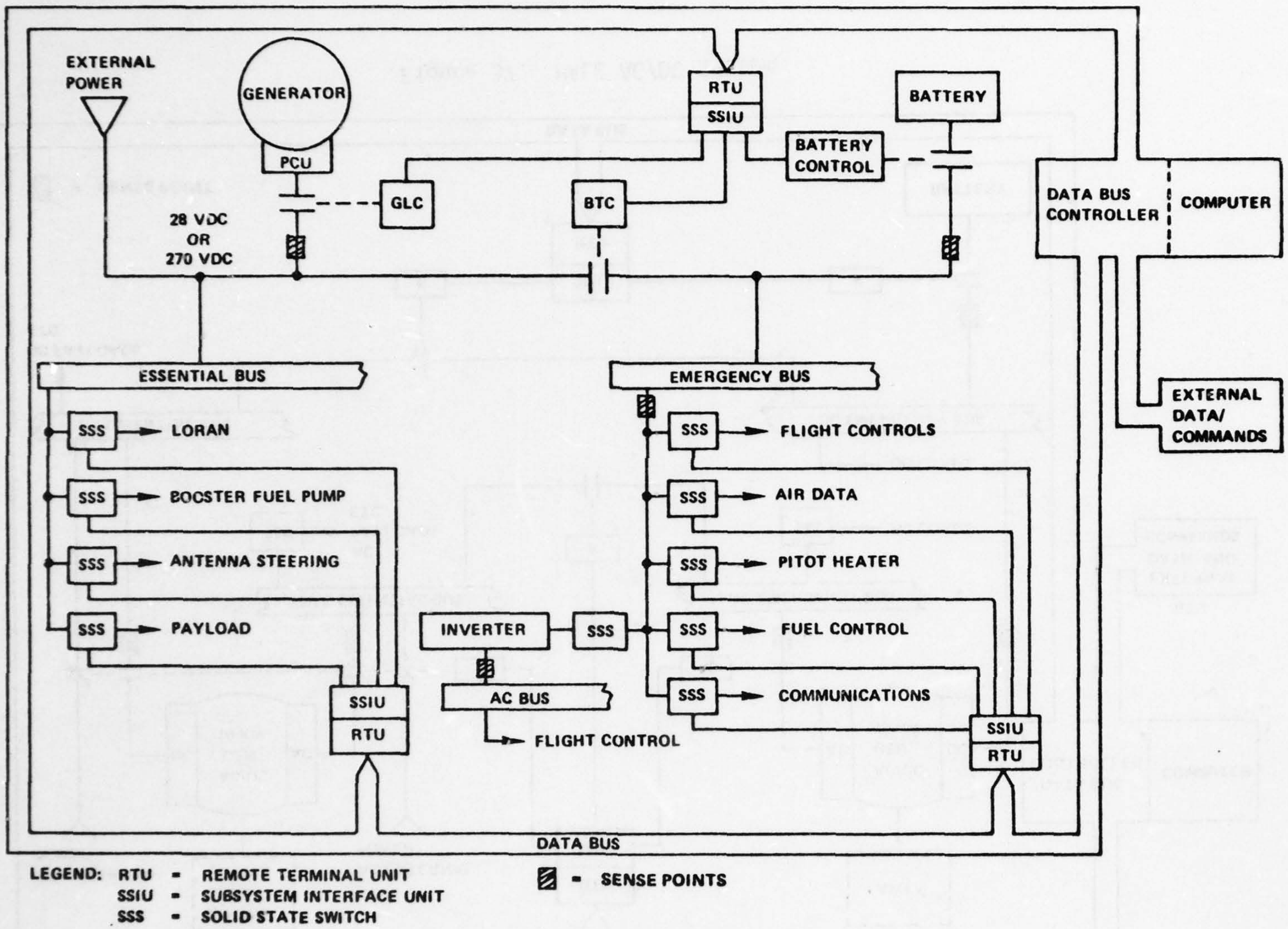


Figure 36. ARPV LVDC/HVDC

AD-A065 008 TELEDYNE RYAN AERONAUTICAL SAN DIEGO CA F/G 1/3
RPV ELECTRIC POWER SYSTEM STUDY. PHASE II. HOT BENCH MOCKUP DEV--ETC(U)
NOV 78 F L MILLER, L PICO F33615-76-C-2069
UNCLASSIFIED TRA29318-08 AFAPL-TR-78-93 NL

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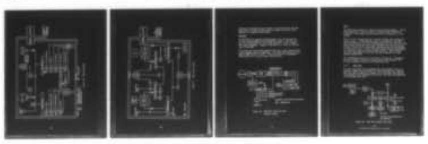

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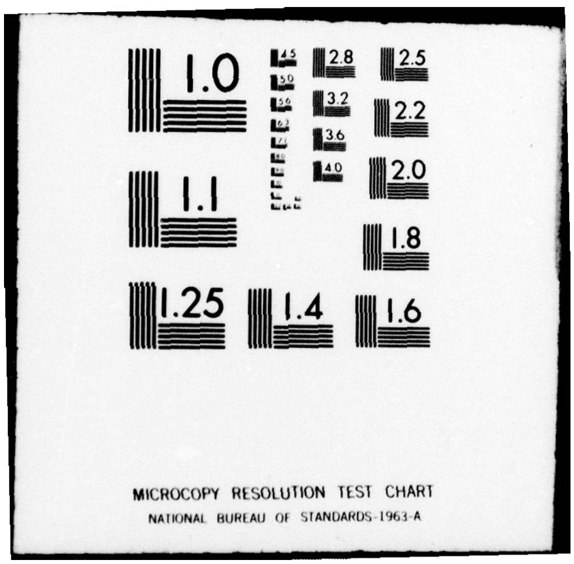
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

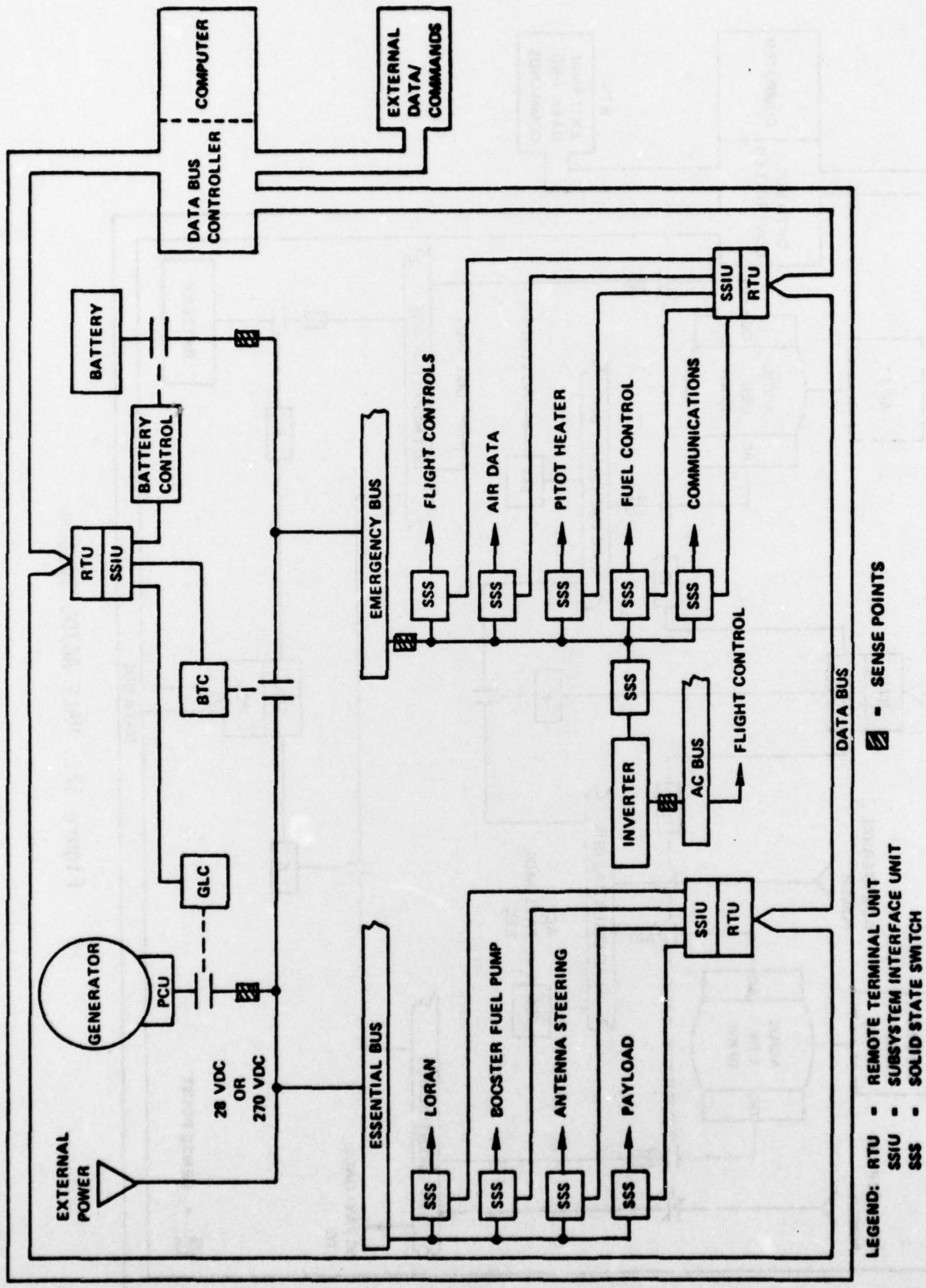

Figure 36. ARPV LVDC/HVDC

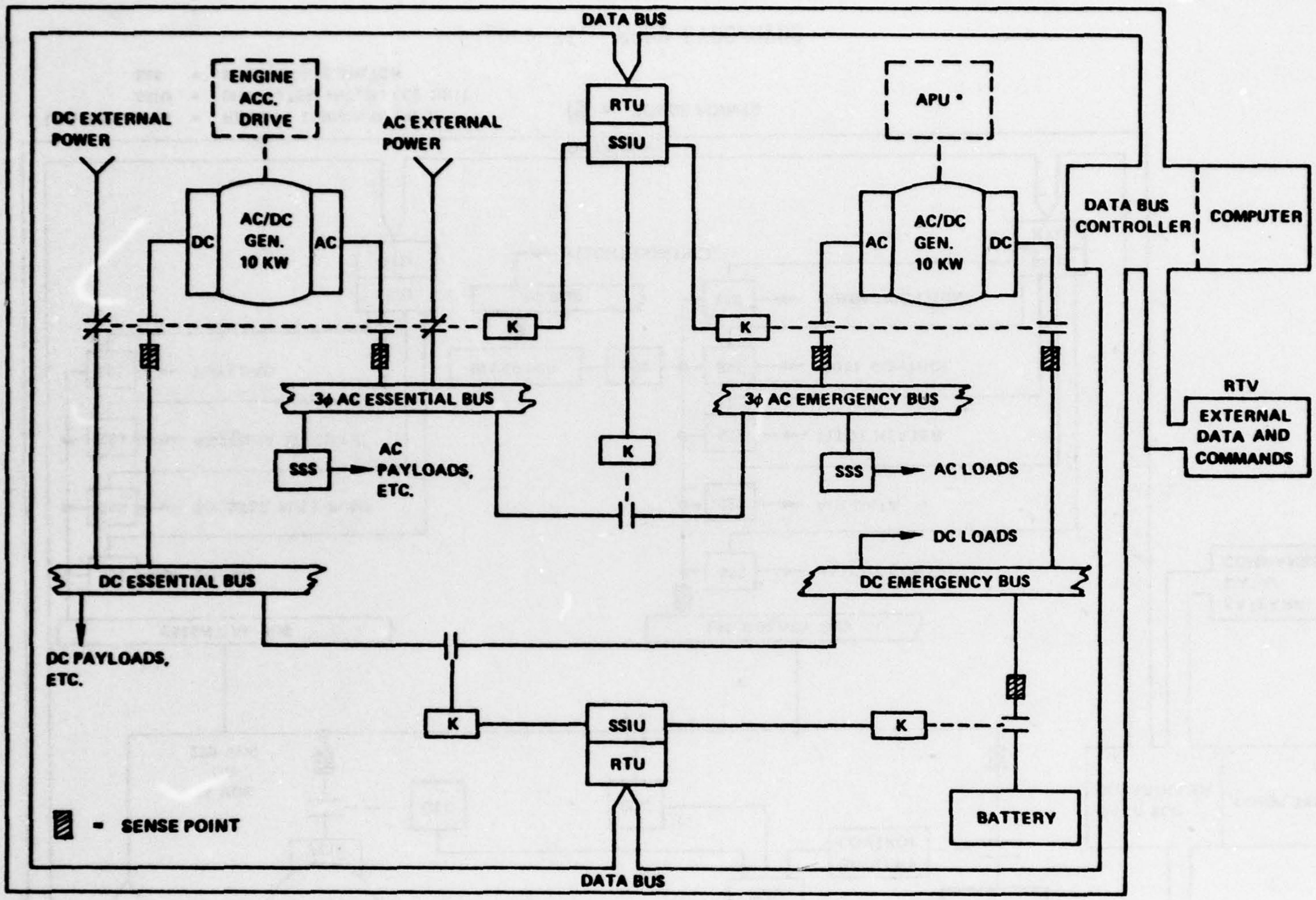

Figure 37. HALE AC/DC System

Additional equipment may be required for system control and data acquisition in order to obtain data on events occurring simultaneously on separate power busses.

MINI-RPV

The Mini-RPV will require DC measurements with the possibility of some AC measurements on the generator output. The chief concerns in this system will be voltage extremes, ripple voltage, and ripple frequency. However, transients will occur as the payload is switched.

Provisions for varying the generator RPM over a wide range during a test sequence would be required. The engine RPM could vary from 3000 to 8000 during a flight. Figure 38 shows the recommended sense points for a single output configuration.

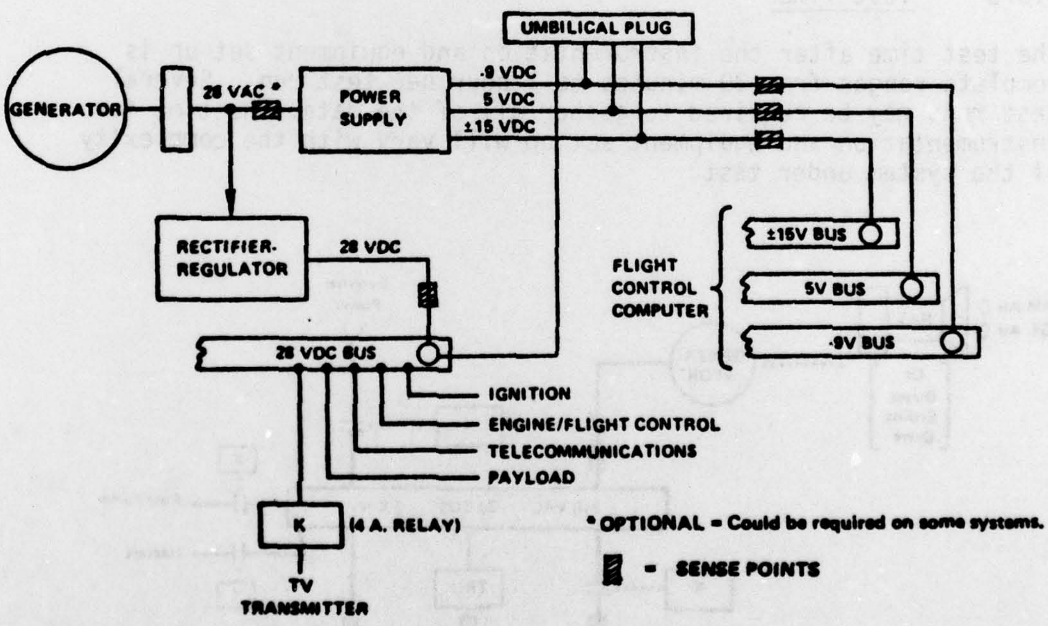

Figure 38. MINI-RPV LVDC With Boxes (Single Output)

TEDS

The TEDS power system will require AC and DC measurements. The DC measurements will consist mainly of transient data created by actuators. Simultaneous bus monitoring will be necessary in this system.

The AC in this system would be a varying voltage and varying frequency source. A high sampling rate, as required for the HALE, would be necessary since the frequence could be from 2 kHz to 5 kHz. The greatest variations would occur between start and cruise condition. Variations and transients created by the cycling payload in flight will occur. These conditions would have to be evaluated for the effect they could have on the avionics. RPM variation would not be necessary since the TEDS would operate at a near constant engine RPM.

The recommended sense points are shown in Figure 39. Parameters would be voltage, current, and power quality measurements such as total harmonic distortion, AC modulation, etc.

5.3.5 Test Time

The test time after the instrumentation and equipment set up is complete ranges from 30 minutes to 1 hour per test run. Several test runs may be required to gather all of the data. The time for instrumentation and equipment set up will vary with the complexity of the system under test.

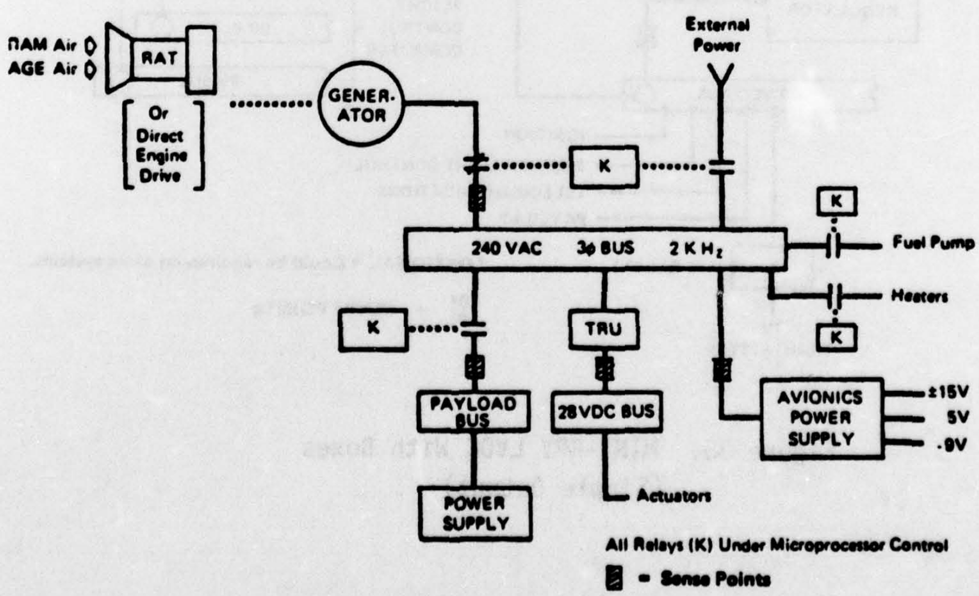

Figure 39. TEDS VSVF System With Boxes

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