NASA Conference Publication 2213

Space Power Subsystem Automation Technology

Proceedings of a workshop held at
Marshall Space Flight Center, Alabama
October 28-29, 1981

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1982

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SPACE POWER SYSTEM AUTOMATION WORKSHOP

MARSHALL SPACE FLIGHT CENTER

OCTOBER 28 - 29, 1981

BLDG 4610 ROOM 5025

AGENDA

WEDNESDAY/OCTOBER 28

8:30 - 8:45	-	INTRODUCTION	JIM MILLER
8:45 - 9:00	-	OPENING REMARKS.	DICK CARLISLE
9:00 - 9:15	-	POWER SYSTEM AUTOMATION PLANS. .	JERRY MULLIN
9:15 - 9:45	-	POWER SYSTEM COMPONENT MODELING PROGRAM.	LOU SLIFER
9:45 - 10:15	-	RECENT ADVANCES IN AUTOMATION COMPONENTS TECHNOLOGY	BOB FINKE
10:15 - 10:45	-	AUTOMATION TECHNOLOGY FOR POWER SYSTEM MANAGEMENT	RON LARSON
10:45 - 11:15	-	SPACECRAFT SYSTEM/POWER SUB-SYSTEM INTERACTIONS	CHRIS CARL
11:15 - 11:45	-	TECHNICAL ISSUES IN POWER SYSTEM AUTONOMY FOR PLANETARY SPACE-CRAFT	FRED VOTE
11:45 - 12:15	-	POWER SYSTEM AUTOMATION EXPERIENCE AT MARTIN.	FRED LUKENS
12:15 - 1:15	-	LUNCH	
1:15 - 1:45	-	AIR FORCE REQUIREMENTS FOR POWER SYSTEM AUTOMATION	DAVE MASSIE
1:45 - 2:15	-	POWER SYSTEM AUTOMATION REQUIREMENTS FOR EARTH ORBIT. .	ROY LANIER
2:15 - 3:00	-	AMPS PROGRAM STATUS AND OBJECTIVES.	ART SCHOENFELD
3:00 - 3:30	-	STRAWMAN IDENTIFICATION OF TECHNOLOGY ISSUES AND SPECIFIC AUTOMATION OBJECTIVES	JIM GRAVES
3:30 - 4:00	-	GROUP DISCUSSION	JIM MILLER
5:30 - 7:00	-	DINNER AT THE ELEGANT STEAK ROOM	

THURSDAY/OCTOBER 29 (ROOMS AS INDICATED)

8:00 - 12:00	-	WORKSHOP DISCUSSIONS	WORKSHOP CHAIRMAN
		o TECHNOLOGY ISSUES IDENTIFICATION	
		GROUP 1 (Bldg. 4487 - Rm. A-204)	SID SILVERMAN
		GROUP 2 (Bldg. 4487 - Rm. A-214)	FLOYD FORD
		o SPECIFIC AUTOMATION OBJECTIVES	
		GROUP 3 (Bldg. 4610 - Rm. 5025)	HOWARD WEINER
		GROUP 4 (Bldg. 4487 - Rm. 238)	WAYNE WAGNON
12:00 - 1:00	-	LUNCH	
		BLDG. 4610 - ROOM 5025:	
1:00 - 2:30	-	TECHNOLOGY ISSUES REPORT	WORKSHOP CHAIRMAN
2:30 - 4:00	-	SPECIFIC OBJECTIVES REPORT	WORKSHOP CHAIRMAN
4:00	-	WRAP UP AND TURN IN WORKSHOP RESULTS	JIM MILLER

WORKSHOP ASSIGNMENTS

TECHNOLOGY ISSUES		SPECIFIC OBJECTIVES	
GROUP 1 BLDG. 4487, ROOM A-204	GROUP 2 BLDG. 4487, ROOM A-214	GROUP 3 BLDG. 4610, ROOM 5025	GROUP 4 BLDG. 4487, ROOM B-238
SID SILVERMAN/CHAIRMAN	FLOYD FORD/CHAIRMAN	HOWARD WEINER/CHAIRMAN	WAYNE WAGNON/CHAIRMAN
DICK CARLISLE	FRED VOTE	JERRY MULLIN	RON LARSON
MATT IMMAMURA	JOHN LEAR	CHRIS CARL	FRED LUKENS
BILL BRANNIAN	CHARLIE SOLLO	JIM WILLIAMS	ART SCHOENFELD
DAVE PETERSON	JOE NAVARRO	KENT DECKER	RON GIVEN
BOB GIUDICI	MIKE GLASS	GEORGE VON TIESENHAUSEN	IRVING STEIN
ROY LANIER	DON ROUTH	JACK MACPHERSON	C. S. CROWELL
JOHN ARMANTROUT	WAYNE HUDSON	JOE VOSS	DAVE MASSIE
DOUG TURNER	DON WILLIAMS	LU SLIFER	DICK GUALDONI
		LT. ED GJERMUNDSEN	

IMPROVE SPACECRAFT AFFORDABILITY THROUGH AUTOMATION

BY
RICHARD F. CARLISLE
MANAGER, SPACECRAFT SYSTEMS OFFICE
OAST

Introduction

The goal of the Spacecraft Technology Automation task is to reduce the spacecraft life cycle cost, extend expected spacecraft operational life, and improve performance.

Life cycle cost includes the cost of non-recurring design, manufacturing and test, launch, and on-orbit operation including maintenance, repair, and redundance management. The operation cost to meet ten year satisfactory performance adds considerable spacecraft complexity with respect to redundancy management and fault tolerant design. Spacecraft self management by automation can offer considerable operation costs benefits. The more complex the spacecraft, the larger the benefit of automation whether implemented on board the spacecraft or on the ground.

The technology development schedule has a severe sense of urgency based on current NASA planning that requires a technology readiness for a potential FY 1986 phase C/D major new start for an Earth orbiting vehicle that will establish a long term United States prominance in space.

Spacecraft Automation Technology Approach

The approach planned by OAST is to establish a long term automation objective with phased technology outputs. The long term objective includes a high degree of automation that will require minimum involvement of man. A short term, low risk objective is to automate the present manned involvement thus reducing the routine ground operational support. This can be a major early cost savings even if the initial application is automated on the ground. The decision to transfer these functions to the spacecraft will probably be made based on economics and/or the availability of hardware.

The planned OAST FY 1982 Spacecraft Automation Technology task is comprised of three major tasks. JPL will study a total spacecraft performance requirement and prepare an automation technology plan at the spacecraft level. This plan will be based on a review of the baseline automation of the existing Voyager spacecraft. It will expand to a strawman generic future spacecraft automation design. The task will trade-off such things as: central vs distributed control, alternative spacecraft automation architecture, heirarchial command and control ground rules, interfaces between spacecraft subsystems and mission rules to establish priorities when conflicts occur in the spacecraft command and control system.

If there were sufficient funds available, it would be desirable to conduct subsystem automation technology tasks in each of the spacecraft systems as part of the spacecraft automation task. With limited funds, we plan to initially develop the automation design for only the power subsystem in parallel with the broad spacecraft task. Task 2, the power system automation task will be performed by MSFC. The details of Tasks 1 & 2 are somewhat a function of the output of this workshop. Task 3 will be the development of generic automation technologies.

It is highly desirable that the power system automation task achieve both a long term objective and a near term benefit. It is envisioned that this can be successfully accomplished from an orderly and systematic growth of a power system automation technology development program that is compatible with a parallel spacecraft system automation program. Other systems, in turn, can benefit from the efforts in the power system automation task.

The degree of power system automation can increase with time. There is little urgency to eliminate manned involvement completely. The DoD has an autonomy requirement with respect to security and/or survivability. The degree of autonomy (operation with no involvement of man) required with respect to time increases the complexity and cost of the orbiting spacecraft in a non-linear way. Therefore, the affordability benefit of automation is significantly impacted by the degree of autonomy. The technology to enable, and the cost-benefits of automation, will be determined by future trade-off studies.

I expect that the spacecraft and power systems automation tasks will continue for several years. The two tasks must establish a technology interface between them. Orderly periodic interactions must occur between the two tasks. This interaction will result in the definition of interfaces between the two programs and these interfaces will in some cases become design constraints on either or both programs. These constraints must be reviewed and modified in the best interest of the spacecraft systems in order that this coordinated program can provide the technology to support an optimized spacecraft design.

Later this morning you will hear a presentation by Chris Carl that will describe JPL's background and experience in spacecraft automation. He will also discuss the current spacecraft automation approach and will establish the initial spacecraft/power system automation interaction. I expect the spacecraft system automation task will eventually involve a spacecraft system simulation. I also expect the power system automation technology output will result in a power system automation simulation that can be integrated into the spacecraft system simulation and can be implemented in a MSFC power system breadboard.

You will hear also this morning from Ron Larsen, who will discuss generic automation technology. He will describe degrees of automation from simple preprogramming to the orderly sequencing of man's logic process that will enable the capturing of the complex methodology of decision making involving interactive non-linear functions. He will discuss the technique of capturing the experience of experts and the mathematics and methodology of interrelating this experience into the control of complex mechanisms. He will introduce you to the generic technology of automation software development. The initial generic automation task is planned to be focused on the experience of a "battery systems engineer" as applicable to the on-orbit management of a battery system.

In summary, the Spacecraft Systems Automation Technology tasks consist of three parallel tasks; spacecraft automation to establish the total spacecraft philosophy; power system automation techniques compatible with the system philosophy and near term benefits; and, generic automation technology to develop automation methodology and automation software design.

I am pleased to see the interest illustrated by the collective experience I know you represent. I want to assure you that your recommendations will be seriously evaluated and considered. I am certain in the next two days you are going to make a significant impact on our program. I am pleased to be here with you and am anxious to see how you will advise us.

WORKSHOP PURPOSE

- IDENTIFY TECHNOLOGY ISSUES RELATIVE TO SPACE POWER SYSTEM AUTOMATION DEVELOPMENT

- ESTABLISH SPECIFIC AUTOMATION OBJECTIVES RELATIVE TO SPACE POWER SYSTEM AUTOMATION DEVELOPMENT

J. P. Mullin

MSFC AUTOMATION MEETING 10/28/81

MAJOR NASA THRUSTS

o NOW - GET SHUTTLE OPERATIONAL

o NEXT - ESTABLISH 'PERMANENT' MANNED LEO PRESENCE

OAST THRUST

WORK TECHNOLOGY

TOWARD START IN

85 86 87

J. P. Mullin

10/28/81

MSFC AUTOMATION MEETING

SPACE POWER THRUSTS

- o FOR THE PAST FIVE YEARS PROGRAM DIRECTED TOWARD CRITICAL TECHNOLOGIES NEEDED FOR HIGH POWER IN LEO/A MAJOR SPACE STATION REQUIREMENT
  - HIGH POWER LOW COST SOLAR ARRAYS-LARGE CELLS, CONCENTRATORS
  - HIGH CAPACITY LONG LIFE ENERGY STORAGE - FUEL CELL - ELECTROLYSIS, NiH_2 BATTERY
  - HIGH POWER COMPONENTS - TRANSISTORS, CAPACITORS, TRANSFORMERS, SWITCHES
  - UNDERSTANDING OF PLASMA INTERACTIONS - PIX I & II, NASCAP
  - THERMAL COMPONENTS - HEAT PIPES, RADIATORS
  - ENERGY MANAGEMENT

THE BIGGEST DEFICIENCY IN PRESENT PROGRAM IS IN THERMAL AND ELECTRICAL ENERGY MANAGEMENT

J. P. Mullin

10/28/81

OAST ENERGY MANAGEMENT BACKGROUND

- APSM PROGRAM (AUTOMATED POWER SYSTEM MGT)
  - 1975 - 1981/$2M
  - COMPARED AUTOMATED BASELINE VERSION OF PLANETARY S/C (VO75) POWER SYSTEM - NO THERMAL
  - AUTOMATED VERSION PROVIDED
    - 50% $<$ OPERATIONS COST
    - 50% $>$ SPECIFIC POWER
    - Δ - 40% $<$ CAPITAL COST
    - IMPROVED FAULT TOLERANCE/FLEXIBILITY
- IAPS FLIGHT PROGRAM - REQUIRED ON BOARD AUTOMATION OF ION THRUSTER ENGINEER
- AMPS PROGRAM
  - IN PROCESS NOW
  - ESTABLISH UTILITY - LIKE CAPABILITY TO MANAGE HIGH CAPACITY LEO ENERGY SYSTEM - ELECTRICAL & THERMAL/ARBITRARY 250 kW REFERENCE SYSTEM
- MAJOR OAST - WIDE AUTOMATION THRUST ADOPTED - FY82
  - AMPS UNDER REVIEW FOR COORDINATION WITH OVERALL OAST THRUST

J. P. Mullin

10/28/81

PURPOSE

- IDENTIFY TECHNOLOGY ISSUES IN LEO ENERGY MANAGEMENT
- RANK CRITICAL TECHNOLOGY NEEDS-BARRIERS
- RECOMMEND TECHNOLOGY OBJECTIVES
- COMMENT ON STRAWMAN
- INVOLVE AUTOMATION AS WELL AS POWER TECHNOLOGISTS

PROVIDE MEANINGFUL INPUT
TO PLAN PROGRAM

J. P. Mullin

POWER SYSTEM COMPONENT MODELING PROGRAM
(MODELING/AUTOMATION/AUTONOMY)

PRESENTATION TO:
SPACE POWER SYSTEM AUTOMATION WORKSHOP

L. SLIFER
10/28/81

ANALYTICAL MODELING

RECOMMENDATION:

1. DEVELOP AC MODELS FOR POWER SUBSYSTEM COMPONENTS
2. SYNTHESIZE ANALYTICAL MODEL FOR POWER SYSTEM
3. DEFINE NECESSARY PARAMETERS FOR ELECTRONIC SIMULATION OF AC SOLAR ARRAY MODEL

RATIONALE:

VERY LITTLE AC DATA AVAILABLE FOR COMPONENTS AND SYSTEM

EXISTING DATA NEEDS REVIEW, REVISION, REFINEMENT AND UPDATING

GUIDELINES NEEDED FOR ACCURATE ELECTRONIC SIMULATION

ELECTRONIC ARRAY SIMULATION IS NEEDED - ONLY KNOWN WAY TO "INCLUDE" LARGE ARRAYS IN GROUND TESTS

PAYOFF:

SAFEGUARD AGAINST BUS INSTABILITY

AVOID HARMFUL INTERACTION BETWEEN ARRAY AND FILTER COMPONENTS AT OUTPUT

DEFINE SOURCE IMPEDANCE AT LOAD BUS

SUPPLEMENT INADEQUATE DC ARRAY SIMULATORS WITH MORE ACCURATE AND REALISTIC AC SIMULATION

STATE OF HEALTH MONITORING

RECOMMENDATION:

1. DEVELOP IMPROVED TECHNIQUES FOR ON-BOARD MONITORING AND CONTROL OF POWER SYSTEM AND ITS COMPONENTS
   - SOFTWARE/HARDWARE TECHNIQUES TO MINIMIZE
     - IMPACT ON DATA HANDLING AND COMMAND SYSTEM
     - GROUND OPERATIONS
   - IDENTIFY REQUIRED STATE OF HEALTH DIAGNOSTIC MEASUREMENTS
   - DEVELOP SENSING TECHNIQUES AND SENSORS FOR DETECTING
     - PARTIAL FAILURES
     - DEGRADATION

2. DEFINE TECHNIQUES FOR REDUCING COMPLEXITY OF MANAGING DEGRADED SYSTEM/COMPONENTS FROM GROUND

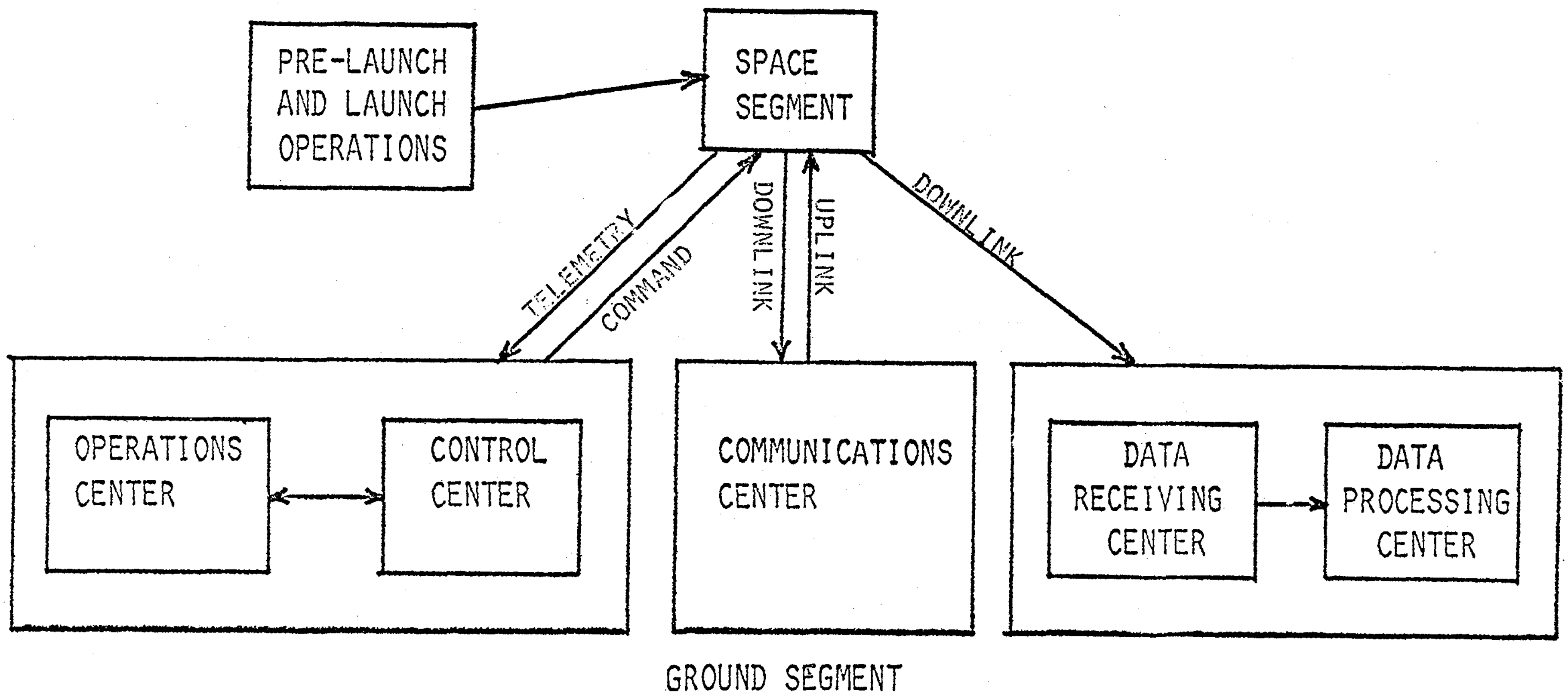
RATIONALE:

- EXISTING ON-BOARD SENSORS/MEASUREMENTS INADEQUATE FOR ACCURATE DEFINITION OF STATE OF HEALTH
- GROUND MONITORING AND ANALYSIS IS INADEQUATE AND EXPENSIVE
- GROUND CONTROL IS COMPLEX AND SLOW TO RESPOND
- INADEQUACIES AFFECT MISSION PLANNING AND FLIGHT OPERATIONS
- REAL EFFECTS OF ENVIRONMENT ON SYSTEM ARE NOT KNOWN

PAYOFF:

- LOWER GROUND SUPPORT COST
- IMPROVED RESPONSE IN COMPENSATING FOR PARTIAL FAILURE/DEGRADATION
- IMPROVED DESIGN CAPABILITY
- IMPROVED MISSION OPERATIONS
- LOWER POWER SYSTEM COST AND WEIGHT
- SIMPLIFICATION IN C & DH SYSTEM

SPACE SYSTEM



DEVELOPMENTS IN AUTOMATION/AUTONOMY

CHARACTERIZED BY DELIBERATE PROGRESS

- WITH NEED
- WITH COMPLEXITY/SOPHISTICATION

BASED ON MODELS

- KNOWLEDGE OF COMPONENT PERFORMANCE CHARACTERISTICS
- SYNTHESIZED SYSTEM CHARACTERISTICS

IMPROVED/INCREASED AS MODELS IMPROVED

POWER SYSTEM AUTOMATION EXAMPLES

SPACECRAFT SHUTDOWN - 1 YR. TIMER

UNDERVOLTAGE LOCKOUT

ARRAY ORIENTATION

SOLAR REACQUISITION

SHUNT REGULATOR TO CONTROL BATTERY CHARGE VOLTAGE

TWO-STEP REGULATOR FOR CONTROL/PROTECTION

SEQUENTIAL SHUNT REGULATION

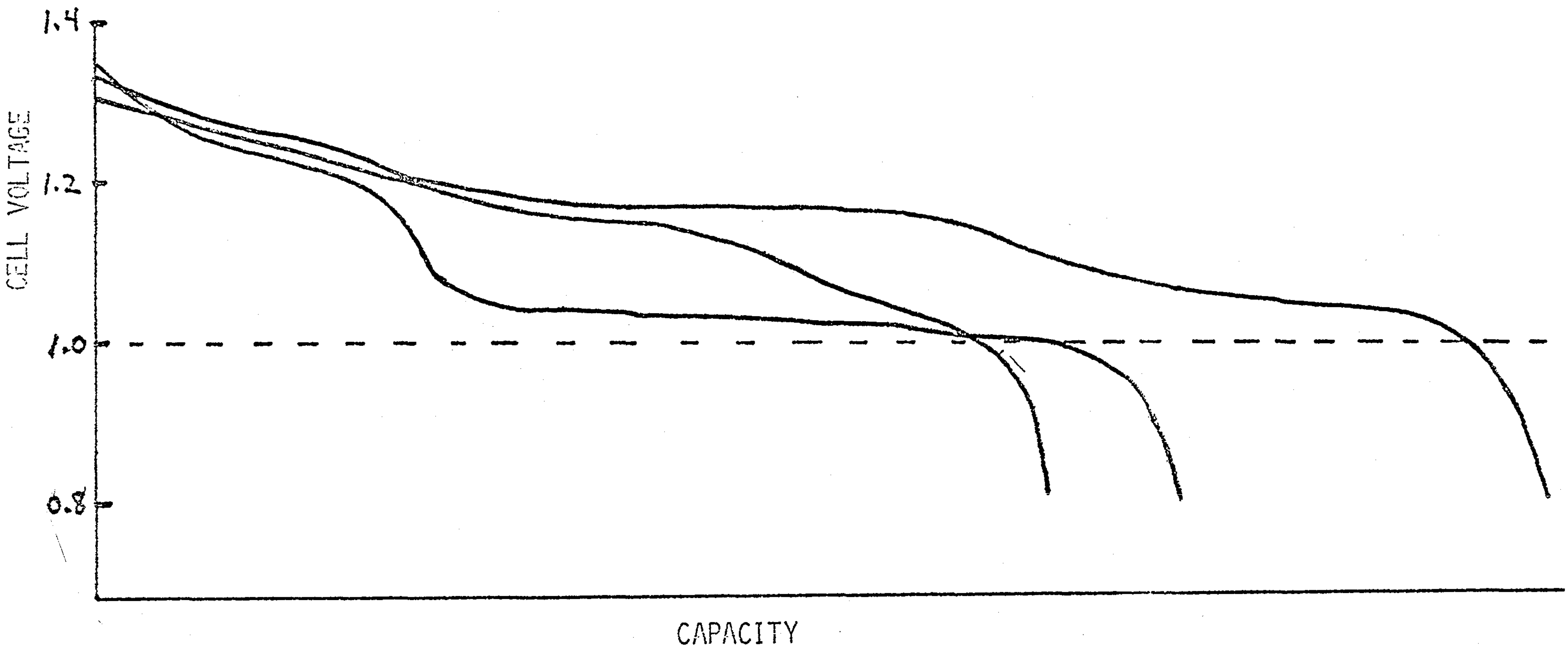
MULTI-STEP (V/T CURVES) TO ADJUST FOR TEMPERATURE

THERMOSTATS TO CONTROL UNDER OVER-TEMPERATURE CONDITIONS

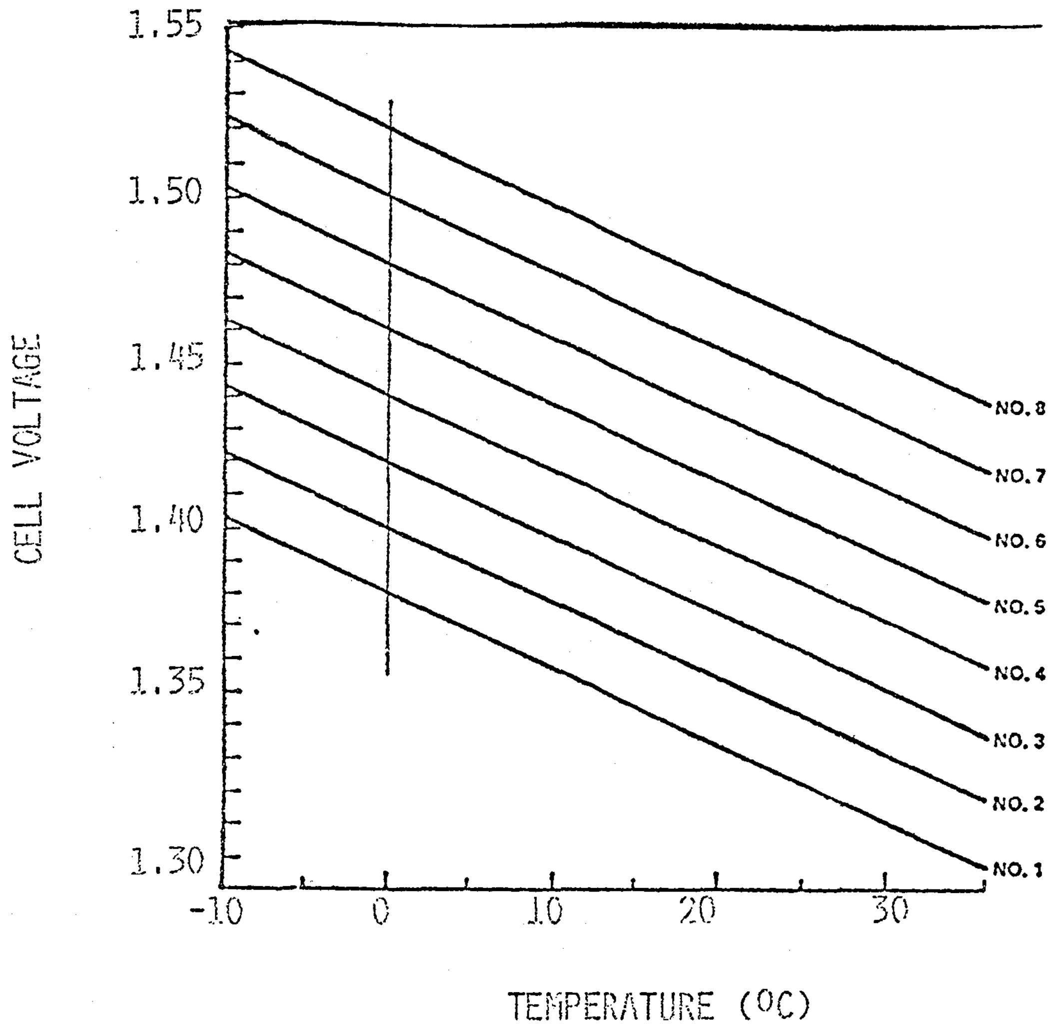
AUTOMATIC SWITCHING BETWEEN REDUNDANT COMPONENTS/SYSTEMS

STANDARD POWER REGULATOR UNIT (PARTIAL)

NiCd CELL DISCHARGE CURVES



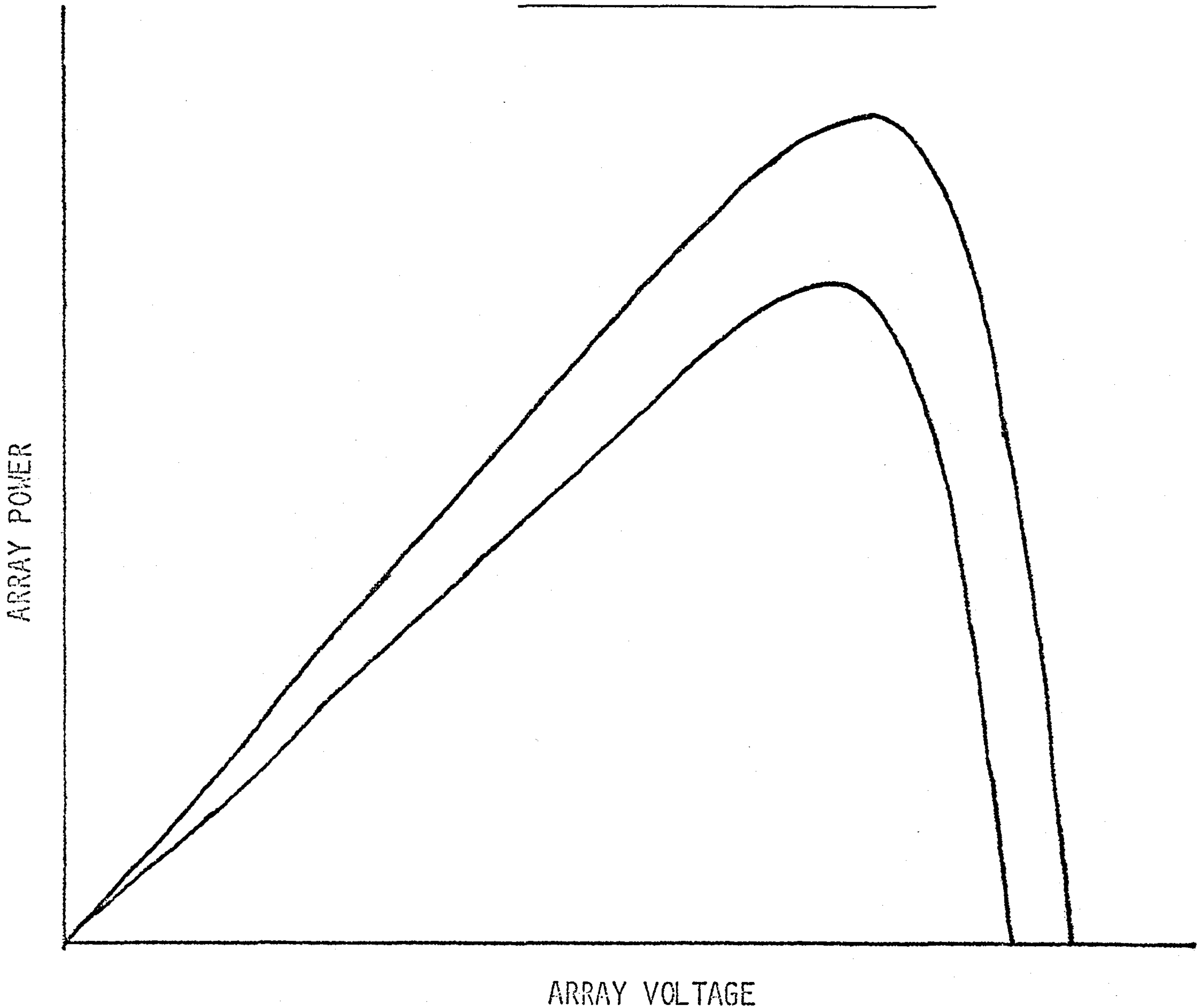
NiCd BATTERY CHARGE V/T LEVELS



STANDARD POWER REGULATOR UNIT

PEAK POWER TRACKING	-	AUTOMATIC (LOAD DEPENDENT)
VOLTAGE LIMIT	-	V/T SELECTION BY COMMAND
CURRENT LIMIT	-	I SELECTION BY COMMAND
STANDBY	-	AUTOMATIC IN ECLIPSE

SOLAR ARRAY POWER OUTPUT



DEGREES OF AUTOMATION

- ROUTINE OPERATIONS
  - CONTROL
  - SEQUENCING
- ROUTING MAINTENANCE
  - BATTERY CHARGING
  - BATTERY RECONDITIONING
- FAILURE HANDLING
  - TOLERANCE
  - DETECTION
  - ISOLATION
  - RECONFIGURATION
- FAULT HANDLING
  - FAULT TOLERANCE
  - FAULT DETECTION
    - SELF-TESTING
    - MODEL UPDATE
  - FAULT CORRECTION
    - RECOVERY
    - RECONFIGURATION

POWER SYSTEM AUTONOMY

SAFE-HOLD AUTONOMY

- UNDERVOLTAGE LOCKOUT
  - AWAIT GROUND COMMAND
  - TIMED (ON-BOARD CLOCK) RESTART
- LOW VOLTAGE/HIGH CURRENT SAFING
  - AWAIT GROUND COMMANDS

PARTIALLY OPERATIONAL AUTONOMY

- FUSING OF INSTRUMENTS/SYSTEM ELEMENTS
- LOAD SHEDDING

OPERATIONAL AUTONOMY

- FAULT DETECTION AND ISOLATION PLUS RECOVERY

CRITICAL ELEMENTS IN AUTOMATION

KNOWN PERFORMANCE CHARACTERISTICS (MODEL)

SENSE PERFORMANCE LEVELS (MONITOR)

COMPARE TO REFERENCES (HEALTH & WELFARE)

ANALYZE DIFFERENCES (DIAGNOSTIC CAPABILITY)

DETERMINE ACTION (DECISION CAPABILITY)

TAKE ACTION (IMPLEMENTATION CAPABILITY)

UPDATE (ITERATION CAPABILITY)

GROUND STATION BACKUP (OVERRIDE)

ANALYTICAL MODELING PROGRAM

BACKGROUND

OBJECTIVE - DEVELOPMENT OF RELIABLE POWER SYSTEMS

PROBLEM - DESIGNS NOT PERFECT

- HARDWARE NOT PERFECT
- SOFTWARE NOT PERFECT
- OPERATIONS NOT PERFECT

SOLUTION - IDENTIFY AND SOLVE PROBLEMS BEFORE THEY BECOME CRITICAL

- PREDICTION AND PREVENTION OF PROBLEMS
- VERIFICATION OF OPERATIONAL ADEQUACY

REQUIREMENT - VERIFICATION

ALL-UP TEST

- UNWIELDY
- COSTLY
- TOO MANY VARIABLES/CONFIGURATIONS
- FURTHER COMPLICATED WITH ON-ORBIT CHANGEOUTS

SIMULATION

- MUST BE REALISTIC
- MUST ADEQUATELY MODEL WHAT IS SIMULATED

ANALYSIS

- SIMPLE - TRACTABLE
- ADEQUATE - CAPTURE IMPORTANT FEATURES
- AUTOMATION OF SOME PRE-LAUNCH OPERATIONS

FIRST PHASE - REQUIREMENTS DEFINITION

STEP 1

REVIEW CURRENT APPROACHES

- EARTH ORBITING SYSTEM MODELS
- INTERPLANETARY SYSTEM MODELS
- GENERAL ANALYTICAL PROGRAMS

DETERMINE PROS (CAPABILITIES) AND CONS (LIMITATIONS)

IDENTIFY AREAS FOR IMPROVEMENT

ESTABLISH REQUIREMENTS FOR "IDEAL" MODEL

STEP 2

IDENTIFY PRELIMINARY REQUIREMENTS FOR COMPONENT MODELS

DETERMINE ADEQUACY OF COMPONENT MODELS

- REGULATION
  - SHUNT LIMITER MODELS
  - SWITCHING REGULATOR MODELS
  - SOLAR ARRAY SWITCHING UNIT MODELS
- GENERATION AND STORAGE
  - SOLAR ARRAY MODELS
  - BATTERY MODELS
- DISTRIBUTION
  - EQUIPMENT
  - CABLES

DETERMINE LIMITATIONS/UNCERTAINTIES IN EACH MODEL

SPECIFY REQUIRED IMPROVEMENTS

STEP 3

IDENTIFY TESTING REQUIRED

COMPONENTS
DEVICES

DETERMINE SEQUENCE

TESTING
ANALYSIS

DEFINE PROCEDURES FOR COMPREHENSIVE POWER SYSTEM MODEL DEVELOPMENT

CONTINUE TO SECOND PHASE

SUMMARY AND CONCLUSIONS

1. IT IS IMPORTANT TO SCOPE "THE AUTOMATION PROBLEM"

    WHAT IS TO BE AUTOMATED?

    WHAT DEGREE OF AUTOMATION IS DESIRED?
NEEDED?
JUSTIFIED?
POSSIBLE?

2. EXPERTISE (KNOWLEDGE) IS BASIC TO AUTOMATION AND MODELING IS AN INTEGRAL PART.

    CONSISTENCY OF UNDERSTANDING
ADEQUACY OF MODEL
ABILITY TO AUTOMATE
DEGREE OF AUTONOMY

3. AUTOMATION SYSTEM WILL ALSO BE IMPERFECT.

    REQUIRES OVERRIDE CAPABILITY
REQUIRES RETENTION OF HISTORY/STATUS/HEALTH AND WELFARE

RECENT ADVANCES

IN

AUTOMATION TECHNOLOGY

R. C. FINKE

10/28/81

THE ION AUXILIARY PROPULSION SYSTEM (IAPS) EMPLOYS A SOPHISTICATED AUTONOMOUS SPACE POWER SYSTEM. THE IAPS CONTAINS 9 INTERACTIVE POWER SUPPLIES, SOME OF WHICH ARE HIGH VOLTAGE, SOME OF WHICH ARE RAISED TO HIGH COMMON MODE POTENTIAL. ALL SUPPLIES ARE VOLTAGE PROGRAMMABLE BY TIME TAGGED ON-BOARD COMPUTER COMMAND. DURING THE TWO-YEAR FLIGHT OF THE IAPS, THE POWER SYSTEM WILL AUTOMATICALLY ACCOMMODATE FOR OUTAGES, ARCING, DEGRADATION OF THE LOAD AND TRANSIENT PHENOMENA. ALL NECESSARY COMMANDS TO OPERATE THE IAPS ARE STORED IN RAM, BACKED UP BY PROM. GROUND COMMAND CAN MODIFY THE RAM PROGRAM AS THE NEED ARISES.

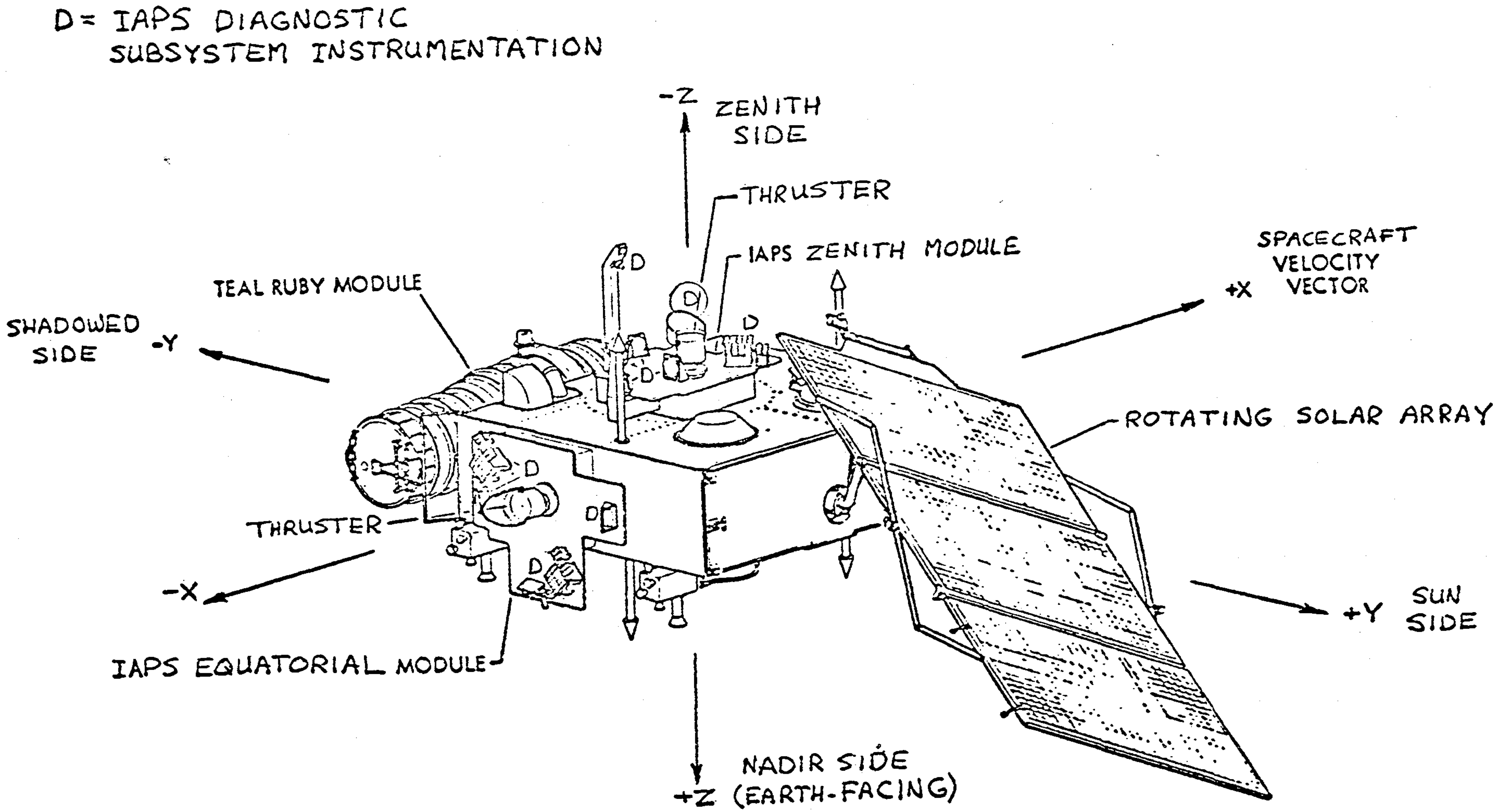
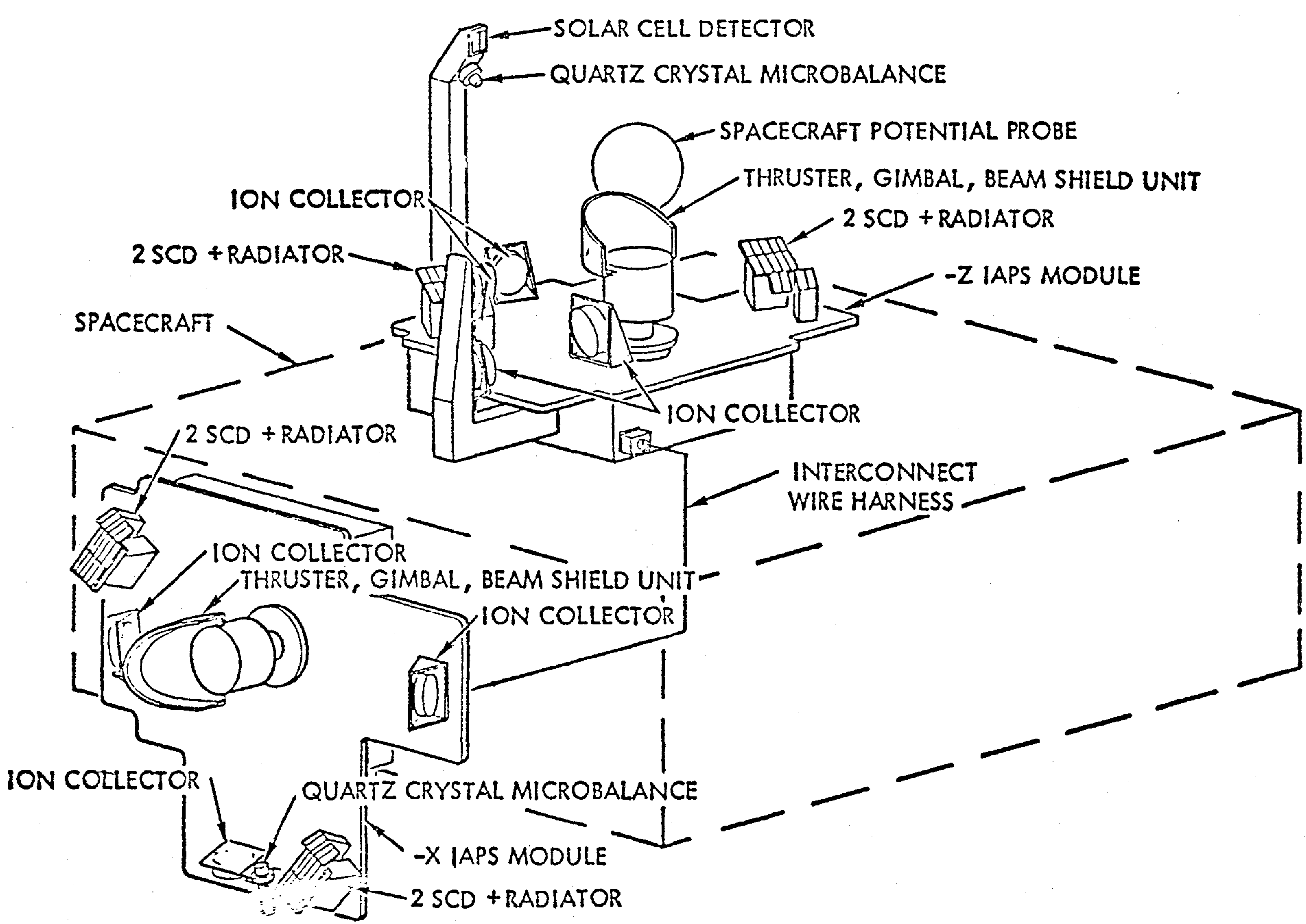


Figure 1. P80-1 Spacecraft - Deployed

IAPS MODULES

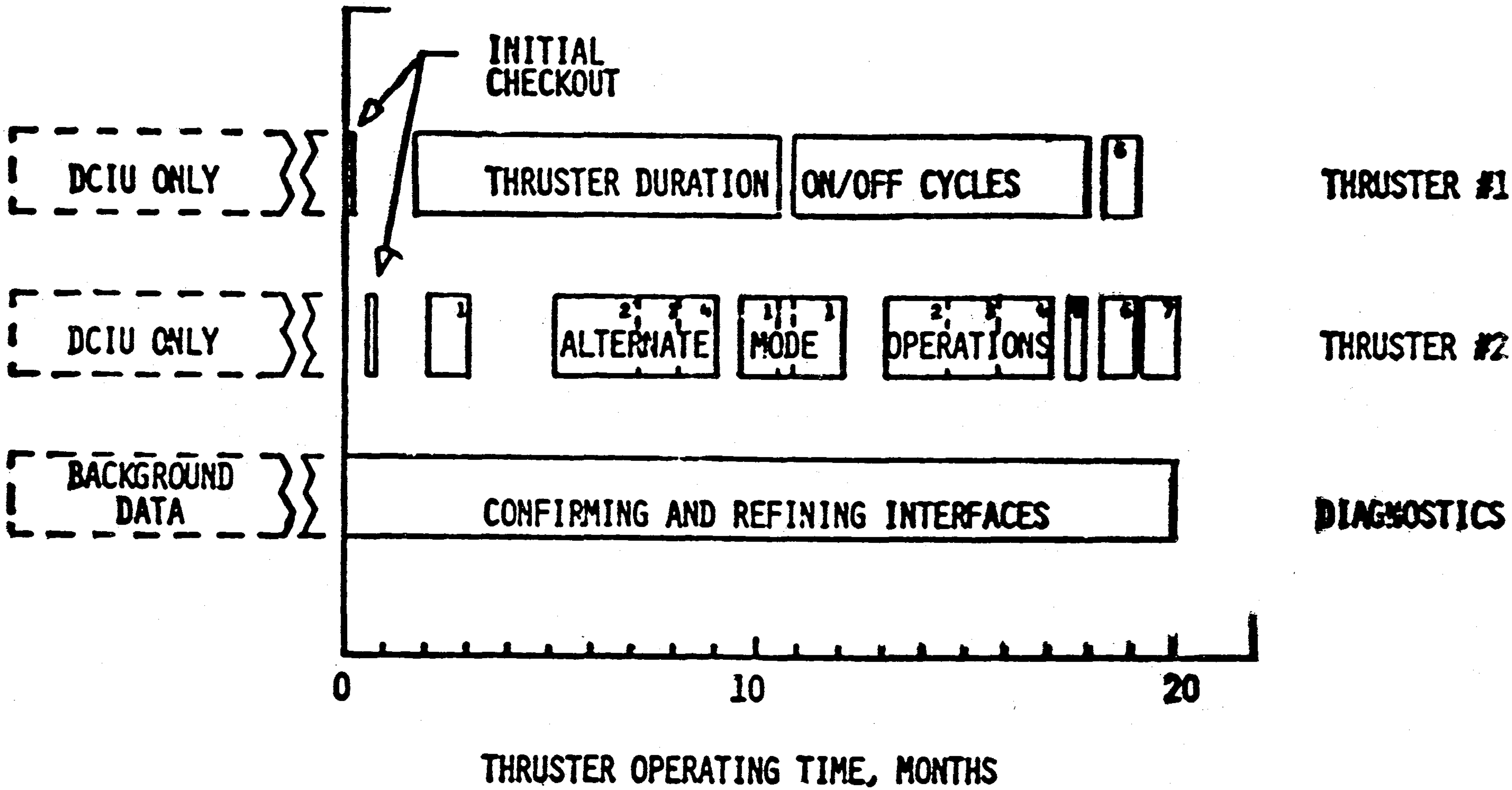


ION AUXILIARY PROPULSION SYSTEM (IAPS) FLIGHT TEST

- OBJECTIVES:
  - DEMONSTRATE THRUSTER SYSTEM PERFORMANCE AND DURABILITY IN SPACE;
  - MEASURE THRUSTER SYSTEM IN-FLIGHT PERFORMANCE
  - MEASURE PRINCIPAL THRUSTER-SPACECRAFT INTERACTIONS
  - DEVELOP COMMERCIAL SOURCE FOR THRUSTER SYSTEM
  - TRANSFER TECHNOLOGY AND INVOLVE USERS

- MISSION MODEL
  - 1000 kg, GEOSTATIONARY COMMUNICATIONS SATELLITE
  - 7 YRS N-S STATIONKEEPING (1X/DAY) TO $\pm 0.01°$
  - 4 8-cm THRUSTERS CANTED 45° TO N-S
  - IMPLIES 2557 CYCLES OF 2.76 hrs FULL THRUST OPERATION (= 7055 TOTAL hrs) FOR EACH THRUSTER
  - DUAL THRUSTER OPERATION

PRELIMINARY MISSION OPERATING PROFILE



1 Dual Thruster Operation

2 Cathode Maintenance

3 Idle

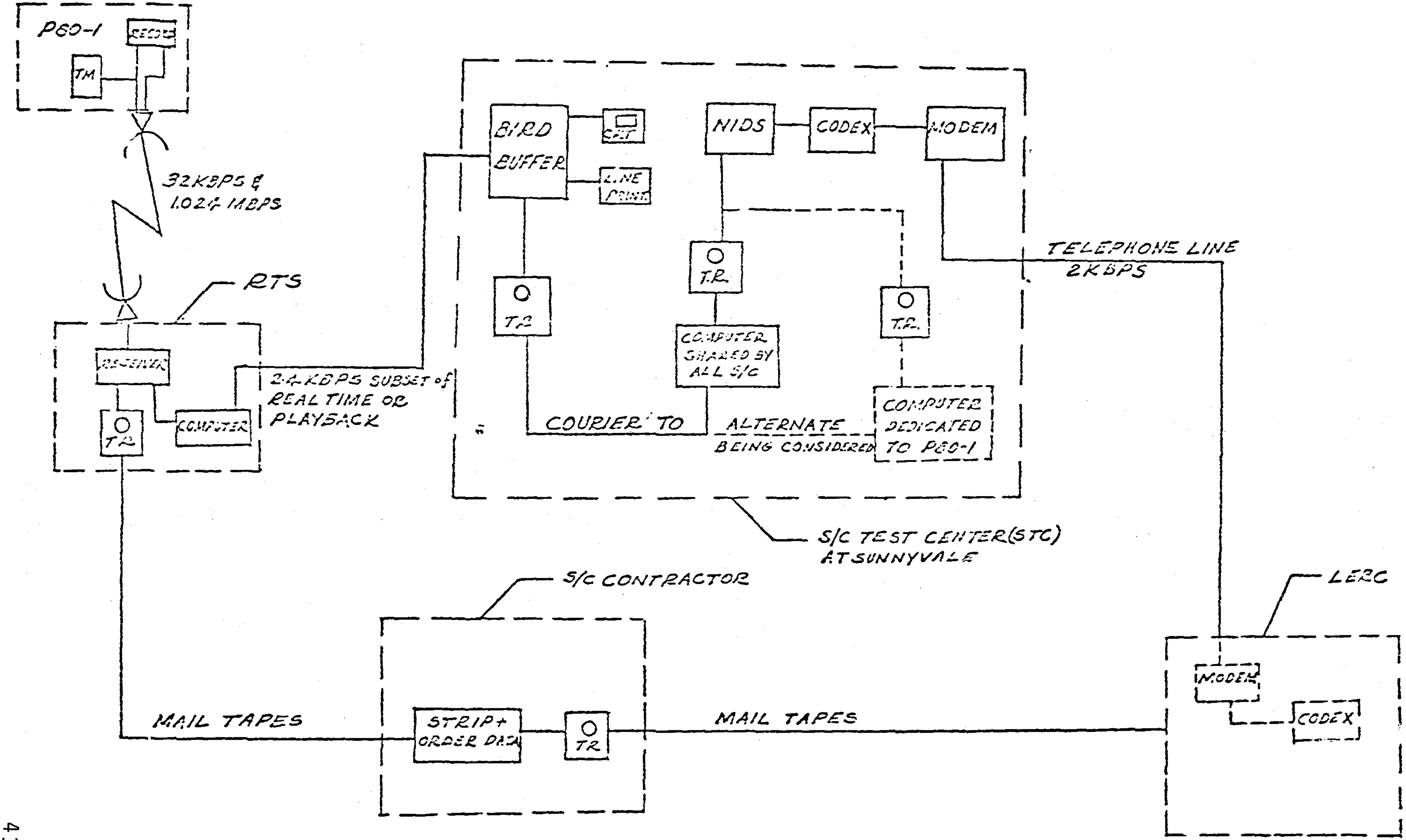
4 Throttled Thrust

5 Gimbal Evaluation

6 Neutralizer Off, Dual Thruster Operation

7 Change Orbital Altitude

FIG 4 DATA FLOW for IAPS



PEU REQUIREMENTS
(TS-200, REV. A)

A. INPUT VOLTAGE RANGE: 50 VDC TO 90 VDC

B. MAXIMUM INPUT POWER: 200 W DC

C. PEU EFFICIENCY: ≥ 75%

D. PEU SIZE (MAXIMUM): 17.0 INCHES (LENGTH) BY 9.0 INCHES (WIDTH) BY 4.5 INCHES (HEIGHT)

E. PEU WEIGHT: ≤ 16.6 POUNDS

F. PEU SUPPLY OUTPUTS PER TABLE 3-1. TS-200

G. PEU TELEMETRY OUTPUTS PER TABLE 3-2, TS-200 (5 V FULL SCALE)

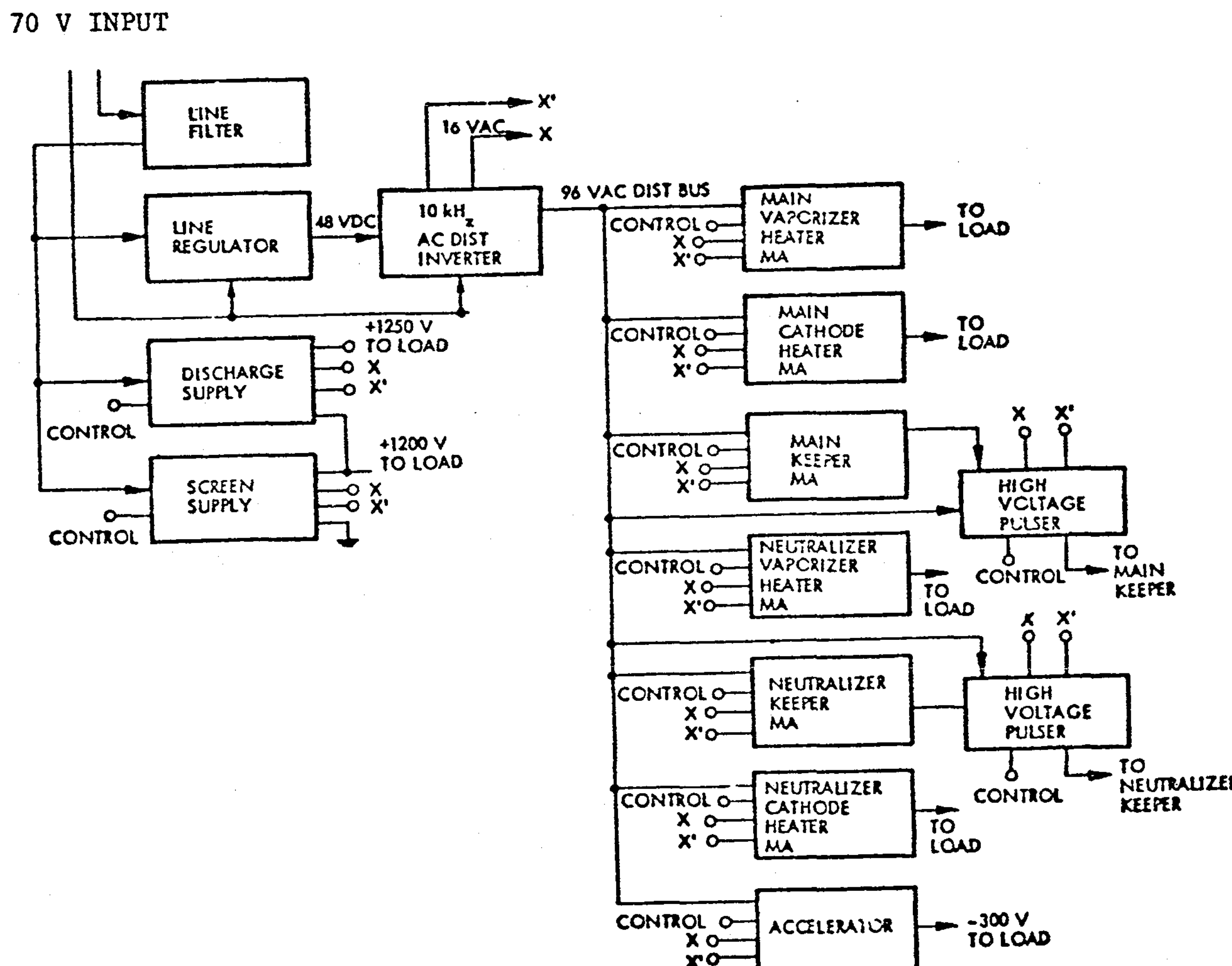
H. PEU SUPPLY OUTPUTS, DC SUPPLIES, RIPPLE: < 10% PEAK

I. PEU SUPPLY OUTPUTS SHALL HAVE INTERNAL OVERLOAD PROTECTION

J. PEU SHALL PROVIDE SCREEN OVERLOAD OUTPUT TO DCIU

K. PEU PULSER OUTPUTS TO BE ≥ 5 KV INTO 1200 μμf OR 100 K OHM LOAD

PEU BLOCK DIAGRAM

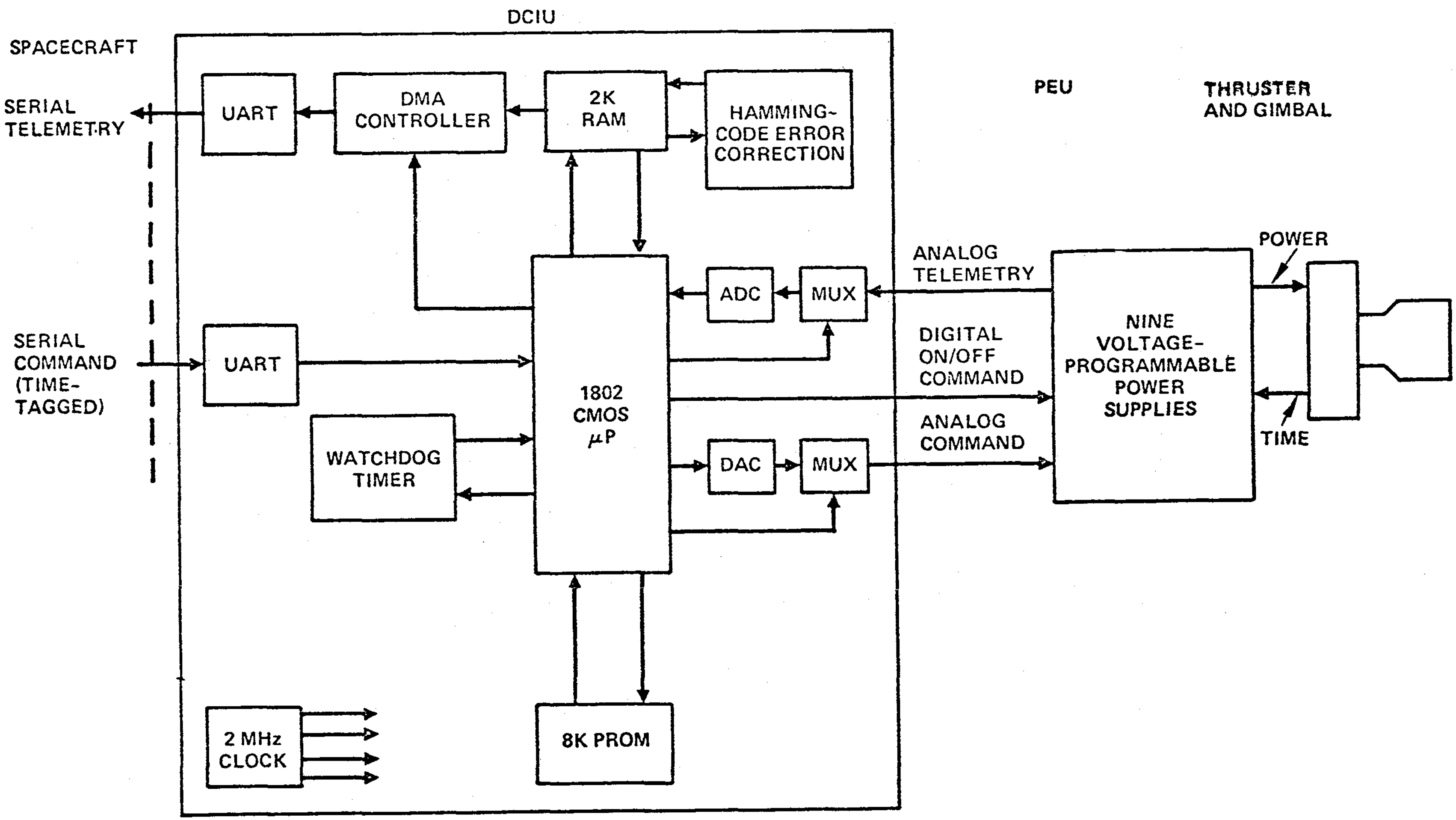


IAPS - S/C INTERFACE

- POWER BUS
- ONE COMMAND CHANNEL PER T/S
- ONE TELEMETRY CHANNEL PER T/S
- ONE TELEMETRY CHANNEL FOR DIAGNOSTICS
- T/S FUNCTIONS CONTROLLED BY TIME TAGGED COMMANDS FROM S/C

SYSTEM HARDWARE CONFIGURATION

10676–19



APRIL 1981

IAPS CONTROL PHILOSOPHY REQUIREMENTS

10816–8

- EXECUTE ALL NORMAL THRUSTER FUNCTIONS ON SINGLE COMMAND
- MAINTAIN THRUSTER ON DESIRED OPERATING POINT
- PERFORM FAILURE WORKAROUNDS
  - AUTOMATIC (TEMPERATURE SENSORS)
  - GROUND-ENABLED (CATHODE HARDSTARTING)
- PROVIDE T/M AND S/C INTERFACE

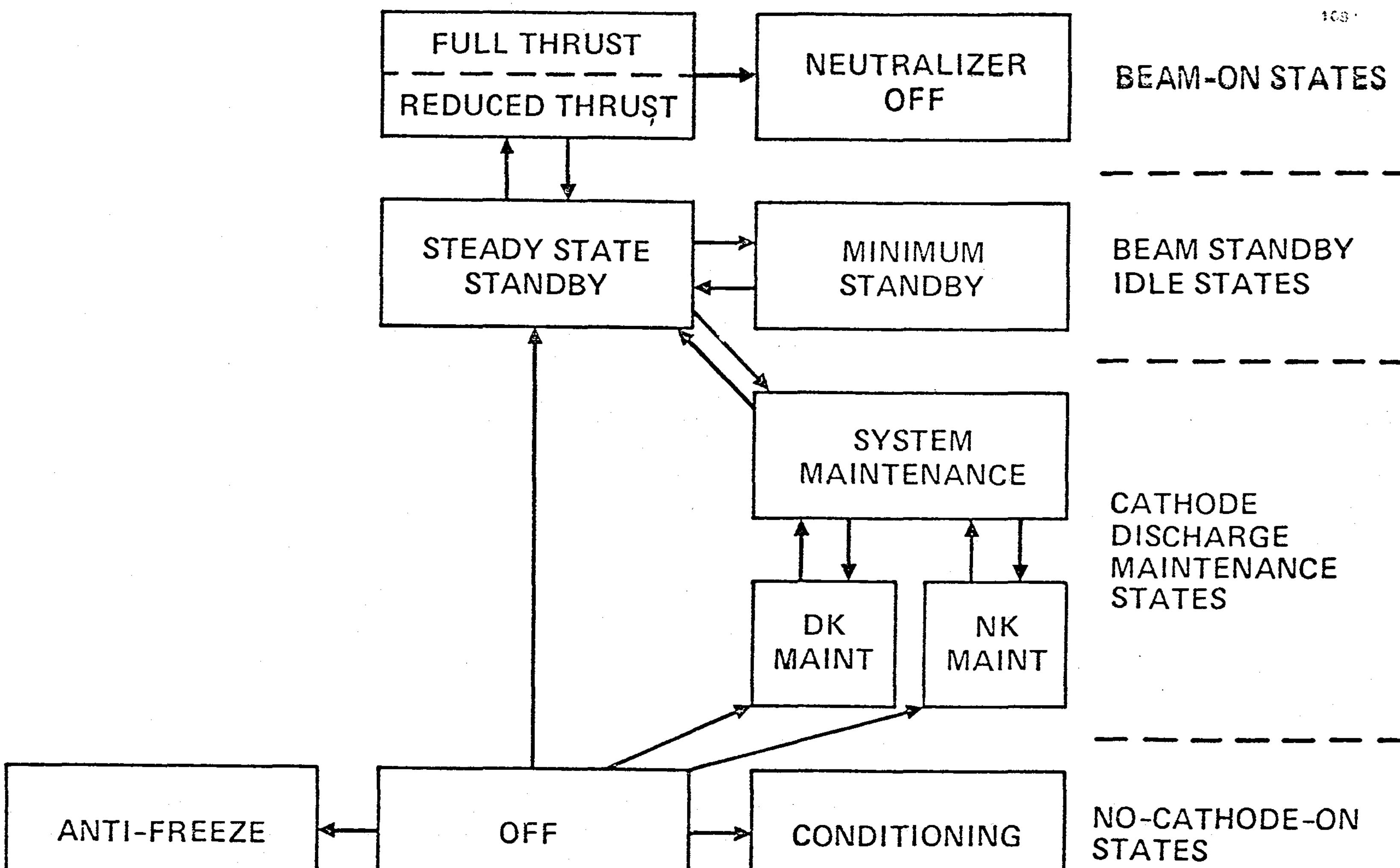
CONTROL PHILOSOPHY APPROACH

10816–9

- STATE DIAGRAM: OPERATING MODES
- THRUSTER MONITOR
  - MODE MAINTENANCE
  - FAULT/FAILURE SERVICE
- MODE-TRANSITION PACKAGES
- EXECUTIVE
  - COMMAND AND T/M PROCESSING
  - HOUSEKEEPING FUNCTIONS

APRIL 1981

IAPS STATE DIAGRAM — ALTERNATIVE OPERATING MODES



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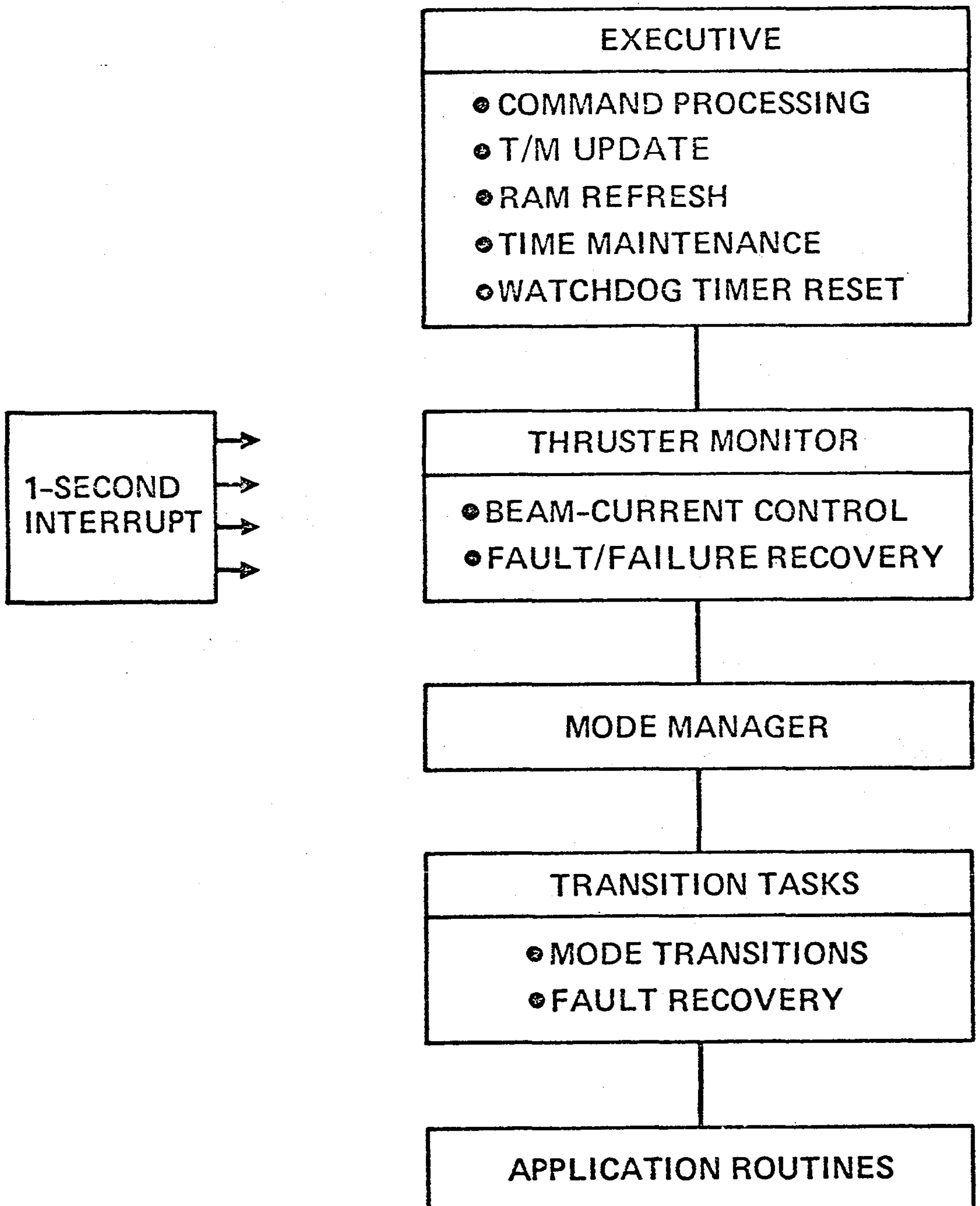
10816–11



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SOFTWARE HIERARCHY

THRUSTER MONITOR

10816–12

- DETECT FAULT/FAILURE CONDITIONS
  - SET FLAGS FOR TRANSITION ROUTINES
  - INVOKE RECOVERY ROUTINES
- CONTROL BEAM CURRENT
  - ADJUST DISCHARGE CURRENT TO GIVE:
    - NOMINAL THRUST 5 mN (1.13 mlb)
    - REDUCED THRUST 4.5 mN (1.00 mlb)

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IAPS THRUSTER SYSTEM FAULTS ACCOMMODATED BY CONTROLLER

10816–14

FAULT/FAILURE	RECOVERY
DV OR NV TEMP SENSOR FAILURE	AUTOMATIC TIME-BASED STARTUP WORKAROUNDS; FIXED SETPOINT VAPORIZER OPERATION
DK OR NK HARDSTART	EXTENSIVE HARDSTART ALGORITHMS; SHUTDOWN TO MAINTENANCE STATE
DK OR NK EXTINCTION	AUTOMATIC RELIGHT AND STATE RECOVERY
DISCHARGE OR NEUTRALIZER FLOODING	AUTOMATIC ANTIFLOODING ROUTINES
V_D, V_{DK}, OR V_{NK} INSTABILITY OR TELEMETRY FAILURE	TEMP OR FIXED SETPOINT VAPORIZER OPERATION
I_{DK} OR I_{NK} TELEMETRY FAILURE	IGNITION TEST ON VOLTAGE
GRID SHORT OR HIGH I_A	AUTOMATIC HIGH VOLTAGE RECYCLE
EXCESSIVE HIGH VOLTAGE RECYCLING	SHUTDOWN FOR GROUND RESTART
EXCESSIVE POWER CONSUMPTION	HIGH VOLTAGE TURNOFF + AUTOMATIC RECOVERY ROUTINE
LOW BUS VOLTAGE	SHUTDOWN AND RESET FOR GROUND RESTART
LOSS OF LOGIC CONTROL	SHUTDOWN VIA WATCHDOG TIMER AND RESET FOR GROUND RESTART
RAM BITFLIP	PERIODIC HAMMING CODE TEST AND REFRESH

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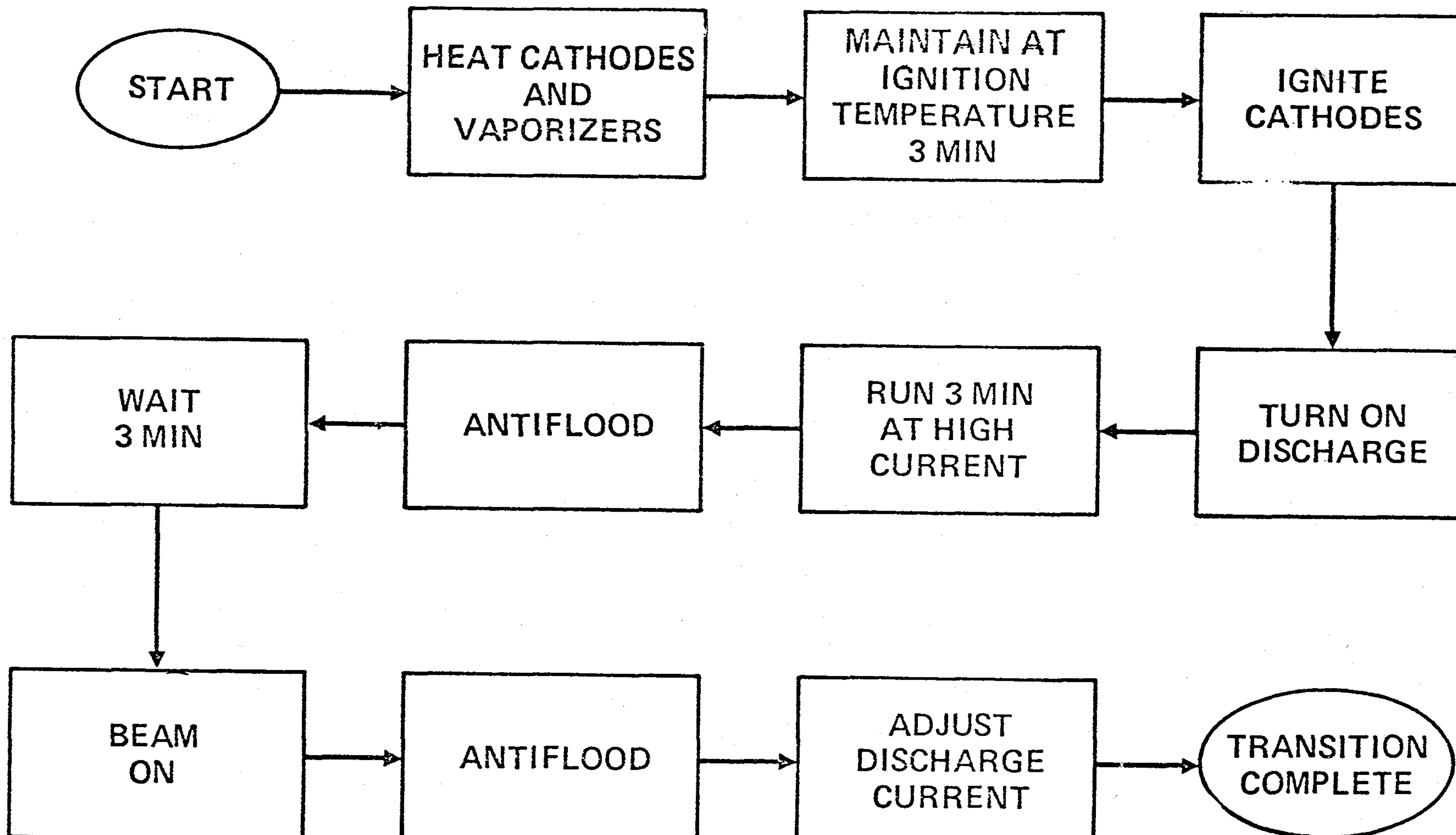
SAMPLE MODE TRANSITION: OFF TO FULL THRUST

10816–15



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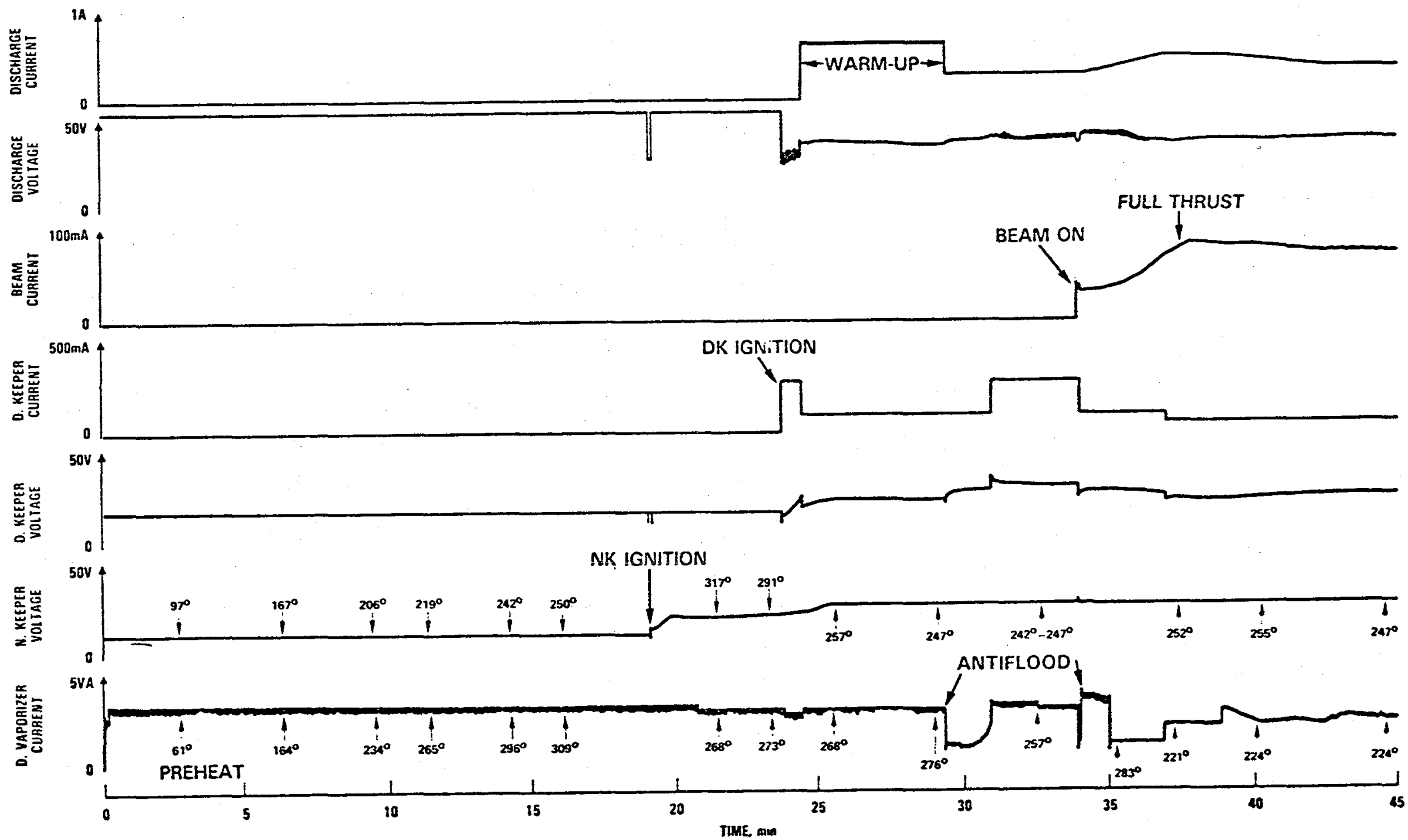
OFF TO FULL BEAM TRANSITION (NORMAL OPERATION)

10816–2



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TEST CONFIGURATIONS

10816–17

TEST	COMPONENT: THERMAL ENVIRONMENT		
	THRUSTER	PEU	DCIU
PREQUALIFICATION	EM: THERMAL VACUUM	EM: THERMAL VACUUM	BREADBOARD: AMBIENT
FLIGHT CHECK-OUT	FLIGHT: THERMAL VACUUM	FLIGHT: AMBIENT	BREADBOARD: AMBIENT
QUALIFICATION	EM: THERMAL VACUUM	EM: THERMAL VACUUM	FLIGHT: AMBIENT

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CONCLUSIONS

10816—19

- CONTROL SOFTWARE SUCCESSFULLY IMPLEMENTED IN CONTROLLER
- CONTROLLER SUCCESSFULLY DEMONSTRATED WITH FLIGHT THRUSTERS
- COMPREHENSIVE CONTROLLER CAPABILITY DEMONSTRATED IN EXTENSIVE TESTING

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AUTOMATION

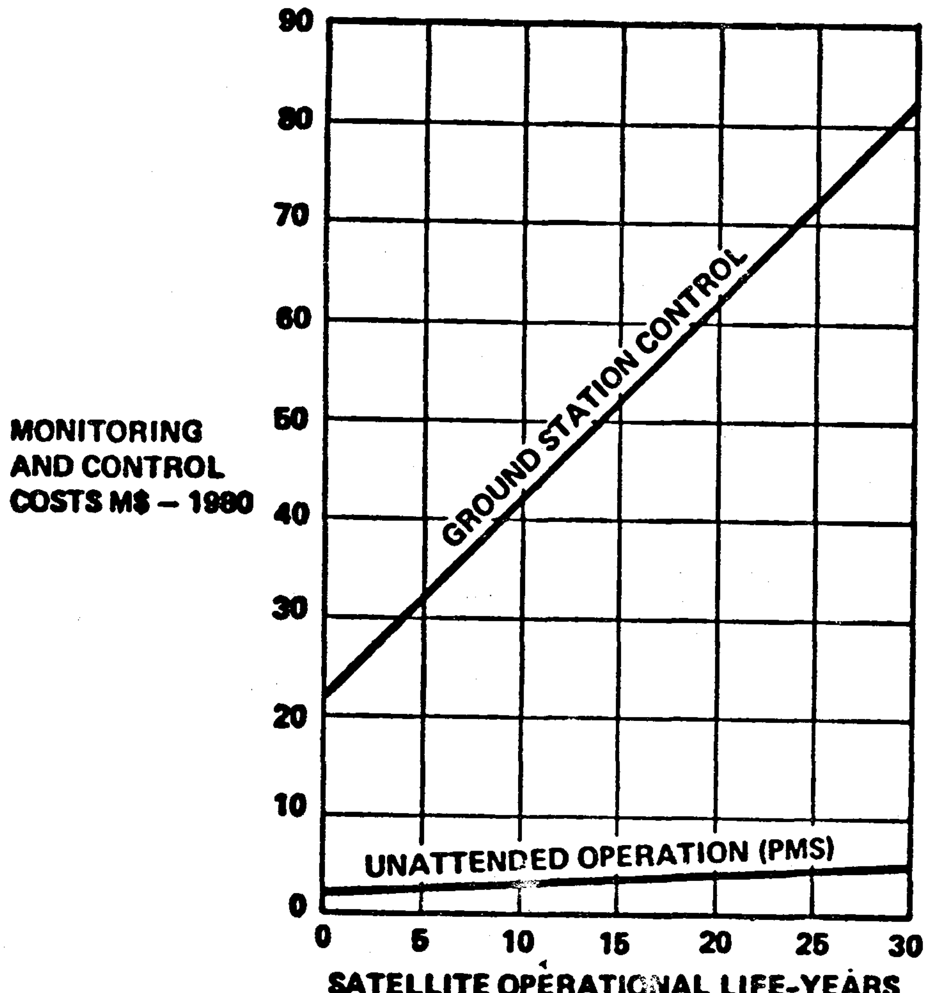
- REQUIRES DETAILED KNOWLEDGE OF:
  - SYSTEM REQUIREMENTS AND FUNCTION
  - SYSTEM ELEMENTS
    - CHARACTERISTICS
    - INTERACTIONS
- CAN ONLY BE ACCOMPLISHED AFTER SUFFICIENT UNDERSTANDING OF SYSTEM CHARACTERISTICS EXISTS

AUTOMATION TECHNOLOGY

FOR POWER SYSTEM MANAGEMENT

Dr. Ronald L. Larsen
NASA Headquarters
October 28, 1981

POWER SYSTEM COST REDUCTION THROUGH AUTOMATION



Ref: TRW PMS Study

FUNCTIONS OF AN EXPERT

- INTERPRETATION - ANALYSIS OF DATA
- DIAGNOSIS - IDENTIFICATION OF FAULT
- PREDICTION - FORECAST FUTURE FROM MODEL
- MONITORING - SET OFF ALARMS, AVOID FALSE ALARMS
- PLANNING - PROGRAM ACTIONS TO ACHIEVE GOALS
- DESIGN - PLANNING TO CREATE OBJECTS
- EXPLANATION - MAKING UNDERSTANDABLE

EXPERT SYSTEMS

MODEL A PERSON'S UNDERSTANDING OF A SYSTEM
RATHER THAN THE SYSTEM ITSELF

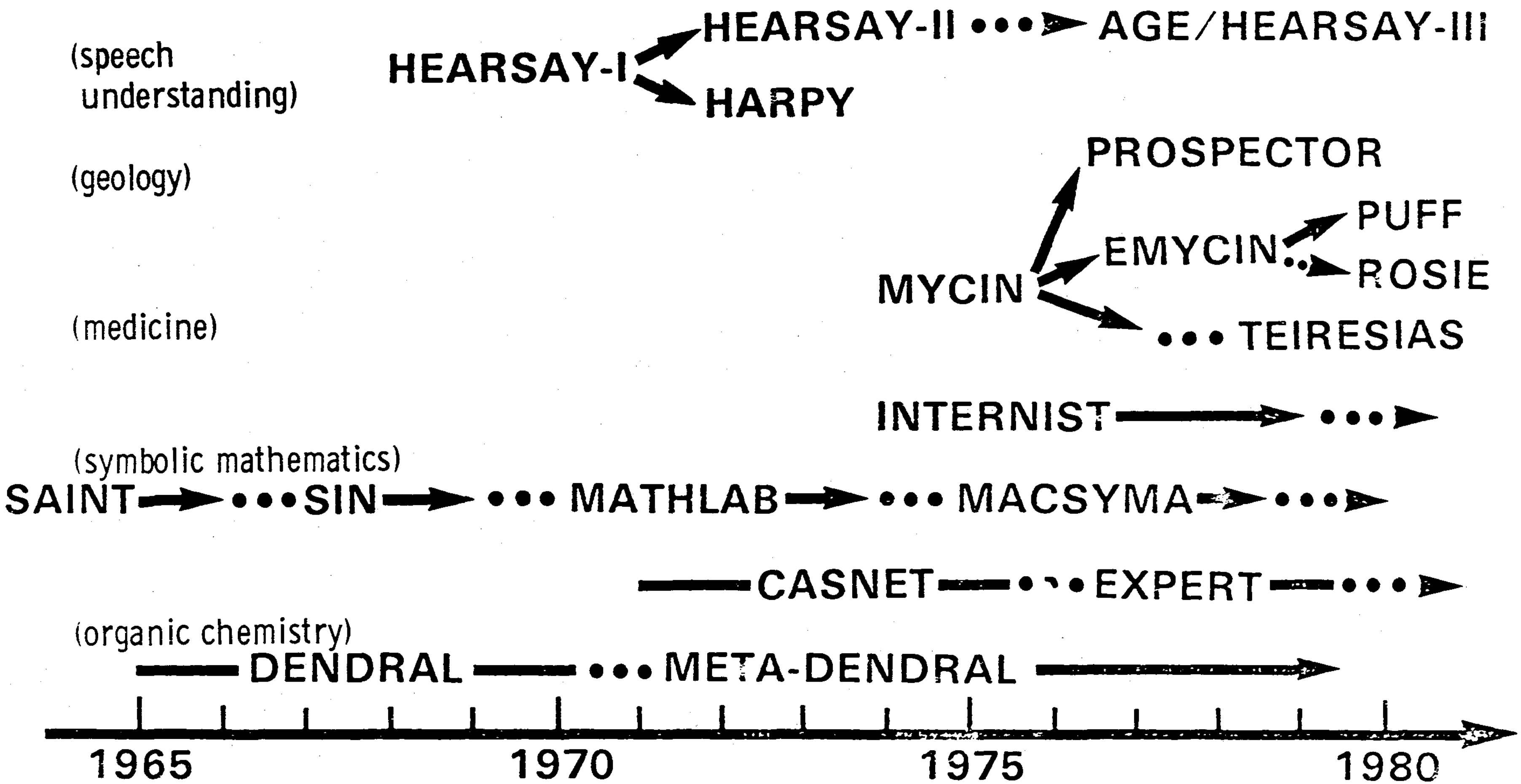
Ref: Hayes-Roth, F., "A Tutorial on Expert Systems: Putting Knowledge to Work," IJCAI-81

DEFINING "EXPERT SYSTEMS."

1. The field of expert systems investigates methods and techniques for constructing man-machine systems with domain-specific problem-solving expertise

2. Expertise consists of knowledge about a domain, understanding of domain problems, and skill at solving such problems

A QUICK HISTORY



WHAT DO EXPERT SYSTEMS DO?

1. Use expert rules to avoid blind search
2. Reason by manipulating symbols
3. Grasp fundamental domain principles and weaker general methods
4. Solve complex problems well
5. Interact intelligibly with users
6. Interpret, diagnose, predict, instruct, monitor, analyze, consult, plan or design

THE BASIC IDEAS

1. Knowledge = Facts + beliefs + heuristics
2. Success = Finding a good-enough answer with the resources available
3. Search efficiency directly affects success
4. Aids to efficiency:
   - The quality and generality of knowledge
   - The rapid elimination of "blind alleys"
   - The elimination of redundant computation
   - The speed of the computer
   - The use of multiple sources of knowledge
5. Problem complexity increases with:
   - Errorful or dynamically changing data
   - The number of possibilities to be ruled out
   - The amount of effort required to rule out a possibility

INSIDE MYCIN

- Problem representation

Context tree

One or more patients,
with one or more symptoms,
with one or more diseases,
with one or more treatments

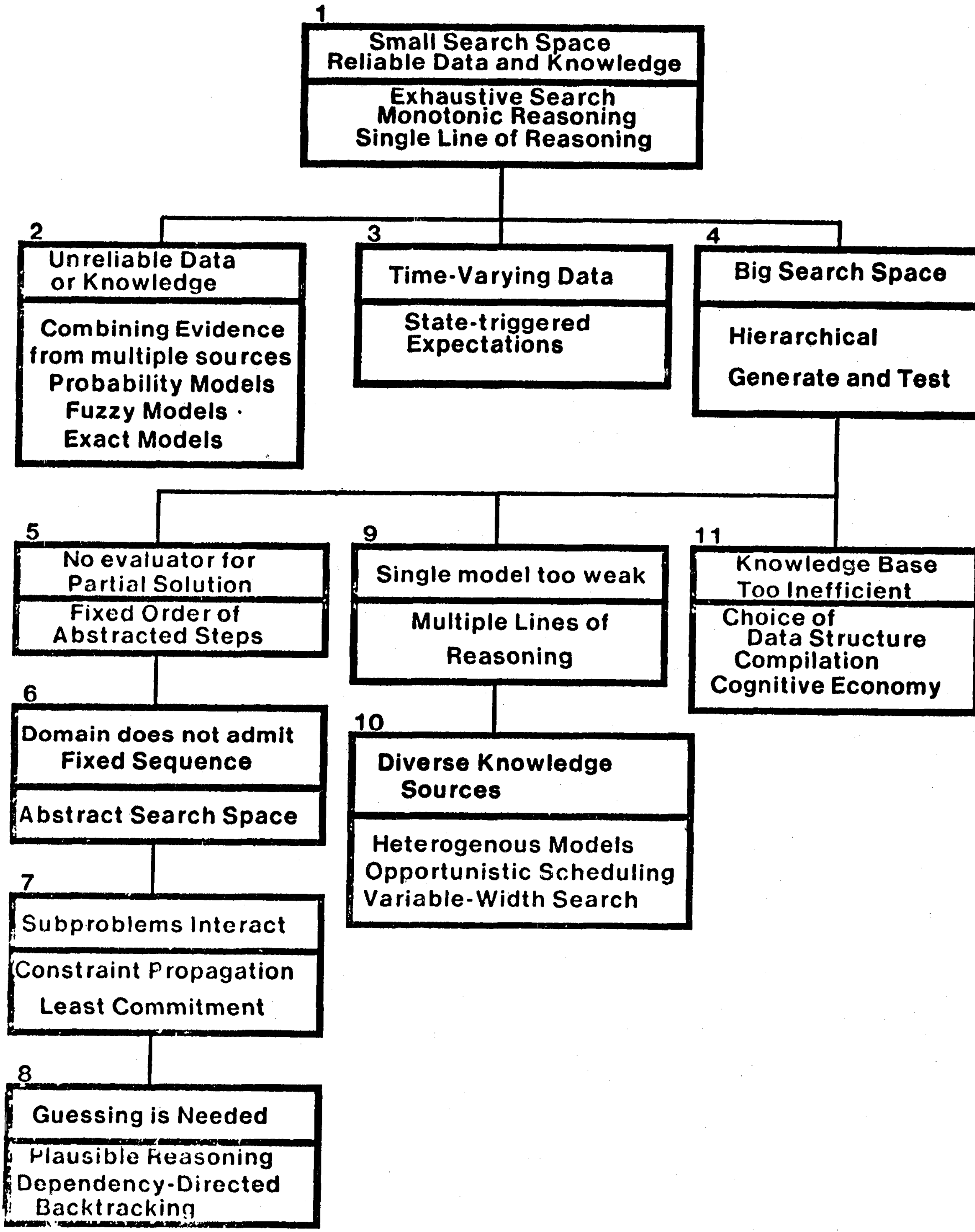
- Table of operators: If-Then rules

If there is <condition>
[and/or <condition>]...
Then there is suggestive
evidence (.8) of <disease>

- Control

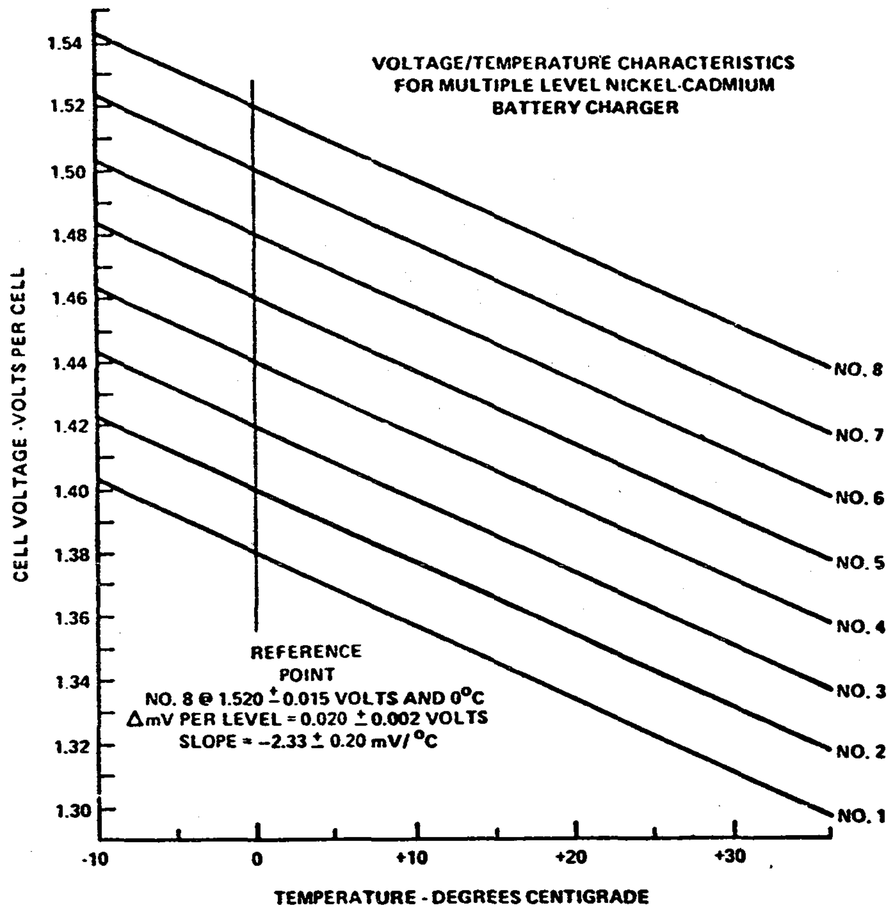
1. Backchaining
2. Exhaustive
3. Certainty factor calculus
   for conflict resolution

COPING WITH COMPLEXITY



EXAMPLE

BATTERY CHARGE CONTROL



THE PUNCH-LINE

An Expert System (as a human expert)
blends fundamental knowledge,
practitioners' wisdom, and skill
in the controlled application
of data, knowledge, and tools

SPACE POWER SYSTEM AUTOMATION WORKSHOP
MARSHALL SPACE FLIGHT CENTER
28/29 OCTOBER 1981

SPACECRAFT SYSTEM/POWER SUBSYSTEM INTERACTIONS

Chris Carl
MANAGER, SPACECRAFT SYSTEMS ENGINEERING SECTION
Jet Propulsion Laboratory
Pasadena, California

INTRODUCTION

- TRENDS IN AUTOMATION
- CANDIDATE SYSTEM REQUIREMENTS/POLICIES
- SYSTEM CONSTRAINTS ON SUBSYSTEM AUTOMATION
- FAULT PROTECTION/CORRECTION EXAMPLES
- CONCLUSIONS

DRIVERS FOR INCREASED ON-BOARD AUTOMATION

- GROUND COSTS
- RESPONSE TIME REQUIRED IS $\ll$ 2 WAY-LIGHT TIME
- BLIND OPERATIONS
- MISSION-CRITICAL ACTIVITIES DURING ENCOUNTER
- LONG FLIGHT TIMES
- HIGHLY VISIBLE, ONE-SHOT PROGRAMS

AUTONOMOUS FEATURES

MARINER IV-X

- SUN ACQUISITION
- STAR ACQUISITION
- REDUNDANT POWER CHAIN SWITCHOVER
- AUTOMATIC SEQUENCE IV-VII
- POWER SHARE

VIKING ORBITER

- SUN ACQUISITION
- STAR ACQUISITION
- REDUNDANT POWER CHAIN SWITCHOVER
- REDUNDANT TRANSMITTER SWITCHOVER
- COMMAND LOSS
- BATTERY OVERTEMP
- POWER SHARE
- PRESSURE REGULATOR FAILURE MONITOR
- ATTITUDE CONTROL POWER CHANGEOVER
- COMPUTER ERROR
- MOI POWER TRANSIENT

VIKING EXTENDED MISSION

- BATTERY FAIL PROTECTION
- BATTERY CHARGE
- RECVR PROTECT
- STOP A/C GAS LEAKS
- SCIENCE PROTECTION
- DOWNLINK OFF
- ROLL DRIFT MODE ENTRY
- STAR TRACKER PROTECTION
- ENGINE MONITOR
- AUTOMATION FUNCTION MONITOR

VOYAGER

- SUN ACQUISITION
- STAR ACQUISITION
- REDUNDANT INVERTER SWITCHOVER
- REDUNDANT TRANSMITTER SWITCHOVER
- BACK-UP AUTOMATIC MISSION
- COMMAND LOSS
- IRS PWR
- PWR CHECK
- THRUSTER MANAGEMENT
- GYRO MANAGEMENT
- COMPUTER ERROR
- TURN SUPPORT
- AACS PROCESSOR SWAP
- AACS HYBIC SWAP
- PLATFORM SAFING

GALILEO

- SUN ACQUISITION
- REDUNDANT INVERTER SWITCHOVER
- REDUNDANT TRANSMITTER SWITCHOVER
- COMMAND LOSS
- PWR CHECK
- THRUSTER MANAGEMENT
- GYRO MANAGEMENT
- COMPUTER ERROR
- TURN SUPPORT
- AACS PROCESSOR SWAP
- PLATFORM SAFING
- TEMPERATURE CONTROL
- PROPULSION SAFING
- SEQUENCE RESTART
- SCIENCE PROTECTION

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

GENERAL REQUIREMENTS

- THE SPACECRAFT SHALL OPERATE W/O GROUND CONTROL FOR TBD DAYS W/O DEGRADATION
    - BLOCK REDUNDANCY
    - FUNCTIONAL REDUNDANCY
    - HI RELIABILITY COMPONENTS
- THE SPACECRAFT SHALL OPERATE W/O GROUND CONTROL FOR TBD DAYS WITH LESS THAN TBD % DEGRADATION
    - GRACEFUL DEGRADATION
- TRANSPARENCY OF AUTOMATED ACTIVITIES
    - RELIABLE, TRANSIENT-FREE RECONFIGURATIONS
    - MEMORY "KEEP ALIVE"
- AUDIT TRAIL OF AUTOMATED ACTIVITIES
    - STORE ACTIVITIES
    - MEMORY READOUT
    - FLAG SET
- GROUND SYSTEM OVERRIDE
    - RESTART
    - REPROGRAMMING

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

RELIABILITY

- NO SINGLE HARDWARE FAILURE SHALL RESULT IN LOSS OF MORE THAN ONE INSTRUMENT OR >50% OF ENGINEERING DATA
  - BLOCK REDUNDANCY
  - FUNCTIONAL REDUNDANCY
  - LOAD MANAGEMENT
  - FUNCTIONAL INDEPENDENCE
- THE CENTRAL DECISION-MAKER SHALL BE THE MOST RELIABLE ELEMENT
- PROCESSORS SHALL PERFORM SELF-TEST PRIOR TO ISSUING ANY COMMANDS

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

FAULT PROTECTION

- FAULT RECOVERY TO AN UNAMBIGUOUS STATE
  - POWER ON RESET
- FAULTS DETECTED/CONFIRMED BY INDEPENDENT SOURCES
  - HIGH RELIABILITY SENSORS
  - MULTIPLE SENSORS
  - VOTING
- FAULT PROTECTION AT LOW LEVELS
  - SENSORS AND SWITCHING AT LOWEST PRACTICAL ELEMENT
- FALSE ALARM PREVENTION
  - HARDWARE/SOFTWARE TOLERANCES TO BE SET AT "UNACCEPTABLE" PERFORMANCE

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

SYSTEM STATES

- SPACECRAFT STATE POSITIVELY IDENTIFIABLE FROM TELEMETRY
  - STATUS WORDS
- AUTOMATED ACTIVITIES REVERSIBLE
  - ANY SPACECRAFT STATE ACCESSIBLE AND COMMANDABLE

SYSTEM TEST

- SYSTEM TEST PLANS SHALL BE PREPARED EARLY IN DEVELOPMENT TO HELP VALIDATE AUTOMATED ROUTINES
  - SUBSYSTEMS SHALL HAVE EARLY DEFINITION OF AUTOMATED OPERATIONS

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

SYSTEM TEST

- ALL UNIT OR BLOCK REDUNDANT ELEMENTS SHALL PROVIDE ACCESS FOR CHECKOUT, CALIBRATION AND REPROGRAMMING
    - TEST PORT FOR FAULT INJECTION AND RESPONSE
    - MEMORY ACCESSIBILITY
    - GROUND/IN-FLIGHT VISIBILITY

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

SOFTWARE

- TELEMETRY SHALL PROVIDE INFORMATION TO DETERMINE THE OPERATIONAL ACTIVITY AND STATUS OF FLIGHT SOFTWARE
- PROTECTION SHALL BE PROVIDED AGAINST WRONG OR INVALID COMMANDS
  - MULTI-COMMANDS
  - HANDSHAKE
  - ECHO
  - PARITY
  - CODED COMMANDS

CANDIDATE SYSTEM REQUIREMENTS/POLICIES

MEMORY

- SUBSYSTEMS WITH VOLATILE MEMORIES SHALL ASSURE THAT DIRECT MEMORY ACCESS IS OPERATIONAL AT POWER ON RESET

- COMPUTER MEMORY MARGINS SHALL BE PRESERVED

  - MEMORY MANAGEMENT DURING DEVELOPMENT AND OPERATIONS

- ON-BOARD COMPUTER MEMORIES VERIFIABLE

  - MEMORY READOUT

  - CHECKSUM

SYSTEM CONSTRAINTS
ON SUBSYSTEM AUTONOMY

AUTOMATION IS NON-INTERACTIVE WITH THE SYSTEM IF IT DOES NOT:

- AFFECT THE STATE OR DATA TAKING OF MORE THAN ONE SUB SYSTEM
- AFFECT THE DOWNLINK MARGIN, TELEMETRY FORMAT OR RATE
- AFFECT 1ST ORDER GROUND PROCESSING CONFIGURATION
- INCREASE CENTRAL COMPUTER PROCESSING OR BUS TRAFFIC OVER ALLOCATIONS
- CHANGE STORED SEQUENCES
- ALTER ATTITUDE CONTROL OR STABILITY MARGINS
- INCREASE POWER DEMANDS ABOVE MARGINS
- ALTER THERMAL BALANCE
- IMPACT SYSTEM INTERFACES

SYSTEM CONSTRAINTS ON SUBSYSTEM AUTONOMY

AUTOMATION IS NON-INTERACTIVE WITH THE SYSTEM IF IT DOES NOT:

- ADVERSELY IMPACT SPACECRAFT SYSTEM LIFETIME, RELIABILITY, OR PERFORMANCE
- ADVERSELY IMPACT SYSTEM OR SUBSYSTEM SAFETY
- RESULT IN SELECTION OF SYSTEM REDUNDANT RESOURCES
- IRREVOCABLY CHANGE SPACECRAFT STATE

FAULT PROTECTION/CORRECTION EXAMPLES
VIKING SHARE MODE CORRECTION

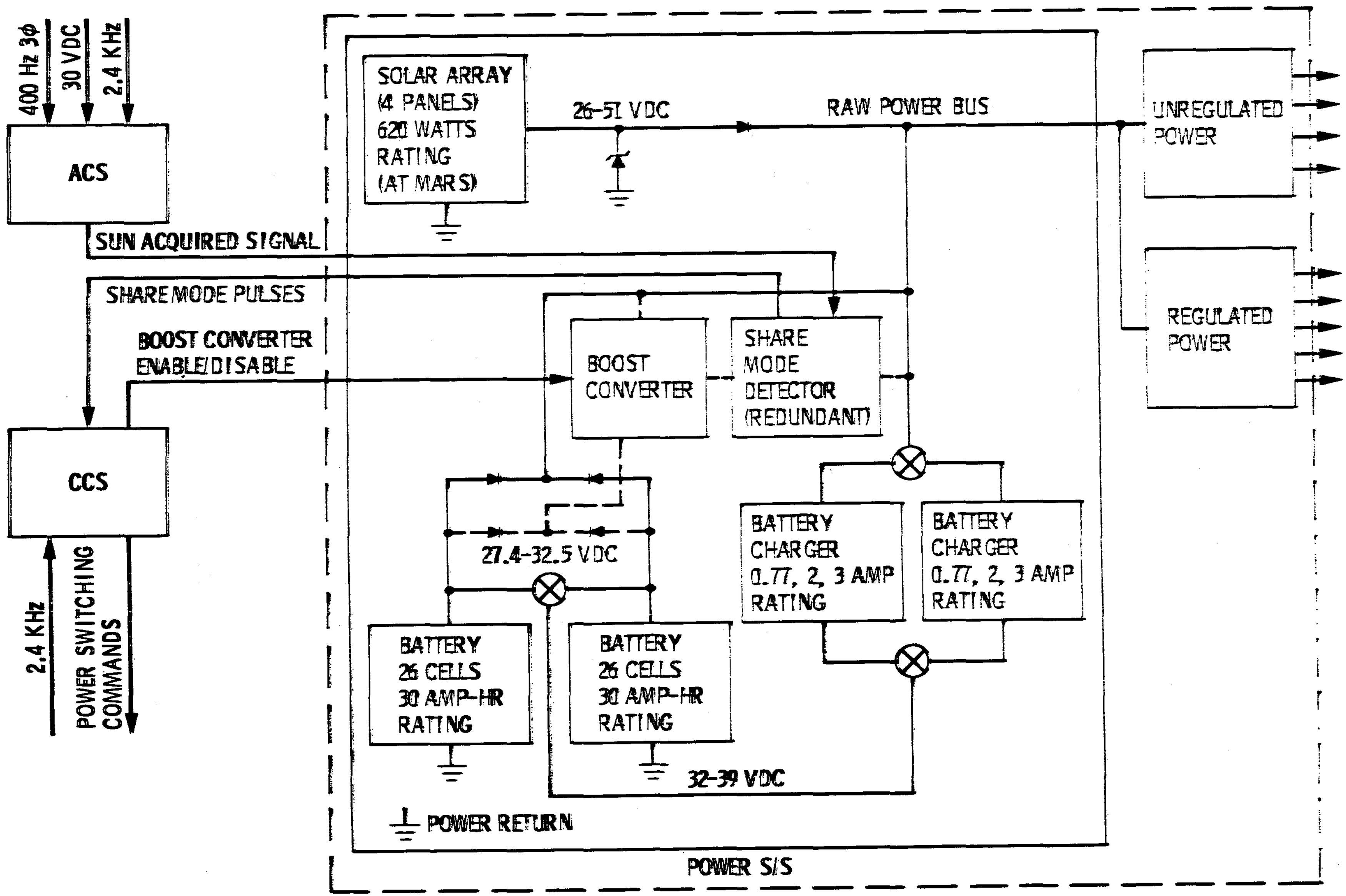
- FUNCTION

  TURN OFF LOADS WHEN POWER SUBSYSTEM IS UNABLE TO BOOST OUT OF AN UNINTENDED SOLAR PANEL/BATTERY SHARE CONDITION WHILE THE SPACECRAFT IS SUN ACQUIRED

- STRATEGY
  - COMPUTER COMMAND SUBSYSTEM (CCS) COUNTS BOOST PULSES FROM REDUNDANT SHARE MODE DETECTORS WITHIN POWER AND TURNS OFF LOADS IN PAIRS EACH TIME THAT THE NUMBER OF PULSES IN A GIVEN TIME PERIOD EXCEEDS A PREDETERMINED VALUE
  - FOR MISSION PHASES OTHER THAN MARS ORBIT INSERTION, THE CCS COMMANDS THE SPACECRAFT TO A SAFE STATE PRIOR TO EXECUTING THE SHARE MODE CORRECTION RESPONSE

FAULT PROTECTION/CORRECTION EXAMPLES

VIKING SHARE MODE CORRECTION

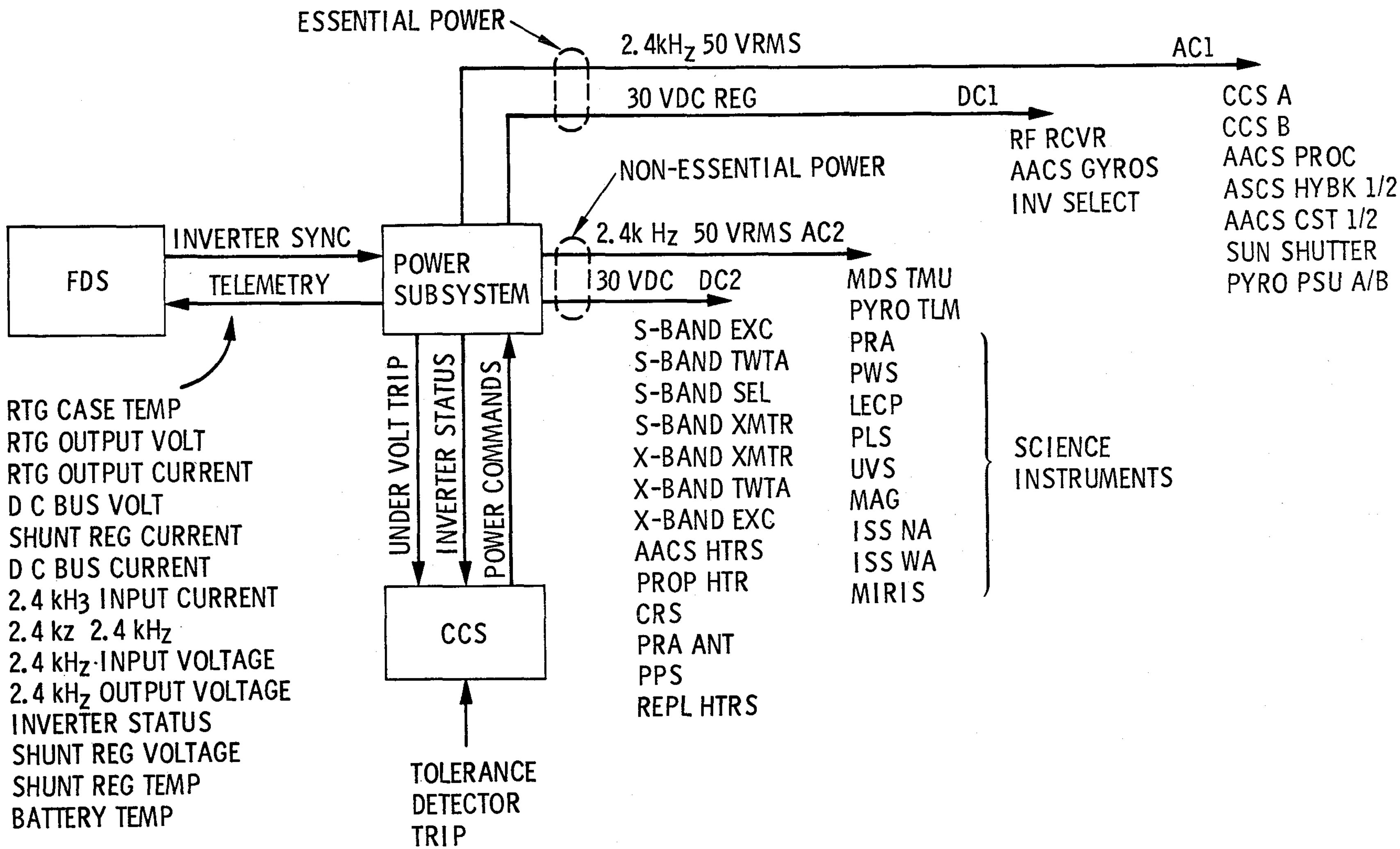


VOYAGER "PWRCHK" EXAMPLE

- FUNCTION - PROTECTS AGAINST:
  - INTERNAL POWER FAILURES
  - EXCESS LOAD POWER DEMAND
- STRATEGY - IF INTERNAL POWER FAILURE---
  - SWITCH TO REDUNDANT ELEMENTS
  - BRING MISSION-CRITICAL SYSTEMS & SEQUENCES BACK ON LINE
  - SWITCH TO LOW RF POWER
  - WAIT FOR GROUND ASSISTANCE

  IF EXCESS LOAD DEMAND ---
  - SHED ALL NON-CRITICAL LOADS (INCLUDING SCIENCE)
  - TURN ON REPLACEMENT HEATERS
  - SWITCH TO LOW RF POWER
  - WAIT FOR GROUND ASSISTANCE

VOYAGER POWER SUBSYSTEM
SIMPLIFIED BLOCK DIAGRAM



CONCLUSIONS

- DEVELOP SYSTEM REQUIREMENTS AND DEFINE SYSTEM INTERFACES
- DEVELOP RELIABLE SENSORS, ALGORITHMS AND EFFECTORS
- DEVELOP VALIDATION AND TEST METHODOLOGY

TECHNICAL ISSUES IN POWER SYSTEM AUTONOMY FOR PLANETARY SPACECRAFT

Fred C. Vote

Electrical Power and
Propulsion Section

Jet Propulsion Laboratory

October 28, 1981

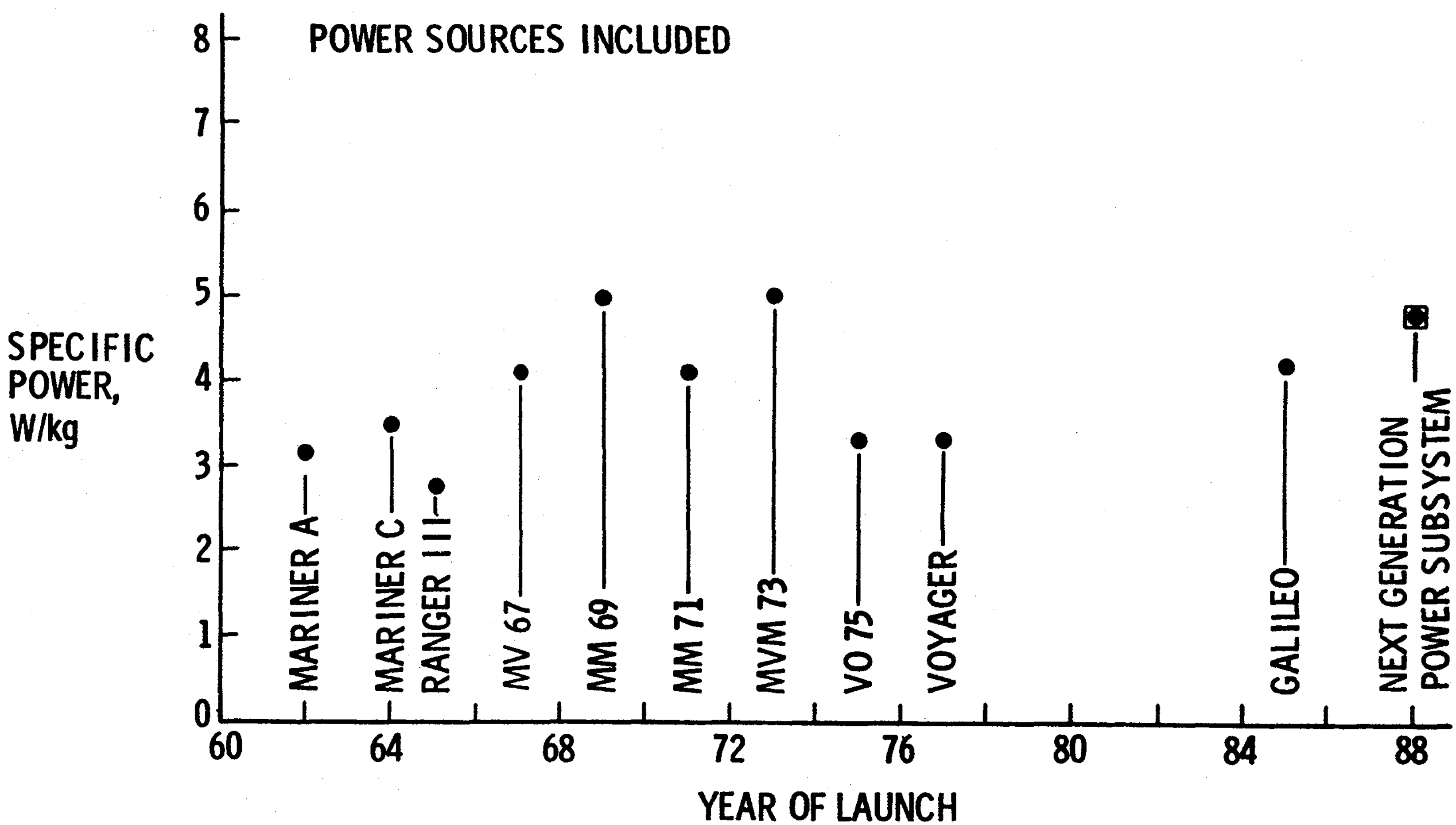
Agenda

- EVOLUTION OF SPACECRAFT POWER SYSTEM REQUIREMENTS
- OVERVIEW OF AUTOMATED SPACECRAFT POWER MANAGEMENT (ASPM) PROGRAM
- FUTURE PLANETARY POWER SYSTEM REQUIREMENTS
- TECHNICAL/SYSTEM-LEVEL ISSUES IN PLANETARY POWER SYSTEM AUTONOMY
- RECOMMENDED POWER SYSTEM AUTOMATION OBJECTIVES

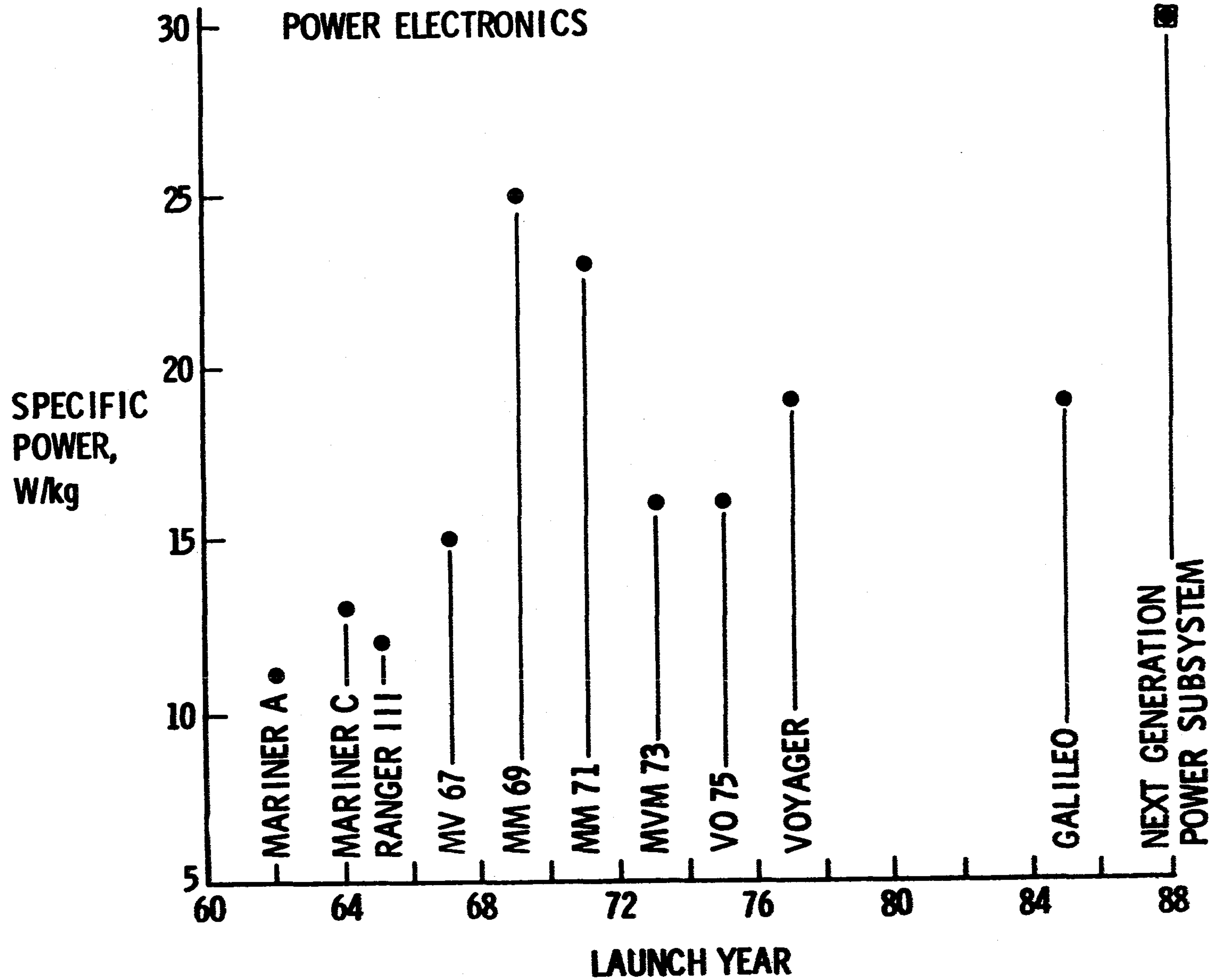
Evolution of Planetary Spacecraft Power System Requirements

- PLANETARY POWER SYSTEM REQUIREMENTS HAVE BEEN DRIVEN BY MISSION/ SPACECRAFT REQUIREMENTS AND DURATION
  - SPECIFIC POWER
  - RELIABILITY
  - FAULT RESPONSE TIME
  - FLEXIBILITY
  - AUTONOMY

Specific Power of Power Subsystems

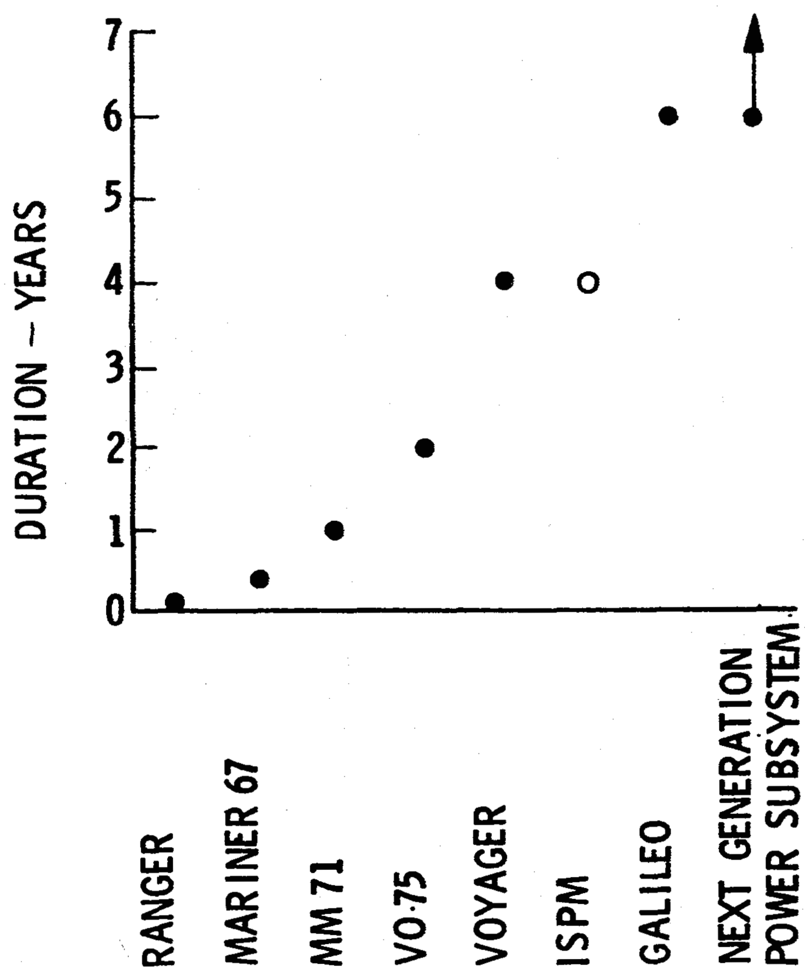


Specific Power of Power Subsystems

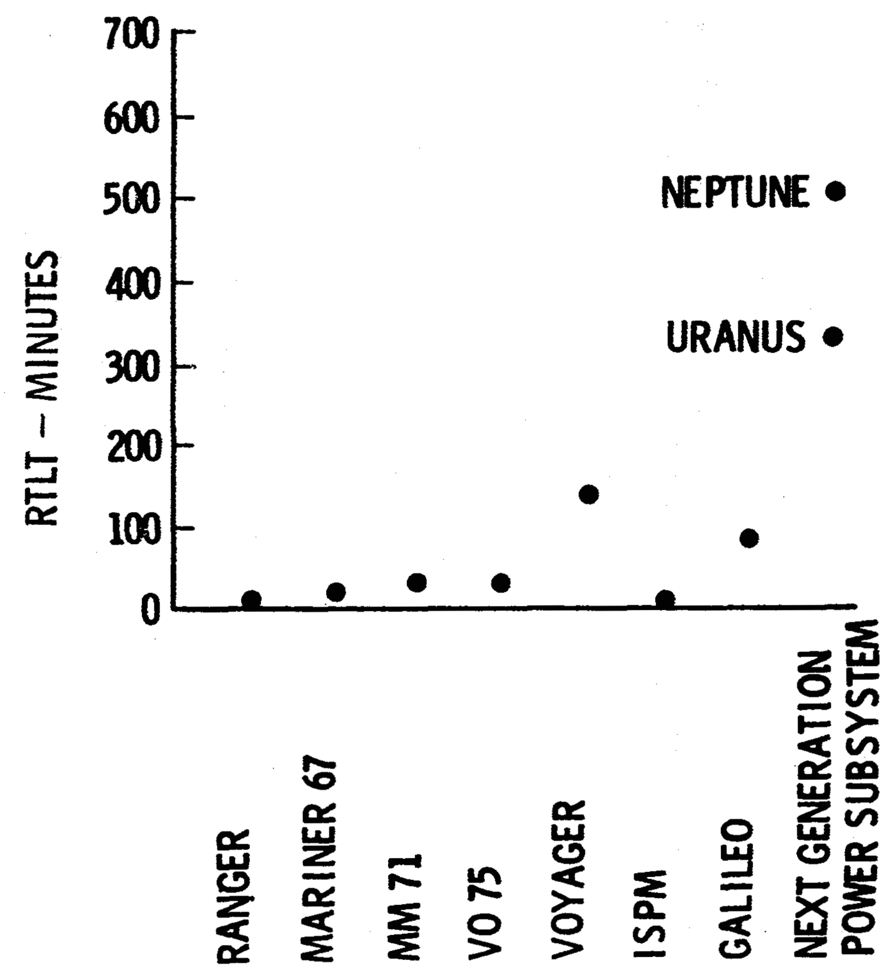


Power Subsystem Reliability Requirements

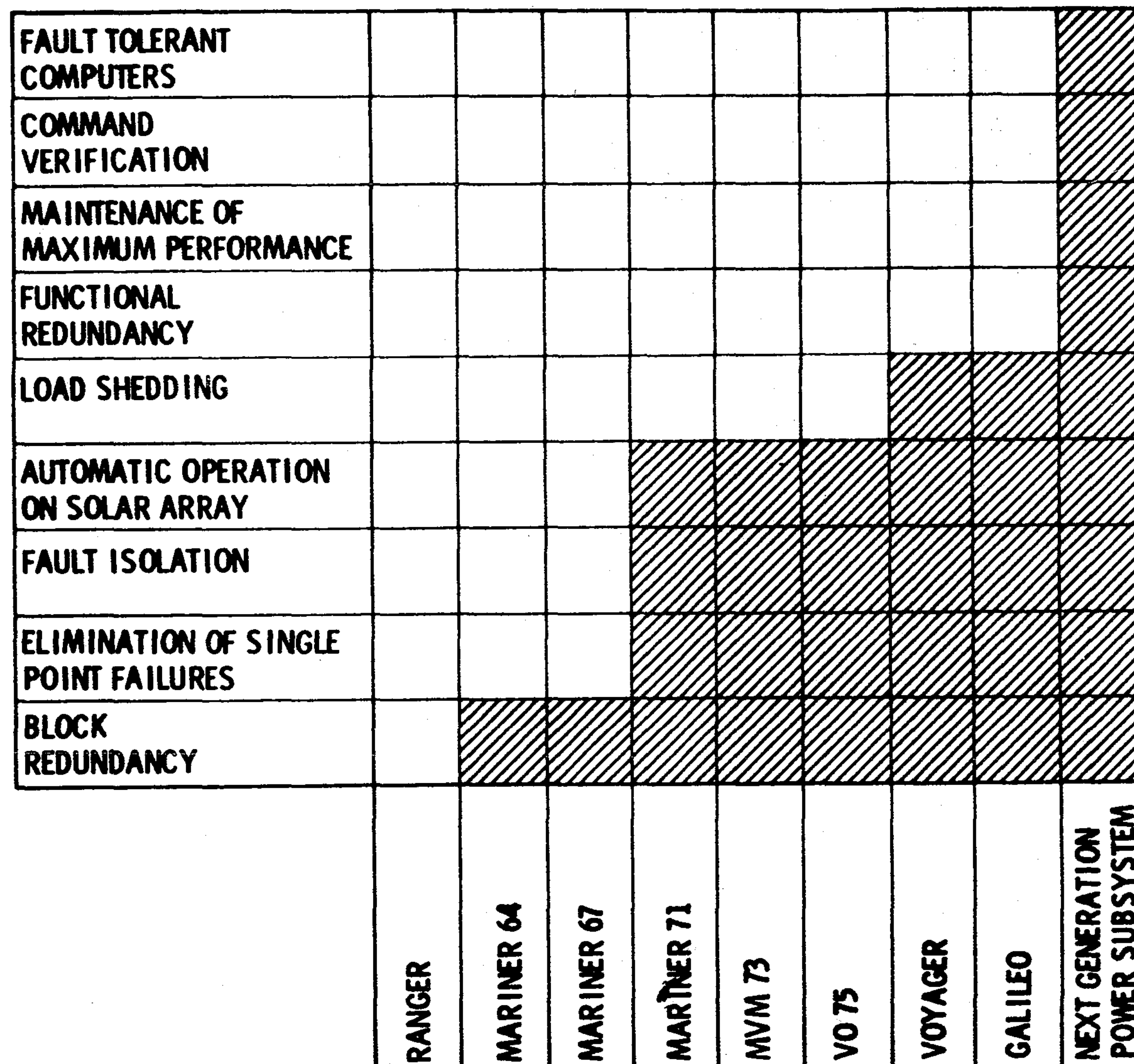
REQUIRED MISSION DURATION



ROUND TRIP LIGHT TIME AT PLANET



Fault Tolerance of Power Subsystems

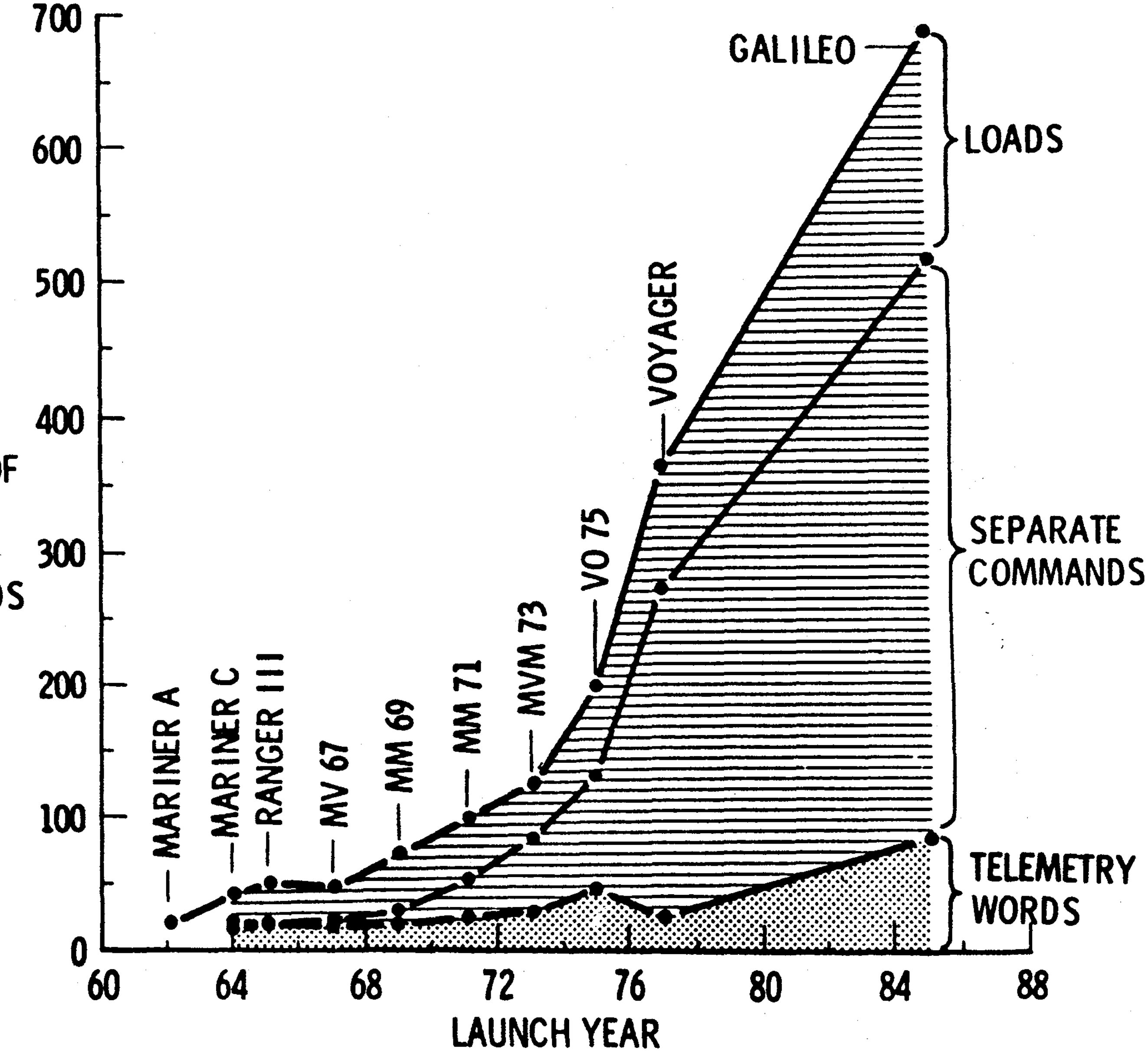


Power Subsystem Flexibility Requirements

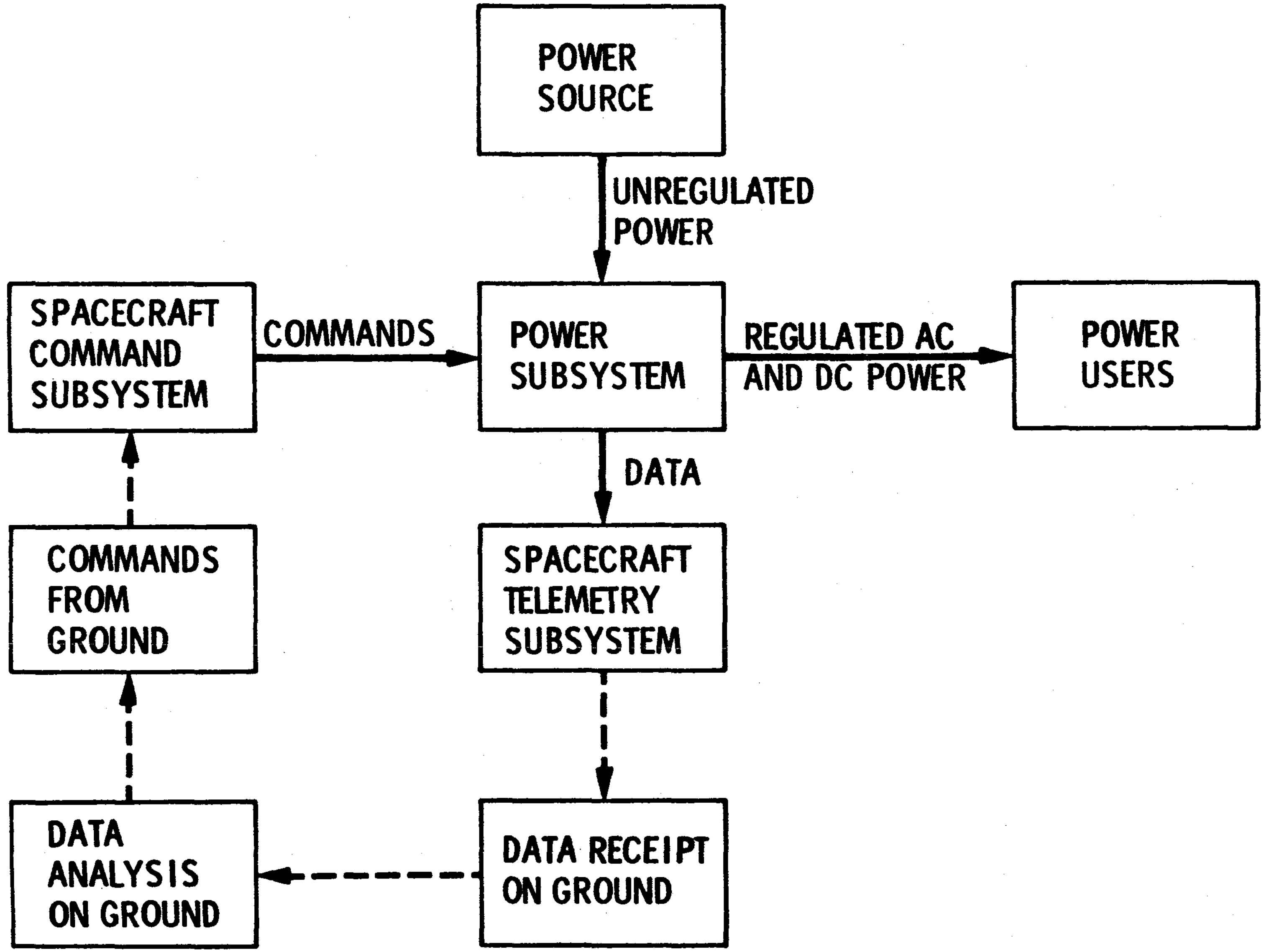
FLEXIBILITY REQUIRED

MEASURED AS NUMBERS OF
- LOADS
- TELEMETRY WORDS
- SEPARATE COMMANDS

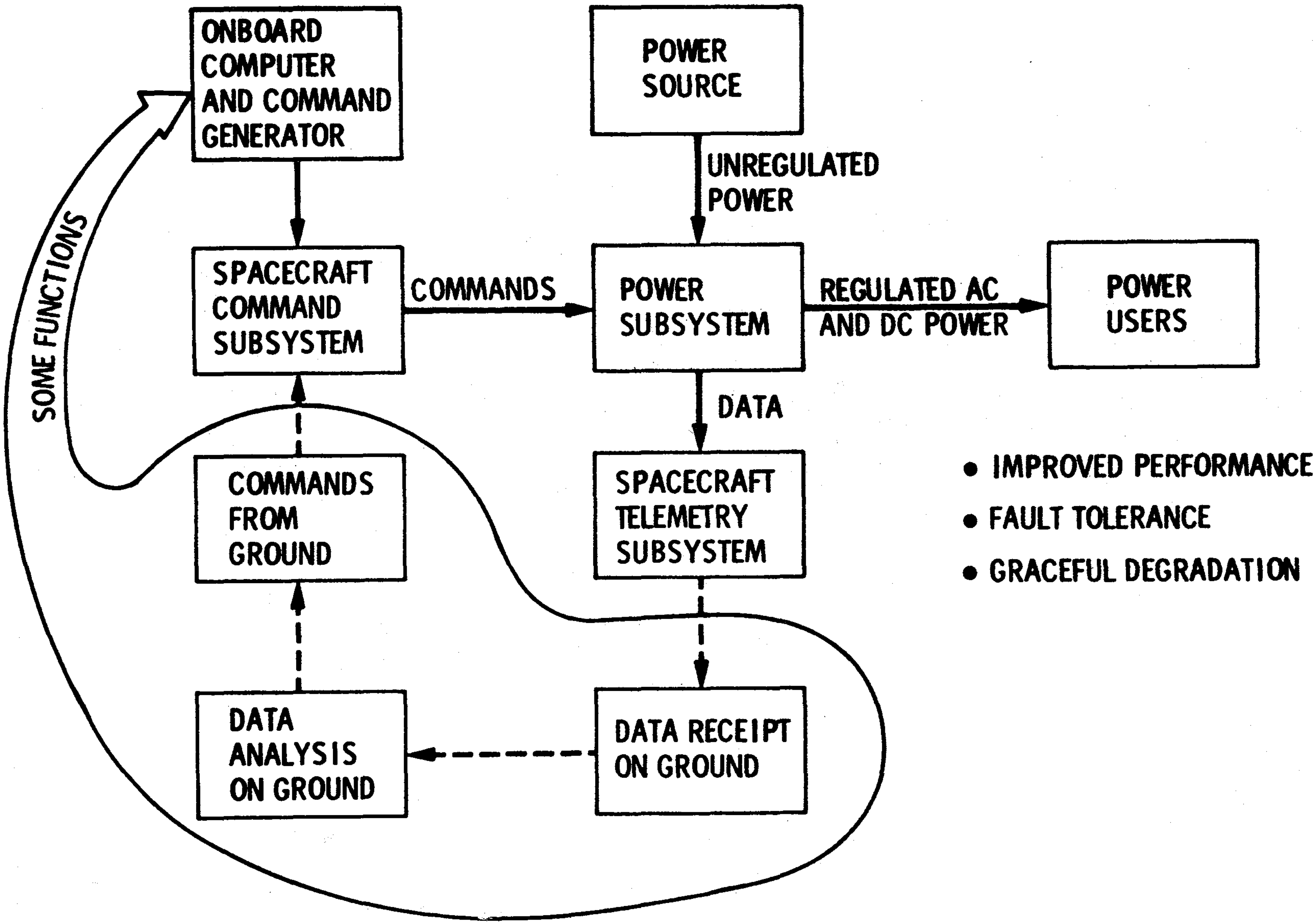
FOR POWER SUBSYSTEM



Power Subsystem Without Onboard Computation Capability



Power Subsystem With Onboard Computational Capability



Overview of Automated Spacecraft Power Management System (APSM) Program

- APSM PROGRAM

  6 - YEAR PROGRAM (1975-1981)

  $1.9M

- OBJECTIVES

  - DEVELOP TECHNIQUES AND DEMONSTRATE TECHNOLOGY TO PROVIDE RELIABLE AUTOMATED POWER SUBSYSTEM MANAGEMENT FUNCTION WITH CAPABILITIES OF:

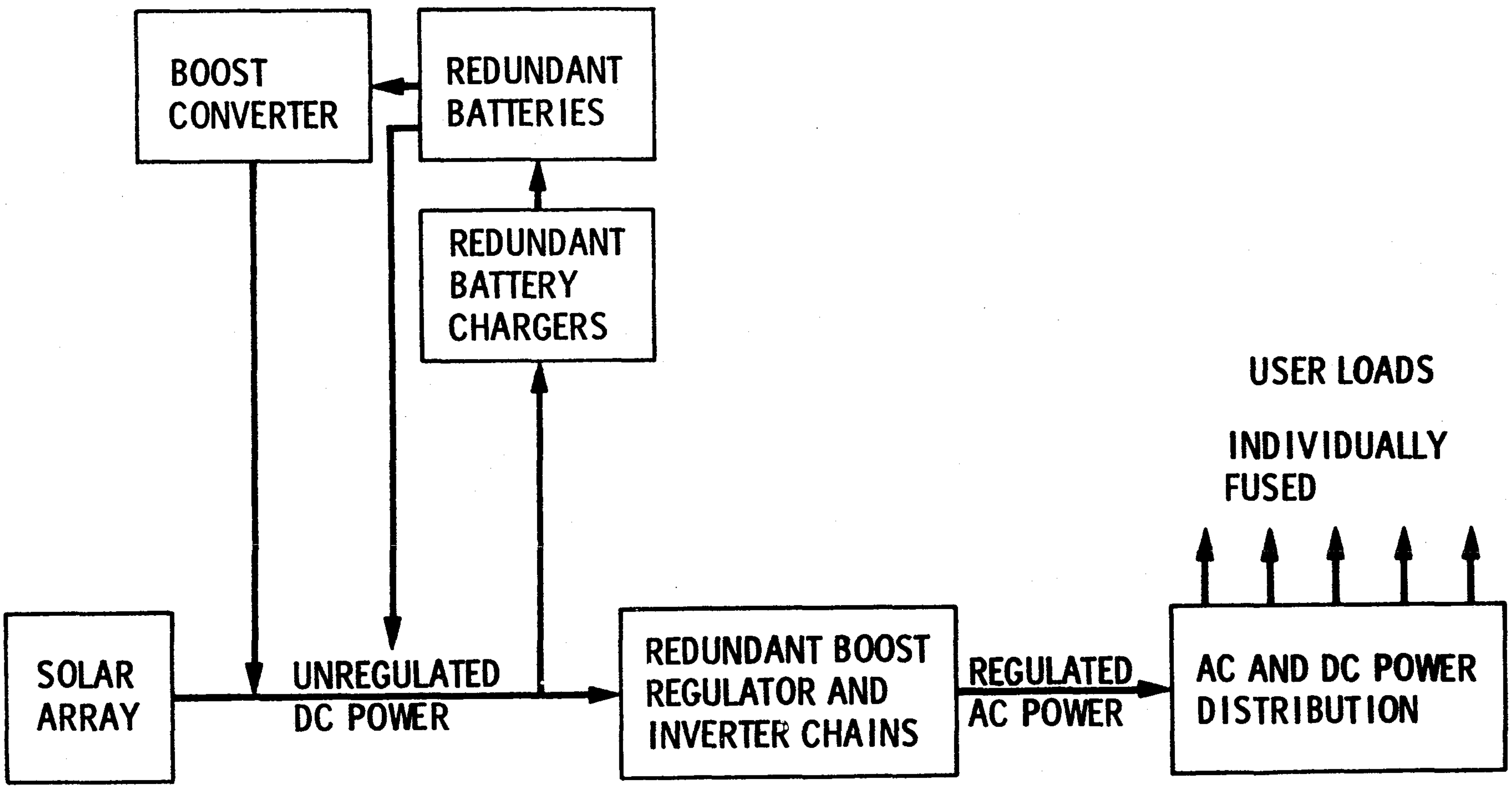
    - PROVIDING ACCURATE ASSESSMENT OF POWER SUBSYSTEM PERFORMANCE
    - DETECTING AND CORRECTING EQUIPMENT FAULTS
    - MANAGING USER LOADS

  - EVALUATE THE PERFORMANCE OF AUTOMATED POWER SUBSYSTEM MANAGEMENT AS APPLIED TO THE SOLAR ARRAY-BATTERY POWER SUBSYSTEM USED ON THE VO 75 SPACECRAFT
  - SERVE AS "PILOT" AUTOMATED POWER SYSTEM

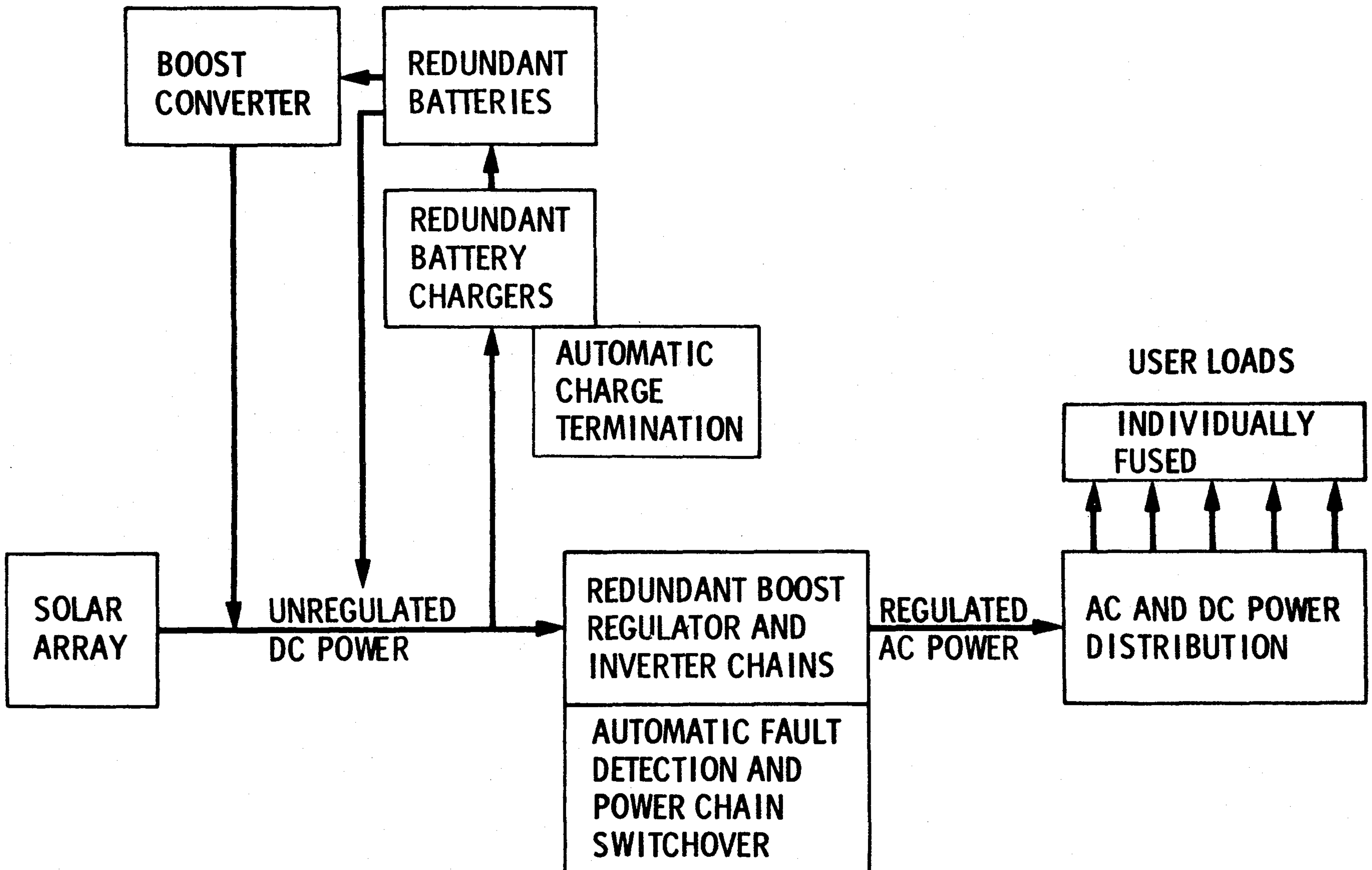
APSM Approach

- DEVELOP UPON A STATE-OF-THE-ART PLANETARY POWER SUBSYSTEM
- UTILIZE THE BREADBOARD VO 75 POWER SUBSYSTEM
- CONTRACTED EFFORT FOR CONCEPT DEFINITION AND IMPLEMENTATION (MARTIN MARIETTA)
- TEST AND EVALUATION BY JPL

VO 75 Power Subsystem



VO 75 Power Subsystem
Automated Elements



Candidate Functions for Automation

Function	Description
BATTERY CHARGE CONTROL	• AUTONOMOUSLY BEGIN CHARGING WHEN SOC FELL BELOW A PREDETERMINED LIMIT • SWITCH TO LOW RATE WHEN SOC REACHED A PREDETERMINED LIMIT • PREDETERMINED LIMITS VARIED ACCORDING TO TEMPERATURE MODEL
POWER CHAIN FAULT DETECTION AND SWITCHOVER WITH CROSS STRAPPING	• MAIN AND STANDBY BOOSTER REGULATORS CROSS STRAPPED TO MAIN AND STANDBY INVERTERS ALLOWING ANY PERMUTATION OF INVERTERS AND BOOST REGULATORS UPON DETECTION OF A FAULT
SUBASSEMBLY PERFORMANCE MONITORING	• EFFICIENCIES CALCULATED VIA INPUT AND OUTPUT VOLTAGES AND CURRENTS FOR POWER DEVICES SUCH AS INVERTERS, CHARGERS, ETC. • CELL MONITORING WITHIN BATTERIES
SUBASSEMBLY FAULT DETECTION AND RECOVERY	• DETECTION THROUGH CALCULATION OF REDUCED EFFICIENCY • RECOVERY THROUGH SUBASSEMBLY REPLACEMENT (BLOCK REDUNDANT)

Candidate Functions for Automation (cont)

Function	Description
POWER MARGIN MANAGEMENT	• SHARE MODE DETECTION AND BOOST CONVERTOR TIME-OUT LEADING TO LOAD SHEDDING
LOAD EQUIPMENT MONITORING AND FAULT DETECTION	• MONITOR LOAD VOLTAGES AND CURRENTS TO DETERMINE IMPEDANCE OF LOAD DEVICES • IF IMPEDANCE FELL BELOW PREDETERMINED LIMIT, DEVICE WAS REMOVED
RELAY STATUS MONITORING	• MONITORED POSITIONS OF ALL RELAY CONTACTS INCLUDING RELAYS FOR CELL BYPASS, CROSS STRAPPING, LOAD DISTRIBUTION, ETC.
DATA ACQUISITION, PROCESSING, AND STORAGE	• SERIAL DATA BIT STREAM - RECONFIGURABLE • DATA STORAGE FOR COMPUTATION
MINIMUM SOLAR ARRAY MARGIN PROTECTION	• PROGRAMMABLE, PRIORITIZED, SEQUENTIAL LOAD SHEDDING IF SOLAR ARRAY MARGIN FELL BELOW A SELECTED VALUE
SUBSYSTEM PERFORMANCE MONITORING	• DETERMINE THE HEALTH (EFFICIENCY) OF THE POWER SUBSYSTEM BY COMPUTING THE INTERNAL POWER LOSSES (TOTAL SOURCE POWER INPUT MINUS THE TOTAL LOAD POWER DELIVERED)

Candidate Functions for Automation (cont)

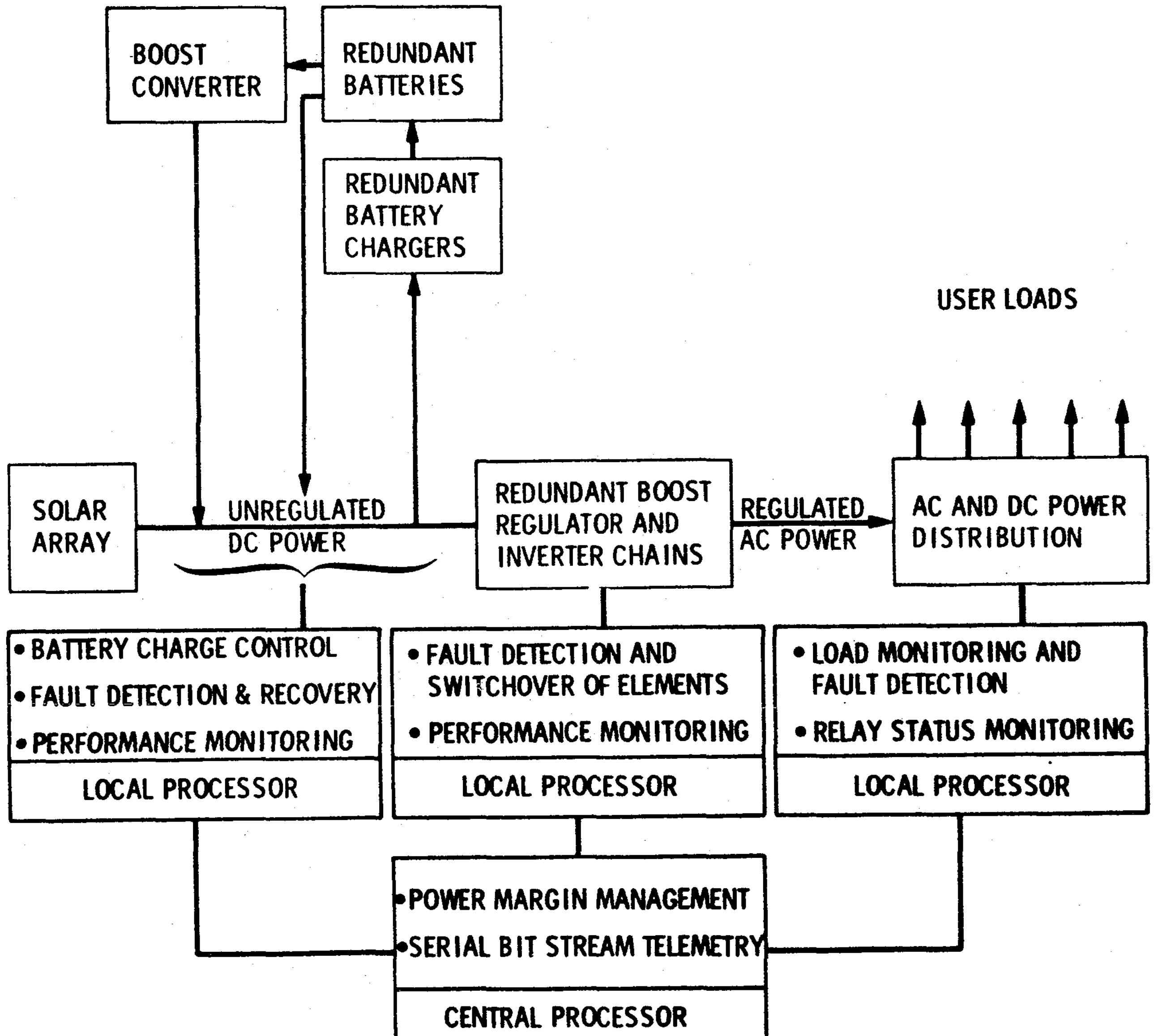
FUNCTION	DESCRIPTION
LOAD PROFILE DETERMINATION	• UTILIZING A PRE-PROGRAMMED OR GROUND GENERATED SEQUENCE OF SPACECRAFT COMMANDS, CALCULATE THE MAXIMUM POWER AND ENERGY STORAGE REQUIREMENT FOR THE SEQUENCE AND COMPARE TO THE SOLAR ARRAY AND BATTERY SOURCES CAPABILITY. SEND AN ALARM FLAG TO THE FLIGHT DATA SYSTEM FOR TRANSMITTAL TO GROUND, IF SOURCE CAPABILITY IS LESS THAN REQUIRED.
LOAD SEQUENCE GENERATION	• UTILIZING THE PRIORITIZED SEQUENTIAL LOAD SHEDDING DATA, GENERATE A NEW LOAD SEQUENCE BASED ON POWER SOURCE CAPABILITY

Implementation Decisions
Candidate Functions For Automation

Function	Rationale
BATTERY CHARGE CONTROL	DEMONSTRATE REDUCED MONITORING REQUIREMENTS
POWER CHAIN FAULT DETECTION AND SWITCHOVER WITH CROSS STRAPPING	DEMONSTRATE INCREASED FAULT TOLERANCE AND FLEXIBILITY
SUBASSEMBLY PERFORMANCE MONITORING SUBASSEMBLY FAULT DETECTION AND RECOVERY	DEMONSTRATE INCREASED FAULT TOLERANCE, FLEXIBILITY, AND RECONFIGURABILITY
POWER MARGIN MANAGEMENT	DEMONSTRATE POTENTIAL FOR REDUCED POWER SOURCE MARGIN
LOAD EQUIPMENT MONITORING AND FAULT DETECTION	DEMONSTRATE INCREASED FAULT TOLERANCE FLEXIBILITY, AND RECONFIGURABILITY
DATA ACQUISITION, PROCESSING, AND STORAGE	DEMONSTRATE MORE FLEXIBLE, RECONFIGUR-ABLE TELEMETRY INTERFACE
RELAY STATUS MONITORING	DEMONSTRATE REDUCED TELEMETRY REQUIREMENT

MINIMUM SOLAR ARRAY MARGIN PROTECTION	MAXIMUM POWER POINT DETECTOR REQUIRED
SUBSYSTEM PERFORMANCE MONITORING LOAD PROFILE DETERMINATION LOAD SEQUENCE GENERATION	COMPLEX, DOABLE SOFTWARE TASK

VO 75 Power Subsystem
APSM Configuration



APSM Evaluation Results

Function	Test	Results
BATTERY CHARGE CONTROL	• STATE OF CHARGE ESTIMATOR EVALUATION	• WITHIN ±10% OVER 3 CHARGE/ DISCHARGE CYCLES
	• BATTERY OVER-TEMPERATURE SIMULATION	• CHARGER SWITCHED TO LOW RATE
	• BATTERY STATE OF CHARGE RESPONSE TEST	
	• BATTERY DISCHARGED	• CHARGER SWITCHED TO HIGH RATE
	• BATTERY OVERCHARGED	• CHARGER SWITCHED TO LOW RATE
POWER CHAIN FAULT DETECTION AND SWITCHOVER	• MAIN INVERTER FAILURE SIMULATION	• SWITCHED TO STANDBY INVERTER
	• MAIN BOOSTER REGULATOR FAILURE SIMULATION	• SWITCHED TO STANDBY BOOSTER REGULATOR
SUBASSEMBLY PERFORMANCE MONITORING	• CALCULATE EFFICIENCIES OF SUBASSEMBLIES AND COMPARE TO RESULTS OF HAND CALCULATIONS	• RESULTS WITHIN 5%

APSM Evaluation Results (cont)

Function	Test	Results
SUBASSEMBLY FAULT DETECTION AND RECOVERY	• BATTERY CHARGER EFFICIENCY BELOW LIMIT SIMULATION	• CHARGER TURNED OFF
	• BATTERY CELL VOLTAGE BELOW LIMIT SIMULATION	• FAILED CELL BYPASSED AND SPARE CELL CONNECTED
POWER MARGIN MANAGEMENT	• TOTAL LOAD SIMULATED TO BE IN EXCESS OF SOLAR ARRAY CAPABILITY	• SEQUENTIAL LOAD SHEDDING SEQUENCE EXECUTED
LOAD EQUIPMENT MONITORING AND FAULT DETECTION	• SIMULATED VARIOUS LOAD FAULTS	• ACCURATELY DETECTED AND DISCONNECTED FAILED LOAD
	• CALCULATED EACH LOAD IMPEDANCE AND COMPARED TO RESULTS OF HAND CALCULATIONS	• CALCULATIONS WITHIN ±2%
RELAY STATUS MONITORING	• TESTED BY EXECUTION OF SEQUENTIAL RELAY EXCITATION COMMANDS	• ACCURATE MAINTENANCE OF RELAY STATUS DATA
DATA ACQUISITION, PROCESSING AND STORAGE	• COMPARE HARDWIRE MEASUREMENTS WITH APSM DATA	• ACCURACY OF APSM DATA WITHIN MEASUREMENT TOLERANCES

APSM Results

- TECHNICAL
- PROGRAMMATIC

APSM Technical Results

- ACCOMPLISHED OBJECTIVES OF DEMONSTRATING THE AUTOMATION OF KEY FUNCTIONS IN POWER SUBSYSTEM
  - CONTINUOUS MONITORING NOT REQUIRED
  - ALGORITHMS FOR KEY FUNCTIONS SUCH AS LOAD MANAGEMENT, SUBSYSTEM FAULT TOLERANCE
  - HIGHLIGHTED IMPORTANCE OF SYSTEM CONSIDERATIONS SUCH AS INTERFACE MANAGEMENT
  - NEW INVENTIONS NOT NECESSARY TO ACCOMPLISH OBJECTIVES
- APSM ACTIVITY HIGHLIGHTED FUNCTIONS THAT WOULD BENEFIT FROM ADVANCED TECHNOLOGY
  - ACCURATE STATE OF CHARGE INDICATOR
  - SELF-TEST OF STANDBY UNITS
  - MAXIMUM POWER POINT DETECTOR
  - MODULARITY

APSM Technical Results (Cont)

- AUTOMATION COULD BE SUCCESSFULLY ACCOMPLISHED WELL WITHIN STATE OF THE ART OF ONBOARD COMPUTATIONAL CAPABILITY
- USE OF ONBOARD COMPUTATIONAL CAPABILITY CAN HAVE POSITIVE EFFECT ON POWER SUBSYSTEM CHARACTERISTICS

SPECIFIC POWER	50% INCREASE WHEN COUPLED WITH ADVANCED TECHNOLOGY
PRELAUNCH COST	SLIGHT REDUCTION - SINGLE SPACECRAFT 40% REDUCTION - FIVE SPACECRAFT
OPERATIONS COST	50% REDUCTION
FAULT TOLERANCE	IMPROVED THROUGH PERFORMANCE MONITORING
FLEXIBILITY	INCREASED WITH RECONFIGURABILITY

APSM Programmatic Results

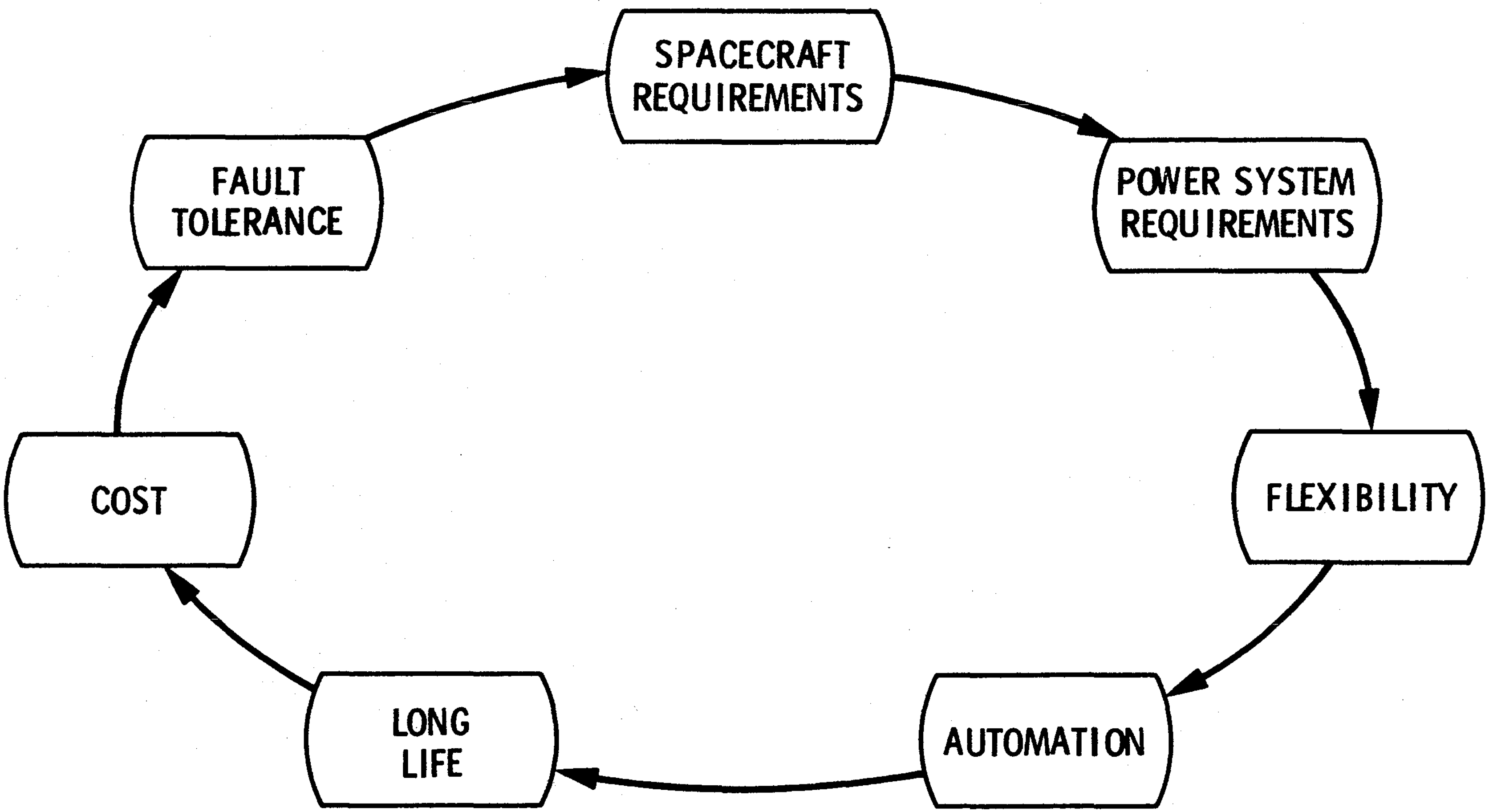
- MORE COMPLEX TASK THAN ORIGINALLY ANTICIPATED
  - IMPORTANCE OF CORRECT MIX OF POWER SYSTEM ENGINEERS, SOFTWARE EXPERTS, AUTOMATION EXPERTS
  - "SYSTEMS" VIEWPOINT ESSENTIAL FOR MAXIMUM BENEFIT
    - DISTRIBUTED vs CENTRALIZED
    - REDUNDANCY MANAGEMENT
    - DEGREE OF MODULARITY
  - NEED FOR MANAGEMENT OF SOFTWARE DESIGN

Future Planetary Spacecraft Power System Requirements

CONSIDERATIONS

- SPECIFIC POWER
- DEGREE OF AUTONOMY
- RELIABILITY
- INTERDEPENDENCE OF POWER/SPACECRAFT DESIGN
- DISTRIBUTION OF COMPUTATIONAL CAPABILITY
- MISSION DURATION
- ROUND TRIP LIGHT TIME
- POWER SYSTEM COST

Advanced Planetary Power System Requirements



- POWER SYSTEM REQUIREMENTS ARE INTERACTIVE WITH MISSION AND SPACECRAFT DESIGN

Typical Power System Mass

	POWER KW	MASS, KG					
		SCIENCE PAYLOAD	SPACE-CRAFT	POWER ELECT	POWER SYSTEM	% PWR/SC	% PWR/PAYLOAD
VIKING ORBITER	0.6	73	2540	37	178	7	240
VOYAGER	0.48	108	792	25	137	17	130
GALILEO	0.6	98	2078	30	147	7	150
NEP (NEPTUNE) ORBITER	100	150	17000	685	3990	24	2660
SEP (HALLEY)	25	124	2082	312	1112	53	900

- HIGH POWER SYSTEMS NEED GROWTH FROM 4 W/KG TO 25 W/KG
- ADVANCED POWER SYSTEM R & D HAS LARGE POTENTIAL PAYOFF!

Future Requirements
Advanced Planetary Power Systems

DRIVERS

- LOW POWER SYSTEMS (0.4 - 1 kw)

  LOW COST DESIGNS - HIGH INHERITANCE

  LONG LIFE

  REDUCED MISSION OPERATIONS

  REDUCED SYSTEM MASS

  FAULT TOLERANCE

- HIGH POWER SYSTEMS (10 - 1000 kw)

  REDUCED SYSTEM MASS

  FAULT TOLERANCE

  LONG LIFE

  REDUCED MISSION OPERATIONS

  LOW COST DESIGNS

System-Level Issues in Advanced Autonomous Planetary Power Systems

1. DEGREE OF POWER SYSTEM AUTONOMY REQUIRED
2. DISTRIBUTION OF ON-BOARD PROCESSING AND CONTROL FUNCTIONS
3. EFFECT OF POWER SYSTEM AUTONOMATION ON USER SYSTEM REQUIREMENTS
4. EVALUATION OF BENEFITS OF FLEXIBILITY AND MARGIN CONTROLS
5. IMPACT OF POWER SYSTEM AUTONOMY ON SPACECRAFT DESIGN
6. DEFINITION OF DIGITAL DATA AND CONTROL INTERFACES

Technical Issues in Advanced Autonomous Planetary Power Systems

1. COST/ BENEFIT UNCERTAINTY FROM POWER SYSTEM AUTONOMY MASS/ COMPLEXITY/ COST

2. DEFINITION OF POWER SYSTEM AUTONOMY STRATEGIES WHICH DO NOT IMPACT RELIABILITY

3. DISTRIBUTION OF POWER SYSTEM AUTONOMY BETWEEN DIGITAL AND ANALOG FUNCTIONS

4. INFLUENCE OF POWER SYSTEM CHARACTERISTICS ON AUTONOMATION STRATEGIES (AC VERSUS DC, etc.)

Recommended Planetary Power System Automation Objectives

1. IDENTIFICATION OF POWER SYSTEM FUNCTIONS WHOSE AUTOMATION HAS HIGHEST PAYOFFS (MASS/COMPLEXITY/COST)

2. DEVELOPMENT OF A METHODOLOGY FOR EVALUATING BENEFIT OF AUTOMATING SPECIFIC POWER SYSTEM FUNCTIONS

3. DEVELOPMENT OF CRITERIA FOR DISTRIBUTING DATA AND CONTROL FUNCTIONS
   - GROUND VERSUS ON-BOARD
   - ON-BOARD CENTRAL VS. DISTRIBUTED

4. ASSESSMENT OF INTERACTION OF AUTOMATION STRATEGIES WITH POWER SYSTEM CHARACTERISTICS
   - AC/DC DISTRIBUTION
   - VOLTAGE LEVEL
   - DIGITAL/ANALOG LOGIC

5. IDENTIFY POWER HARDWARE DEVELOPMENTS REQUIRED FOR AUTOMATION

MARTIN MARIETTA POWER SYSTEM AUTOMATION EXPERIENCE

AUTOMATED POWER SYSTEMS CONTRACTS AND RELATED IR&D PROJECTS

Title	Customer or IR&D	Period of Performance	Description of Effort
Flexible Charge Discharge Controller (FCDC)	D61D IR&D	1975-1976	- Single-Cell Protection and Cell Bypass - A-h Integration Charge Control - Uses Intel 8080 Microprocessor - Breadboard System Controlling Thirty 8 A-h NiCd Cells
Single-Cell Protector (SCP)	NASA LeRC	1975-1976	- Monitor Single-Cell Voltage and Cell Bypass - Analog and Digital Logic Implementation - Prototype System Demonstrated on Single 40 A-h Cell in Life-Cycle Test

AUTOMATED POWER SYSTEMS CONTRACTS AND RELATED IR&D PROJECTS (cont)

Title	Customer or IR&D	Period of Performance	Description of Effort
Multiplexed Cell Protector (MCP)	NASA	1976	- Same as SCP with Following Differences: MCP Multiplexes 18-Cell Battery Prototype System Demonstrated with 18-Cell Battery

AUTOMATED POWER SYSTEM MANAGEMENT (APSM)

Sponsoring Agency: Jet Propulsion Laboratory

Contract Phases:
- Configuration Study
- Hardware Contract

Period of Performance: 1977-1979

Contract Description:
- System H/W Design
- System S/W Design
- System Conceptual Design
- Integrate Design H/W and S/W with Viking Orbiter 75 Government-Furnished H/W

LINEAR CHARGE CURRENT CONTROL (LC^3)

Project Support:

- Air Force Supported Part of Effort
- Internal IR&D Project Supported Another Part of Effort

Period of Performance: 1976-1980

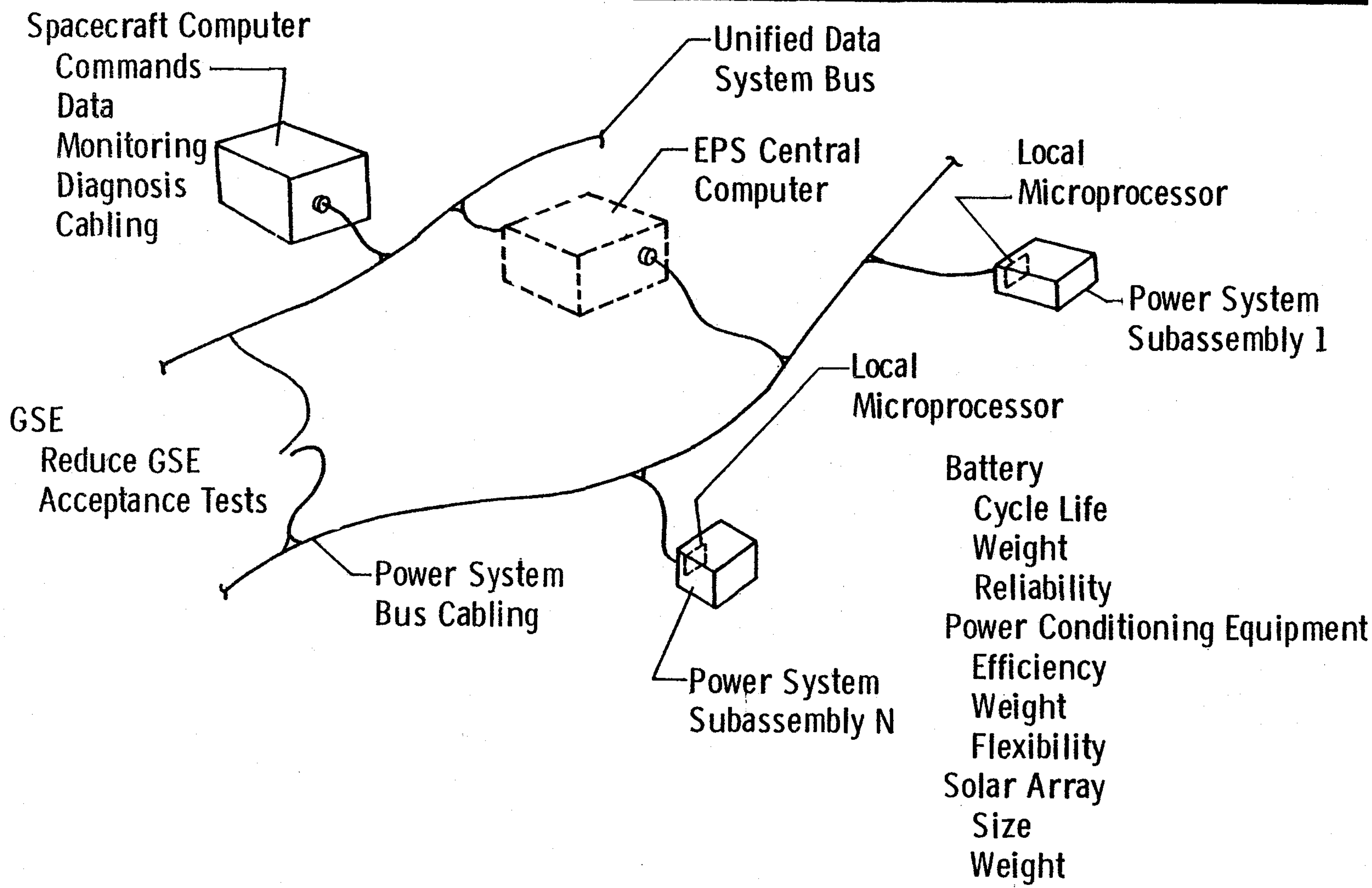
Objective:

- Long Life, High Reliability
- High Level of Load Management
- Lighter Weight and Lower Volume

Implementation Feature

- Special NiCd Charge Control Algorithm
- Individual Cell Monitor
- Accurate State of Charge Monitor and Telemetry
- Unique Power H/W Approach That Does Not Use Switching Regulators

POWER SYSTEM GOALS UTILIZING DISTRIBUTED MICROPROCESSOR APPROACH



Functional Capability

The LC^3 Is a Flexible Battery Charge Control System

- Battery Temperature Control
- Battery Temperature Compensated Voltage Control
- Ampere-Hour Integration
- Caution and Shutdown

Electrical Capability

The electrical capability listed is for the breadboard system. The basic design is not limited to these levels.

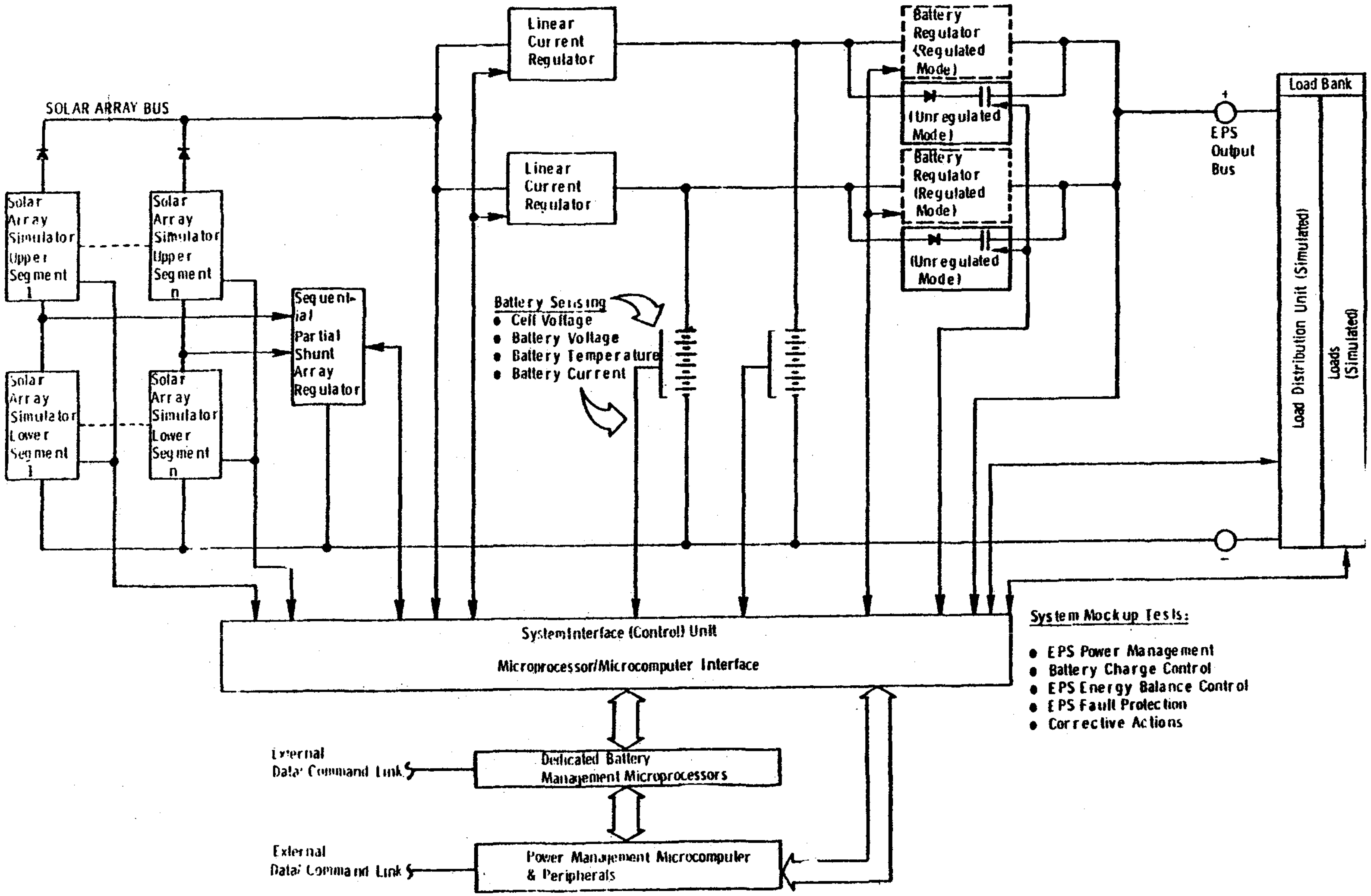
- Output Voltage: 20 to 40 Vdc

- Input Voltage: 20 to 42 Vdc

- Output Current: 0 to 40 A

- Efficiency: 96.7 to 97.1% Maximum Load

EPS MOCKUP FUNCTIONAL DIAGRAM



System Mockup Tests:

- EPS Power Management
- Battery Charge Control
- EPS Energy Balance Control
- EPS Fault Protection
- Corrective Actions

POWER HARDWARE ADVANTAGES

Size and Weight Reduction:

- No Switching Regulators
- No Large Magnetics

Efficiency:

- No Switching Regulator Losses
- Dissipation Reduced by a Factor of 2 to 3
- Solar Array Size Reduction

EMC:

- Switching Regulators are a Prime Noise Source
- Noise is Reduced Considerably

PROGRAMMABLE POWER PROCESSOR (P^3)

NASA MSFC Objective:
- Design, Build, and Test P^3

IR&D Project Objective:
- Perform Qualification Testing on P^3

Period of Performance: Nov 1979-Nov 1981

Objective:	Implementation Feature
- Reduce Development Cost	- P^3 Design Can Be Used for Several Functions - No H/W Changes Other Than ROM Change Required to Change from One Mode to Another
- Usable on Several S/C	- Flexible Interface Command and Data Interface
- Develop Mechanical Design, and Build Engineering Model	
- Minimize Size and Weight	
- Perform Preliminary Qualification Test	

P^3 Functional Capability

A single P^3 component can operate in several different modes.

- Battery Control
  - Battery Charger
  - Peak Power Tracker (Solar Array)
  - Caution and Shutdown
- Bus Voltage Control
  - Voltage Regulator
  - Caution and Shutdown
- Power Limiter (Shuttle Power Extension Package)
  - Peak Power Tracker
  - Fuel Cell Current Limiter
  - Caution and Shutdown
- Power Bus Over Voltage Protection
  - Shunt Regulator
  - Caution and Shutdown

Requirements

Input

Voltage:	26 Vdc to 375 Vdc
Voltage Transient	450 Volts for 20 ms
Power:	Less Than 20 Kw
Inrush:	25 Joules Above Normal Load
Ripple:	5.0 Amps rms

Requirements

Output

Voltage: 24 Vdc to 180 Vdc

Degraded Performance: 0 to 24 Vdc

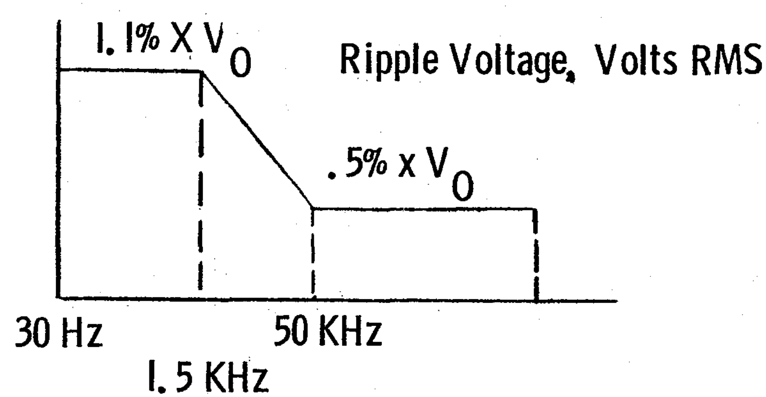
Current: 0 to 100 Adc

DC Power:

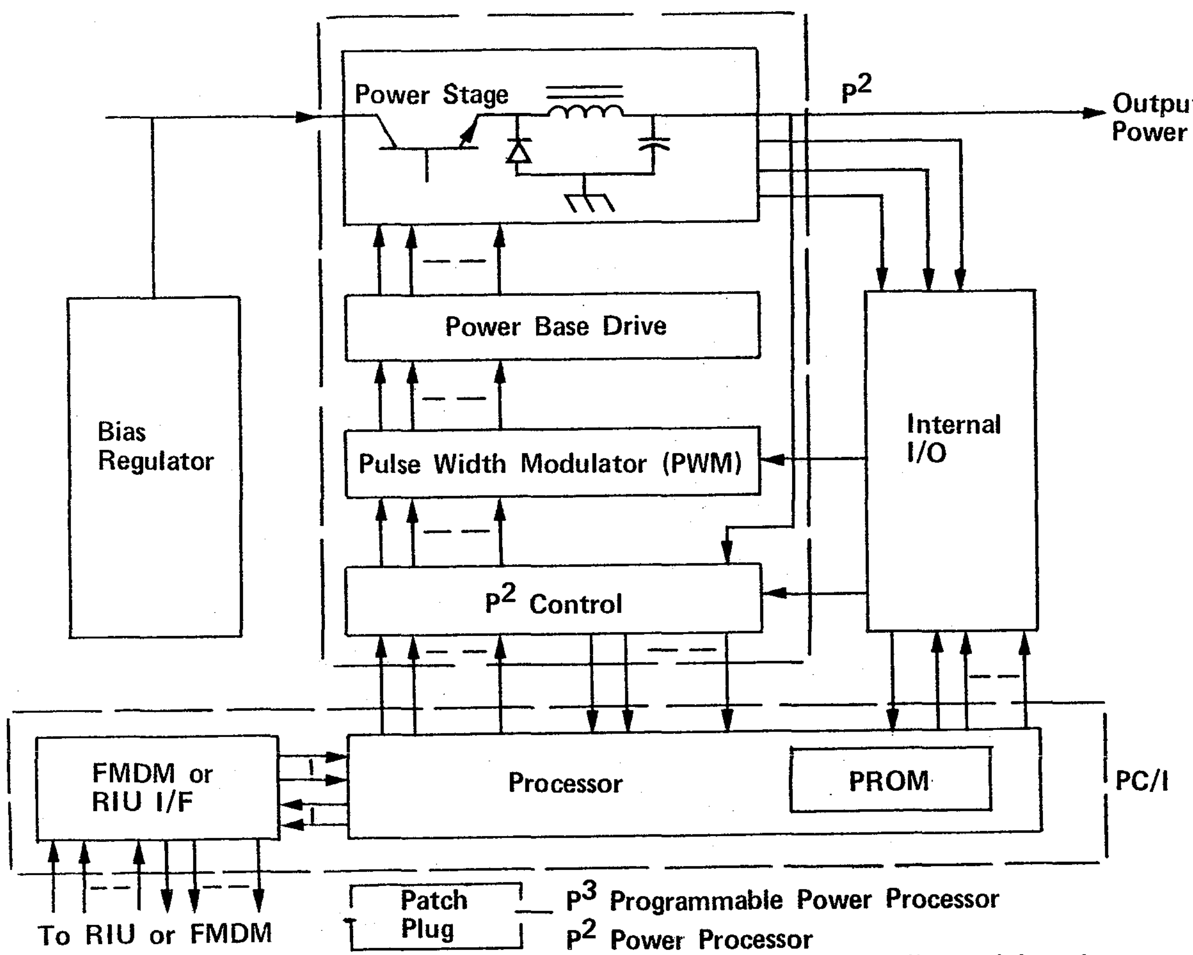
Input Voltage	Output Voltage	Output Current
150 Vdc	30 Vdc	90 Adc
250 Vdc	150 Vdc	40 Adc
200 Vdc	150 Vdc	80 Adc

The above steady levels are required for base plate temperatures of less than 30°C.

Ripple:



P³ Simplified Block Diagram



P^3 Programmable Power Processor
P^2 Power Processor
PC/I Programmable Controller and Interface

MINIATURE AUTOMATED POWER SYSTEM (MAPS)

Period of Performance: May 1982

System Description:

- Totally Automated Terrestrial Battery Charger
- Two Series 6 A-h NiCd Cells
- Solar Array Power Source
- RCA 1802 Microprocessor
- 1-k, 8-bit CMOS ROM
- One Hundred Twenty-Eight 8-bit CMOS RAM
- Monitoring Each Cell, If Cell Is Bad, Replace with One of Four Spare Cells
- Power Supply Operates Down to 0.5 V_{In} Voltage

Status:

- Breadboard Build and Test Complete
- Packaging Design to Be Initiated Soon

TECHNOLOGY ISSUES

1) Developing Entire Power Systems, Power System Submodules, and/or Lower Level Components

2) Approach to Requirement Definition for Advanced Power System Development

3) S/C Power System Control Partitioning in Areas of Load Management, Fault Detection, and Corrective Action

4) S/C and Subsystem Control H/W and S/W Architecture

5) Control Methods and Resulting Algorithms for New Components, such as NiH_2 Batteries, and for New Applications, such as Shuttle PEP Power Limiter

SPACE POWER SYSTEM AUTOMATION WORKSHOP

28/29 OCTOBER 1981

MARSHALL SPACE FLIGHT CENTER

Dave Massie
AFWAL/POOC
WPAFB, OH 45433
513-255-6235

DEVELOPMENT HISTORY - SUPPORTING TECHNOLOGY

- O HIGH VOLTAGE HIGH POWER SYSTEM
- O ADVANCED SILICON AND GALLIUM ARSENIDE SOLAR CELLS
- O NICKEL-HYDROGEN BATTERY TECH.
- O HIGH ENERGY DENSITY RECHARGEABLE BATTERY TECHNOLOGY
- O HIGH EFFICIENCY MULTIPLE BANDGAP CASCADE CELL TECHNOLOGY
- O CONCENTRATING PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY DEVEL.
- O PRIMARY FUEL CELL TECHNOLOGY
- O REGENERATIVE FUEL CELL TECHNOLOGY
- O NUCLEAR RADIATION HARDENING TECH.
- O LASER RADIATION HARDENING TECH.
- O LIGHTWEIGHT SOLAR ARRAY TECHNOLOGY FRUSA, HASPS
- O MEGAWATT TURBOALTERNATOR TECH.
- O PM GENERATOR TECH.
- O HIGH POWER SWITCH TECHNOLOGY
- O ADVANCED POWER PROCESSOR TECH.
- O SC INDUCTIVE ENERGY STORAGE TECH.

AUTOMATION OBJECTIVE

AUTOMATIC REAL TIME MONITORING OF EPS HEALTH, COMPUTATION, AND COMMAND/CONTROL OF SPACE VEHICLE POWER FROM SOURCE TO LOADS BASED UPON SENSING

- TEMPERATURES
- PRESSURES
- CURRENTS
- VOLTAGES
- ANGULAR POSITIONS
- ACCELERATION
- DISPLACEMENTS

BENEFITS OF POWER SYSTEM AUTOMATION

- IMPROVED RELIABILITY/SURVIVABILITY
- SIMPLIFIED GROUND STATION COMMAND AND CONTROL FUNCTIONS RELATED TO SPACE VEHICLE ELECTRICAL POWER SYSTEMS OPERATIONS
- REAL TIME ELECTICAL POWER SYSTEM STATUS AND CONTROL
- QUICK RESPONSE TO CHANGING POWER NEEDS AND NEEDS FOR SELF-PROTECTION - VIRTUALLY NO TIME DELAY BETWEEN SENSING ANOMALOUS OPERATION AND EPS "SAFING"
- LOWER WEIGHT AND COST (PARTICULARLY IN THE ESS)

AUTOMATED POWER SYSTEM GENERAL FUNCTIONS

- O POWER MANAGEMENT
- O LOAD MANAGEMENT
- O RELIABILITY MANAGEMENT
- O CONFIGURATION MANAGEMENT

AUTOMATED POWER SYSTEM SPECIFIC FUNCTIONS

- O BATTERY CHARGE/DISCHARGE CONTROL, PROTECTION AND RECONDITIONING
- O POWER SOURCE CONTROL AND VOLTAGE REGULATION
- O FAULT DETECTION, ISOLATION, AND AUTOMATIC CORRECTION/COMPENSATION/RE-CONFIGURATION
- O EPS HEALTH AND STATUS MONITORING
- O EPS DATA PROCESSING, DATA STORAGE AND RETRIEVAL
- O SOLAR ARRAY ORIENTATION CONTROL

ISSUES

- FAILURE TO INCORPORATE AUTOMATIC DETECTION OF EPS FAULTS WITH SUBSEQUENT ON-BOARD CORRECTION/RECONFIGURATION WILL RESULT IN CONTINUED INCREASE IN RELIANCE ON GROUND STATION COMMAND/CONTROL/DATA PROCESSING

- STATION COMMAND AND CONTROL FUNCTIONS VERSUS AUTOMATED COMMAND AND CONTROL FUNCTIONS

- ABILITY TO PREDICT POWER SYSTEM PERFORMANCE PARAMETERS FOR THE LIFETIME OF THE SPACE VEHICLE

- NEED FOR CONTINUED OPERATION OF MILITARY SPACE VEHICLES WITHOUT GROUND STATION COMMAND/CONTROL

- DEVELOPMENT OF STATUS MONITORING/SENSING CIRCUITRY AND CONTROL ALGORITHMS

TASK 682J10 - FAULT TOLERANT POWER SYSTEM

Section I Requirement

a. Background - Program Genesis and Motivation

Satisfactory operation of military satellites is dependent upon an adequate and reliable source of electrical power. Over the years solar array/battery power systems have operated to a significant degree under the command/control capabilities of satellite tracking stations which periodically monitor the health of the system. With the advent of advanced microprocessor and computer technology is is now feasible to provide an autonomous electrical power system management capability. Such a capability would greatly relieve and simplify ground station command and control functions related to satellite electrical power system operations.

Satellites are not always in communication with ground stations. Therefore, in the event of a power system anomaly, the capability to autonomously sense the anomaly and reconfigure the operation of the power system would enhance the reliability of the system. The key to achieving this capability is to place each element of the power system under the control of a dedicated local microprocessor/microcomputer as illustrated in Figure 1. This approach would permit power system capability to perform automatic real time monitoring of health, computation, and command/control of spacecraft power from source to loads. Virtually no time delay would be encountered in sensing and "safing" electrical power system operations in the event of malfunctions thus avoiding severe system degradations which might otherwise occur. The automatic fault detection and correction capability could also significantly enhance the survivability of the spacecraft power system.

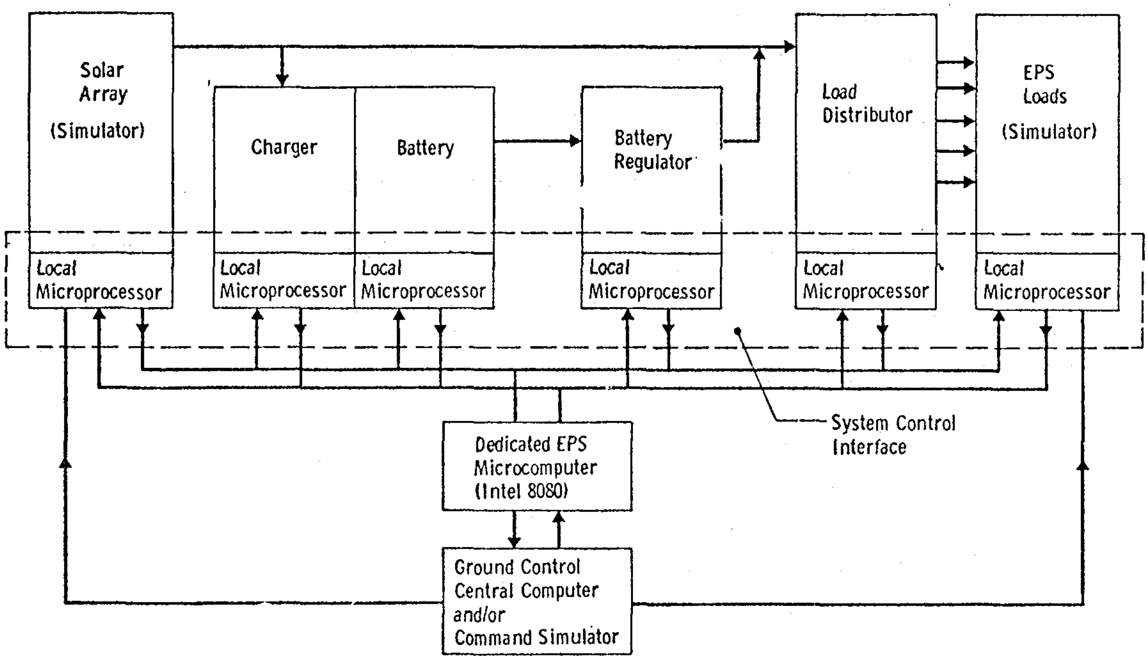


Figure 1 - Fault Tolerant Power System Schematic

b. Objective - Improvements Anticipated

The objective of this new task is to demonstrate a Fault Tolerant Power System for military space vehicle applications. Ability to autonomously diagnose, detect, and correct faults are principal features of the system. As such the system would possess inherent capability to operate independent of external command/control normally provided by satellite ground tracking stations. Ground station command/control involvement would only be required in the event that a system anomaly results in an alarm situation where parameters being automatically monitored exceed pre-established maximum or minimum limits. For any anomalous situations short of alarm situations, automatic on-board reconfiguration/correction would be implemented with a subsequent report to ground stations. Improvements resulting from a Fault Tolerant Power System Concept include:

- Autonomy
- Survivability
- Improved Reliability
- Real Time Electrical Power System Status
- Lower Cost and Weight
- Design Simplicity and Flexibility

The Fault Tolerant Power System (FTPS) will be able to quickly respond to changing mission power needs and needs for electrical power system self protective measures. Examples include (a) load matching to power system capability such as switching off non-essential loads under conditions of low bus voltage or supplementing solar array power with battery power, (b) automatic disconnect of defective loads, and (c) switching out defective battery cells and switching in good spare cells. The ability to utilize spare battery cells as opposed to use of redundant batteries provides a tremendous weight savings in the electrical power system - doubling or perhaps tripling effective energy density of the energy storage subsystem in the FTPS approach may be possible.

c. Potential Applications

Technology derived from the FTPS ADP will be applicable to a wide range of future Air Force space vehicles where a high degree of autonomy, survivability, and reliability are required. Further satellite traffic in earth orbit will escalate substantially in the post 1980 time period. Consequently, it will become increasingly difficult for these stations to keep up with command/control and data processing requirements. Automation features such as those provided by the FTPS will help to relieve and simplify ground station satellite support requirements. The spectrum of mission operations to wnich this technology applies include surveillance, communications, meteorology, and navigation.

d. Requirements Document List

The latest approved technical direction document covering work related to this task is Program Management Directive R-S 2133 (9)/PE 63401F dated 23 December 1977. It should be pointed out however that this task is being proposed as a new initiative for FY81 start. This task is responsive to SAMSO/ESD Technology Needs TN-SAMSO-AFAPL-1002-70-15, "Solar Cell Power Systems"; TN-SAMSO-AFAPL-1002-76-20, "High Efficiency Spacecraft Power Generation". and TN-ESD-AFAPL/AFCRL-1002-70-01, "Solar Energy Conversion".

Section II Technical Approach

a. Technical Approach

The technical approach encompasses (1) command and control design tradeoffs, (2) development of sensing circuitry, signal conditioning circuitry, and associated algorithms, (3) microprocessor/microcomputer interface definition, (4) design, fabrication and demonstration of a breadboard Fault Tolerant Power System as illustrated in Figure 1 for ground demonstration, and (c) development of preliminary design specifications for fault tolerant systems operating in the load power range from 5 to 25 KW_e. The FTPS breadboard will be configured to perform and demonstrate the following general type functions:

- Load Management Functions
- Power Management Functions
- Reliability Management Functions
- Configuration Management Functions

In providing the above type of general functions, the FTPS will demonstrate many specific functions. Examples of specific functions are as follows:

- Battery Charge/Discharge Protection and Reconditioning
- Solar Array Orientation Control
- Power Source Control and Voltage Regulation
- Fault Detection, Isolation, and Correction
- Power System Data Storage and Retrieval

The ground tests of the FTPS breadboard hardware will be geared to demonstrating the general and specific functions defined above. Results of these tests plus the knowledge gained during the course of the FTPS program will be utilized in the preparation of design specifications.

b. Alternative Approaches

Redundancy at the unit level is a possible alternative approach to the FTPS concept, however; standby units would add considerable cost and weight. Automatic failure detection and switchover to standby units is really a trend toward the FTPS concept anyway. Failure to incorporate automatic failure detection and switchover would increase reliance on active ground station command/control/data processing rather than relieve such reliance. Thus, there are no apparent good alternative approaches to the FTPS for providing the requisite high degree of autonomy, reliability, and survivability.

c. Technology Transition

Results of this task will establish an advanced technology base for implementing FTPS concepts into future Air Force space vehicle systems. The task will demonstrate the autonomy and flexibility of the concept through a complete and thorough ground test program. Specifications will be developed from which future systems can be tailored. The technology derived from this program will be factored into the development of the High Voltage High Power System of Task 682J08.

Section III Development Summary

a. Proposed contractual and AFAPL supporting efforts under Task 682J10 are structured for the successful development and laboratory demonstration of a Fault Tolerant Power System breadboard model. Test data and FTPS specifications will be end items of this advanced development program task.

The work will not require the development of specialized microprocessor microcomputer technology. Instead, commercially available microprocessors and a microcomputer will be utilized. Some specialized sensing circuitry will have to be developed. An example is an ampere-hour integrator circuit for measuring battery state-of-charge.

A development step outline for the FTPS Task is as follows:

Development Step/Event	Initiation Date	Completion Date
FTPS SOW/RFP Preparation; Technical Evaluation of Proposals; Contract Prep.	1 Oct 1980	1 Feb 1981
Power System Performance Predictions; Command & Control Design Tradeoffs	1 Feb 1981	1 Aug 1981
Develop Sensing Circuits and Algorithms	1 Jun 1981	30 Oct 1981
Microprocessor/Microcomputer Integration	1 Sep 1981	30 Nov 1981
Breadboard FTPS Ground Demonstration Hdw Design	1 Feb 1981	1 Mar 1982 (Go/No Go)
Fabrication of FTPS Ground Demonstration Hdw	1 Mar 1982	30 Sep 1982
FTPS Test & Evaluation	1 Oct 1982	30 Jul 1983
Final Report & Design Specifications	30 Jul 1983	30 Oct 1983

b. Evaluation Criteria

Key items effecting development of the breadboard FTPS are (a) power system performance predictions, (b) command and control design tradeoffs and (c) development of sensing circuits and algorithms. These key elements of work will receive priority attention early in the program. An Interim Technical Report will be delivered at the twelfth (12th) program month covering results of these key items.

Design of the breadboard FTPS will proceed in parallel with other elements of work culminating in a Critical Design Review upon completion of approximately fifteen (15) months of effort. The CDR is a Go/No Go decision point in the program. Provided there are no insurmountable problems identified as a result of the CDR, the contractor will be authorized to proceed with hardware manufacture, integration and test.

c. Schedule

The overall schedule for the various elements of work to be conducted under Task 682J10 is shown in the attached AFSC Form 103 - Program Schedule. Total duration of the effort is approximately thirty-six (36) months funded over three fiscal years - FY81, 82 and 83.

d. Progress and Accomplishments

AFAPL has initiated a literature review pertaining to the various tec hnical considerations related to the proposed Fault Tolerant Power System. Knowledge resulting from this review will be used to improve Task 682J10 planning and preparation of a high quality statement of work if this task is approved.

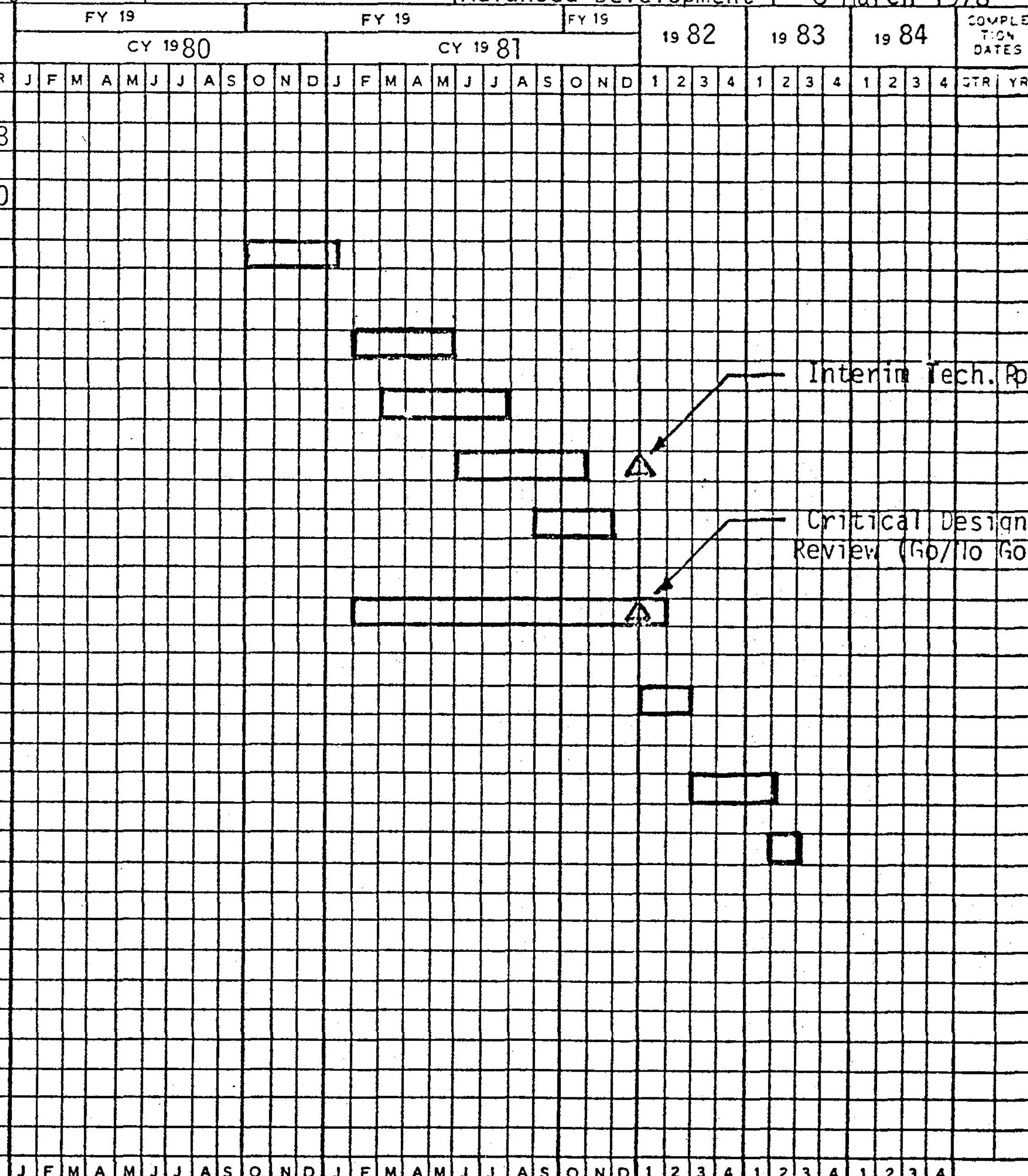
e. Resources

1. Financial and Manpower - see summary.

PROGRAM SCHEDULE

SYSTEM (Project) NUMBER	SUBSYSTEM	TYPE OF SCHEDULE	AS OF DATE
Fault Tolerant Power System		Advanced Development	8 March 1978

LINE		PRIOR SCHED DATES MO	PRIOR SCHED DATES YR
1			
2	FTPS TPP Submission	3	78
3			
4	Preliminary Planning Complete	3	80
5			
6	FTPS SOW/RFP Preparation		
7	and Tech. Eval. of Proposals		
8			
9	Power System Performance Predictions		
10			
11	Command & Control Design Trades		
12			
13	Develop Sensing Circuits & Algorithms		
14			
15	Microprocessor/Microcomputer		
16	Integration		
17			
18	Breadboard FTPS Ground		
19	Demonstration Hdw. Design		
20			
21	Fabricate FTPS Ground		
22	Demonstration Hdw.		
23			
24	FTPS Breadboard Test & Evaluation		
25			
26	Final Technical Report &		
27	Design Specifications		
28–36			



AUTHENTICATION

PREVIOUS EDITION WILL BE USED.

Section IV <u>Management Concept</u>

a. <u>Management Agency</u>

The AFAPL is responsible for the management of all contractual and in-house efforts under this task while SAMSO is responsible for management of Program Element 63401 (including 682J - Advanced Space Power Supply Technology) funds and the identification of Spacecraft power technology needs.

b. <u>Participating Agencies</u>

1. Responsibilities

SAMSO will manage all P.E. 63401F funds, identify user needs and coordinate on all Statements of Work, AF Form 111, DD Form 1634, Technical Program Plans and Requests for D&F. The AFAPL will manage all Project 682J contracts and in-house efforts, support SAMSO through submission of appropriate documentation and participation in briefings and studies and will provide the manpower for these activities.

2. A Memorandum of Agreement between SAMSO, Deputy for Technology and the AFAPL covers the work of Project 682J. This MOA and Annex 1 were signed in August 1975.

c. <u>Execution</u>

1. Execution of the FTPS program will be through an Advanced Development Contract awarded the successful bidder on a multiple source proccurement. Specific tasks associated with this program are identified by Phase in Section II above.

2. Procurement Approach

All contemplated procurements will be publicized by synopsis in the Commerce Business Daily utilizing the R&D Source Sought procedure. A Cost-Plus-Fixed-Fee type contract is presently contemplated based upon inability to obtain definitive specifications and lack of previous pricing information. Higher risk type contracts will be considered at the time of negotiation and will be utilized if practicable.

3. Program Controls

The contract resulting from Task 682J10 will require the submittal of a Contract Funds Status Report (DD Form 1586), and R&D Technical Plan and Monthly Program Schedule and R&D Status Reports.

Section V Assessments

This is a proposed new Space Power Advanced Development program for which a priority assessment remains to be made. It is proposed for the purpose of significantly enhancing non-nuclear power systems capability for future high energy military space vehicle systems using the Space Shuttle.

POWER SYSTEM

AUTOMATION REQUIREMENTS

FOR EARTH ORBIT

J. R. LANIER, JR.

EPS AUTOMATION QUIZ

A SYSTEM IS____________* WHEN IT CAN, TO SOME DEGREE, ____________* SEQUENCE THROUGH A SERIES OF MEASUREMENTS OF EQUIPMENT OUTPUTS, COMPARE THESE MEASUREMENTS AGAINST STANDARDS, AND TAKE CORRECTIVE ACTION IF THERE IS AN UNACCEPTABLE DEVIATION BETWEEN THE MEASUREMENT AND THE STANDARD.

*SUPPLY THE PROPER WORD; "AUTOMATIC" OR "AUTONOMOUS" AND "AUTOMATICALLY" OR "AUTONOMOUSLY" AS DESIRED.

EPS AUTOMATION DEFINITIONS

AUTOMATIC:	(SELF-ACTING) HAVING A SELF-ACTING OR SELF REGULATING MECHANISM
AUTONOMOUS:	(INDEPENDENT) CARRIED ON WITHOUT OUTSIDE CONTROL; EXISTING INDEPENDENTLY.
AUTOMATION:	AUTOMATICALLY CONTROLLED OPERATION OF A SYSTEM BY MECHANICAL OR ELECTRONIC DEVICES THAT TAKE THE PLACE OF HUMAN ORGANS OF OBSERVATION, DECISION, AND EFFORT.

EARTH ORBITAL POWER SYSTEM AUTOMATION REQUIREMENT

TO PROVIDE CONTROL OF AN EPS, WITHOUT EXTERNAL INTERVENTION, TO EFFECT SYSTEM OPERATION EQUIVALENT TO THAT WHICH WOULD BE PROVIDED BY A TEAM OF EPS EXPERTS IN CONTROL OF THE SYSTEM.

EPS AUTOMATION

A SYSTEM HAS BEEN AUTOMATED WHEN IT CAN INDEPENDENTLY SEQUENCE THROUGH A SERIES OF MEASUREMENTS OF EQUIPMENT OUTPUTS, COMPARE THESE MEASUREMENTS AGAINST STANDARDS, AND TAKE CORRECTIVE ACTION IF THERE IS AN UNACCEPTABLE DEVIATION BETWEEN THE MEASUREMENT AND THE STANDARD.

EPS AUTOMATION REQUIREMENT IMPLIES:

- INFORMATION AVAILABLE - SENSORS
- DATA REDUCTION - COMPUTER
- LOGIC - COMPUTER
- DECISION MAKING - COMPUTER
- CONTROL - COMPUTER/RECEIVERS (SWITCHE ETC.)

POWER MANAGEMENT SYSTEM FUNCTIONS

- DECODE/ISSUE COMMANDS FROM S/C COMPUTER
- ACQUIRE/REDUCE EPS DATA
- TRANSMIT SELECTED DATA TO TELEMETRY SYSTEM
- TIME/SYNCHRONIZE POWER SYSTEM EVENTS
- CONTROL EPS OPERATION
    - POWER GENERATION MANAGEMENT
    - ENERGY STORAGE MANAGEMENT
    - DISTRIBUTION SYSTEM MANAGEMENT
    - LOAD MANAGEMENT
- INTERACT WITH THERMAL SYSTEM

DRIVERS FOR EARTH ORBITAL POWER SYSTEM AUTOMATION

- DATA AVAILABILITY
  - GROUND COVERAGE
  - DATA LINK AVAILABILITY
  - TELEMETRY SHARING
- DECISION TIME
  - DATA REDUCTION
  - HUMAN RESPONSE
- COST
  - TEAMS OF EXPERTS
  - DATA NETWORKS

SPACE POWER SYSTEM AUTOMATION WORKSHOP

AMPS PROGRAM STATUS AND OBJECTIVES

ARTHUR D. SCHOENFELD

MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

1981 OCTOBER 28

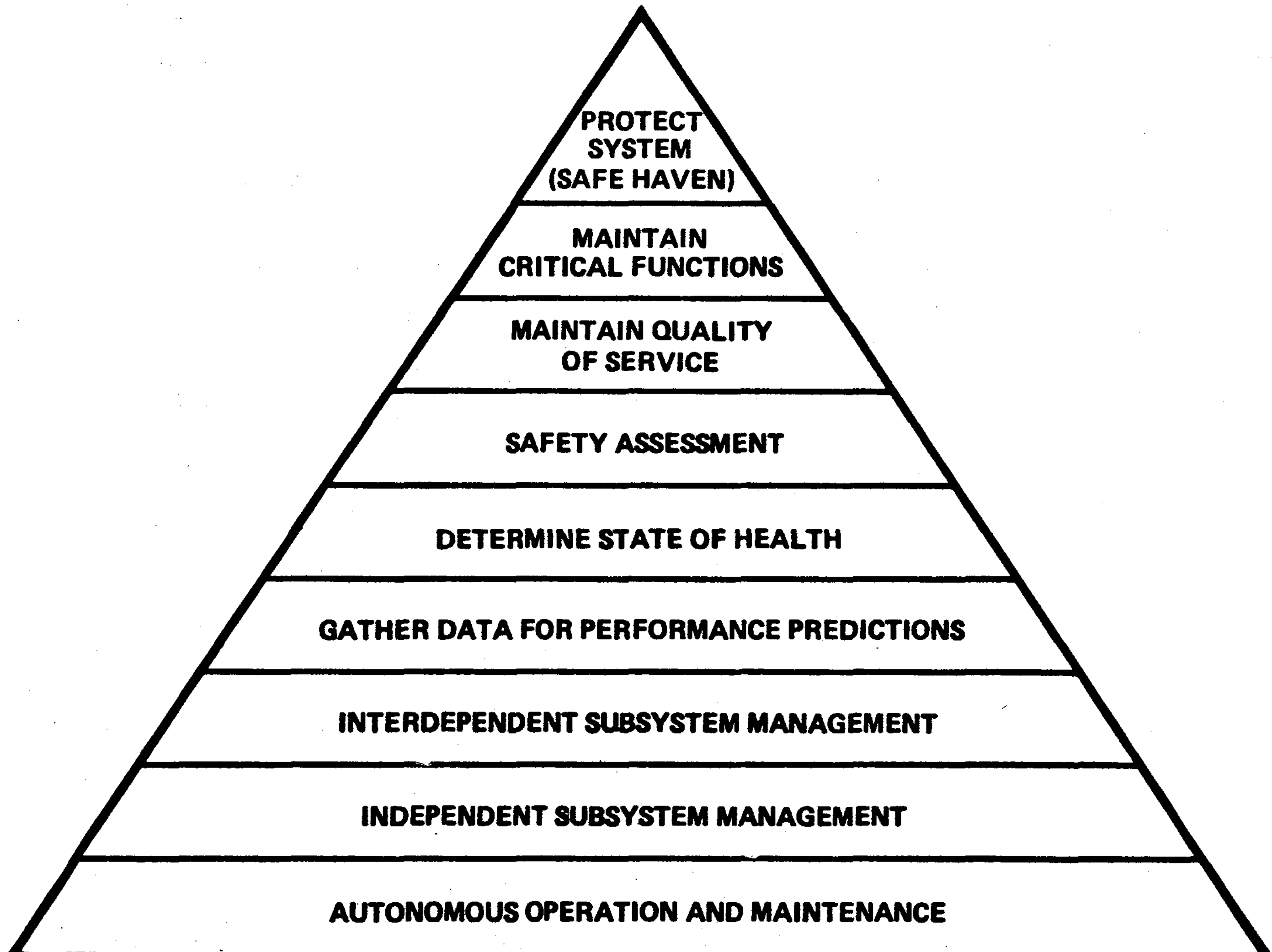
AUTONOMOUS SPACECRAFT MANAGEMENT CONCEPT (ASM)

- AUTONOMOUS MAINTENANCE – MAINTENANCE AND OPERATIONS TASKS PERFORMED ONBOARD WITHOUT GROUND INTERACTIVITY
- AUTONOMOUS FAULT DETECTION, ISOLATION, AND REMOVAL – SAFEGUARD HEALTH OF THE SPACECRAFT
- AUTONOMOUS RECONFIGURATION OR RECOVERY – FOLLOW PROCEDURES FOR REPLACING FAILURES WITH REDUNDANT PARTS OR SWITCH TO ALTERNATE MODES

ASM VERSUS PRESENT APPROACH SUMMARY

ASM	PRESENT
• HANDS-ON ON-ORBIT CHECKOUT	• HANDS-ON ON-ORBIT CHECKOUT
• SELF PERFORMANCE MONITOR	• PERFORMANCE MONITOR VIA TELEMETRY
• SELF HEALTH MONITOR	• HEALTH MONITOR VIA TELEMETRY
• MORE DIRECT MEASUREMENT OF HEALTH - ADDITIONAL SENSORS INDIVIDUALLY MONITORED	• INDIRECT MEASUREMENT OF HEALTH - LIMITED TELEMETRY LIST
• DATA ANALYZED AND SWITCHING COM-MANDED BY ON-BOARD FAULT MONITOR	• DATA REVIEWED AND SWITCHING COMMANDED BY GROUND CREW
• TREND ANALYSIS POSSIBLE	• TREND ANALYSIS PREDICTS FAILURES
• HIERARCHY OF RESPONSE UP TO SAFE HAVEN	• SAFE HAVEN MODE

HIERARCHICAL STATES



CRITERIA FOR ASM ACCEPTANCE AND APPLICATION

- ESTABLISH NEED
  - ENHANCED MANAGEMENT OF COMPLEX SYSTEMS
  - VULNERABILITY REDUCED
  - LIFE CYCLE COST REDUCED
  - CONVENIENCE INCREASED
- DEMONSTRATE NEW TECHNOLOGIES
  - SUBSYSTEM ALGORITHMS
  - SPACECRAFT MANAGEMENT STRATEGIES
- PROVE THE DESIGN CONCEPT
  - SHOW THAT RELIABILITY AND AVAILABILITY ARE IMPROVED
  - SIMULATE AND ANALYZE
- QUANTIFY RISKS AND BENEFITS

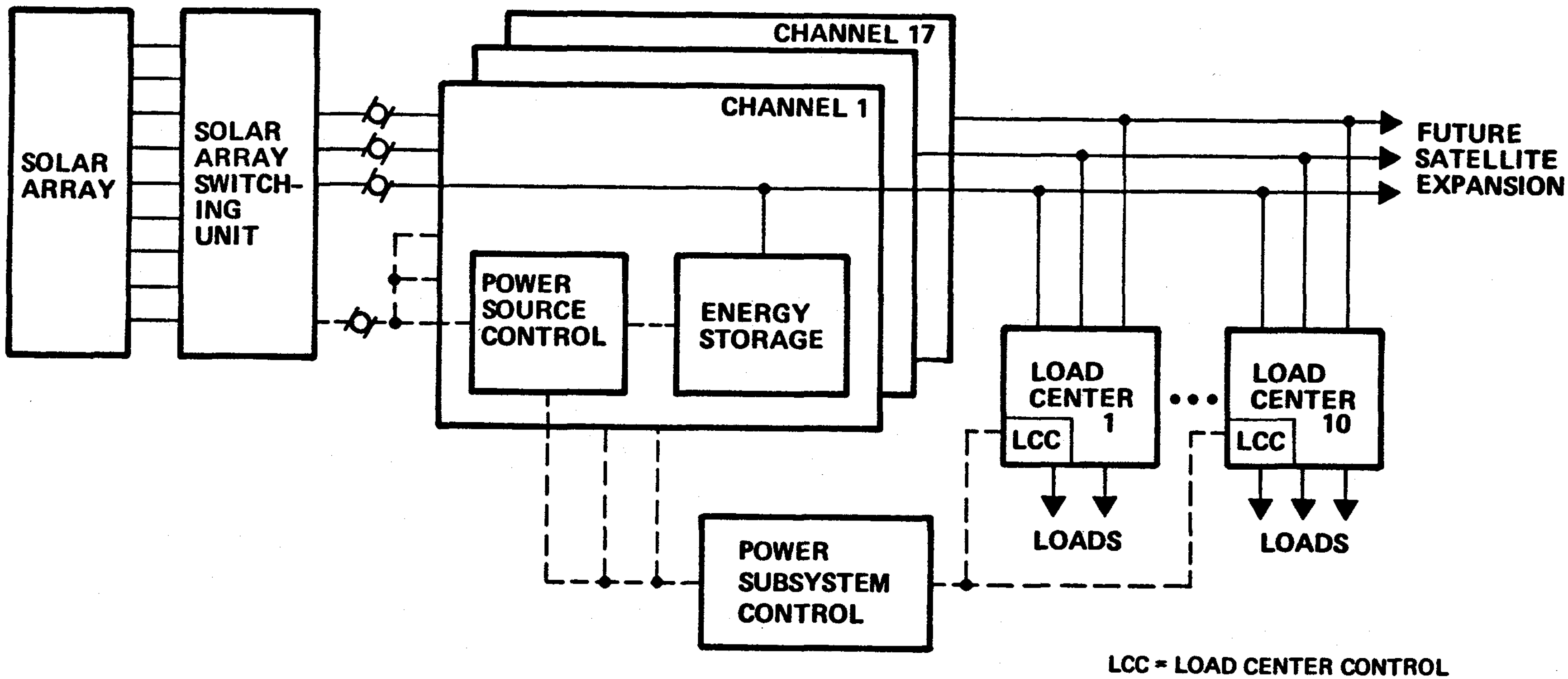
PROGRAM HIGHLIGHTS

- ESTABLISHED BASELINE DESIGN FOR MODULAR 250 kW ELECTRICAL POWER SYSTEM – MULTIPLE POWER SOURCES AND LOAD CENTERS
- DEVELOPED MANAGEMENT CONCEPT FOR UTILITY TYPE POWER SYSTEM – FULL POWER SOURCE UTILIZATION AND ADAPTIVE CONTROL OF LOAD BUSES
- DEFINED POWER SUBSYSTEM ALGORITHMS
- DEVELOPED POWER MANAGEMENT SUBSYSTEM ARCHITECTURE – POWER SUBSYSTEM PROCESSORS, AND DISTRIBUTED POWER SOURCE AND LOAD CENTER PROCESSORS

PROGRAM HIGHLIGHTS (Continued)

- SELECTED FLIGHT QUALIFIED MICROPROCESSORS FOR POWER MANAGEMENT SUBSYSTEM
- DEFINED DATA BUS NETWORK AND DATA COMMUNICATIONS PROTOCOLS
- INITIATED SOFTWARE DEVELOPMENT OF KEY POWER SUBSYSTEM ALGORITHMS USING HIGH LEVEL LANGUAGE (FORTH)
- DEVELOPED CONCEPT FOR A TEST BED AND DEMONSTRATION SYSTEM OF AN AUTONOMOUSLY MANAGED 250 kW POWER SYSTEM - INITIAL FACILITY OF 48 kW EXPANDABLE IN 16 kW INCREMENTS

MULTICHANNEL REFERENCE ELECTRICAL POWER SYSTEM DESIGN

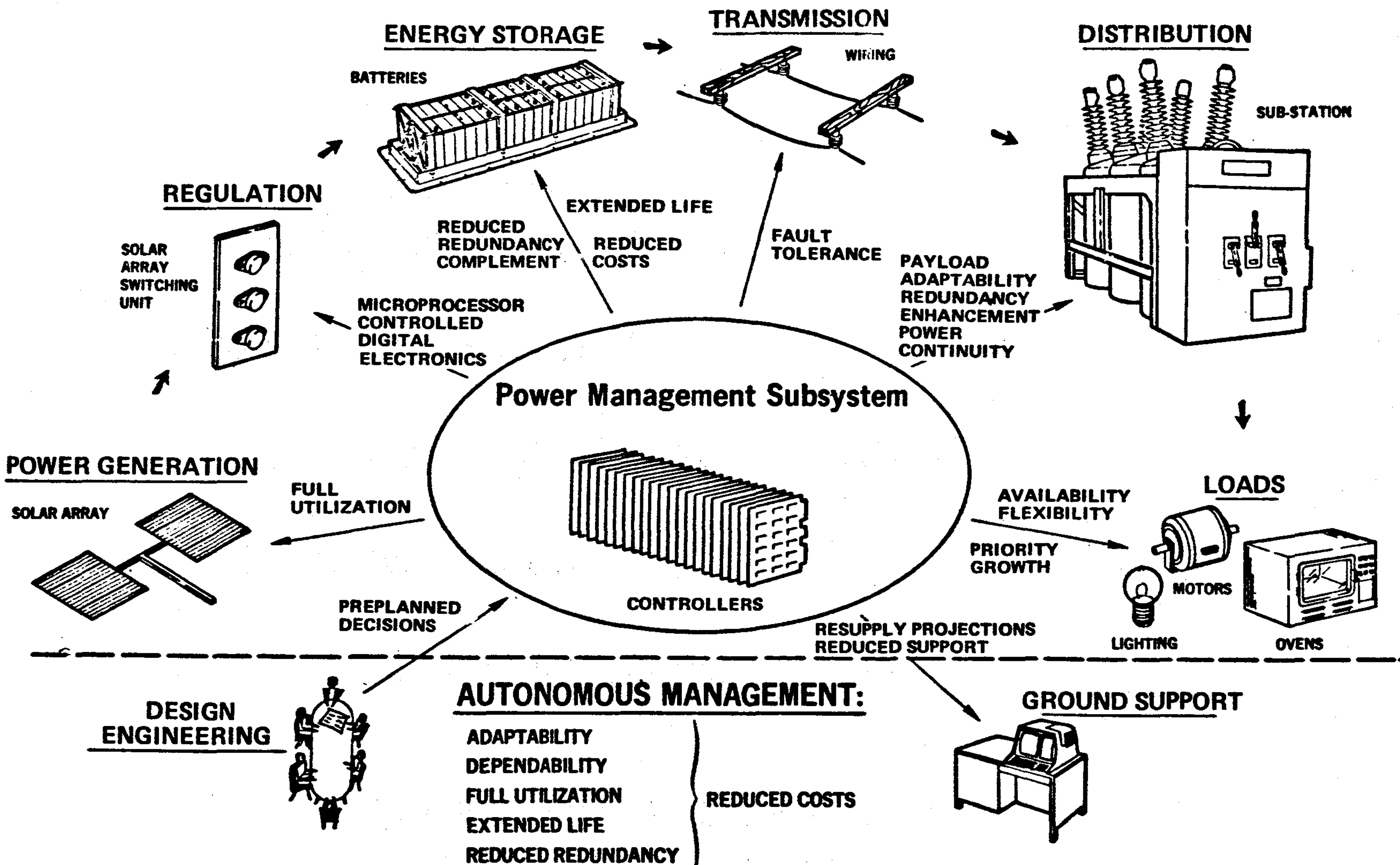


GENERATION – CASSEGRAIN CONCENTRATOR SOLAR ARRAY
ENERGY STORAGE – NICKEL-HYDROGEN BATTERY (160, 150-AH CELLS)
BATTERY CHARGER – SOLAR ARRAY SWITCHING UNIT
REGULATION – 220 ± 20 VOLTS (BATTERY CHARACTERISTICS)
POWER TRANSMISSION – DIRECT CURRENT AT SOURCE VOLTAGE
POWER DISTRIBUTION – DIRECT CURRENT AT SOURCE VOLTAGE
POWER PROCESSING – AS NEEDED WITHIN EACH PAYLOAD OR LOAD CENTER
CHANNEL QUANTITY – DEFINED BY BATTERY CAPACITY (17)
RELIABILITY – FAIL OPERATIONAL, FAIL SAFE
GRACEFUL CAPACITY DEGRADATION WITH FAILURES
LIFE – INDEFINITE; REPLACE FAILED UNIT AT NEXT SERVICE OPPORTUNITY

CENTRAL PROCESSING FUNCTIONS
POWER SUBSYSTEM RELATED

- PAYLOAD OPERATION AND MAINTENANCE
- INTER-SUBSYSTEM CONTROLS
- MONITOR STATE OF HEALTH OF SUBSYSTEM PROCESSORS
- PAYLOAD FAULT MANAGEMENT
- FAULT ISOLATION AND CONFIGURATION MANAGEMENT OF SUBSYSTEM PROCESSORS
- FAULT TOLERANT CENTRAL PROCESSING

AUTONOMOUS MANAGEMENT IS THE HEART OF UTILITY SPACECRAFT POWER



BENEFITS FROM AMPS

- REDUCES REDUNDANCY REQUIREMENTS/COSTS
  - ACCOMMODATES WIDESPREAD DEGRADATION/FAILURES THROUGH FLEXIBLE LOAD MANAGEMENT TECHNIQUES
- REDUCES DEVELOPMENT COST THROUGH MANAGEMENT OF COMPLEX MODULARIZED SYSTEMS USING LOWER POWER MODULES AND NEAR TERM TECHNOLOGY
- REDUCES RESUPPLY COSTS BY:
  - OPERATING EQUIPMENT TO EXTEND LIFE
  - EARLY DEGRADATION DETECTION AND CORRECTIVE ACTION
  - RESUPPLY PROJECTIONS
  - MISSION ADAPTABILITY
- REDUCES GROUND STATION OPERATIONAL COSTS
  - REDUCES COMMUNICATION TRAFFIC REQUIREMENTS
  - MINIMIZES GROUND FACILITIES FOR INCREASING SATELLITE QUANTITY/COMPLEXITY
  - FEWER PERSONNEL
  - CONTINUING SUPPORT COSTS REDUCED

BENEFITS FROM AMPS

- IMPROVES DEPENDABILITY AND PERFORMANCE THROUGH USE OF EXTENSIVE DIAGNOSTIC DATA
- DECREASES ASTRONAUT MONITORING REQUIREMENTS
- OPERATES UTILITY TYPE POWER SYSTEM FOR A WIDE VARIETY OF PAYLOAD MISSIONS AND LOADS

AUTONOMOUS POWER MANAGEMENT APPLICATIONS

- SPACE PLATFORMS
- MILITARY SPACECRAFT
- MANNED SPACE STATION
- ELECTRIC PROPULSION SPACECRAFT

CONCLUSIONS

- A UTILITY TYPE POWER SYSTEM CONCEPT HAS BEEN DEVELOPED THAT ALLOWS LARGE SYSTEM POWER TO BE ATTAINED WITH NEAR TERM TECHNOLOGY
- MODULAR APPROACH REDUCES DEVELOPMENT AND RESUPPLY COSTS AND ENABLES INCREMENTAL ASSEMBLY/EXPANSION OF LARGE POWER STATIONS
- UTILITY TYPE POWER SYSTEM VERSATILITY REQUIRES A NEW APPROACH TO POWER MANAGEMENT IN SPACE
- AMPS PROVIDES A COST EFFECTIVE APPROACH TO THE REQUIRED POWER MANAGEMENT BY:
  - MINIMIZING GROUND STATION SUPPORT
  - IMPROVING EQUIPMENT LIFE
  - REDUCING RESUPPLY COST
  - ACCOMMODATING WIDE VARIETY OF PAYLOAD MISSIONS AND LOADS
  - RECOVERY FROM EQUIPMENT DEGRADATION AND FAILURE
- AMPS POWER MANAGEMENT STRATEGIES ARE A KEY TECHNOLOGY DEVELOPMENT FOR LARGE POWER SYSTEMS AND MILITARY SPACECRAFT

"STRAWMAN"

TECHNOLOGY ISSUES

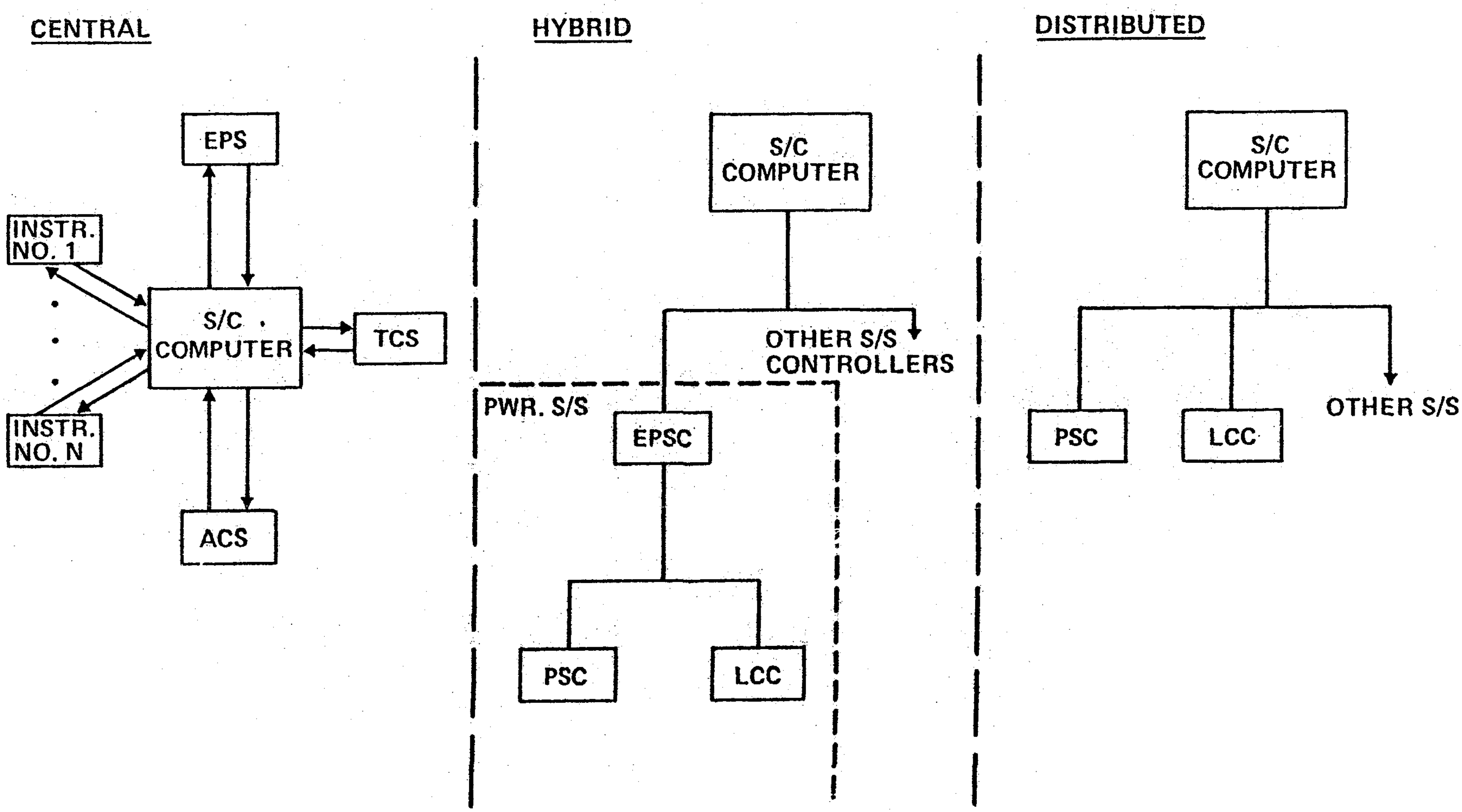
AND

SPECIFIC OBJECTIVES

TECHNOLOGY ISSUES

- o DISTRIBUTED VERSUS CENTRAL CONTROL
- o ALGORITHM MODELING
- o CONTROL REQUIREMENTS
- o CONTROL PHILOSOPHY

- DISTRIBUTED VERSUS CENTRAL CONTROL



TECHNOLOGY ISSUES

- ALGORITHM MODELING

ACCURATE MODELING/CHARACTERIZATION OF COMPONENTS

BETTER UNDERSTANDING OF COMPONENT CHARACTERISTICS AND THE EFFECTS OF VARYING PARAMETERS ON THE COMPONENT RELIABILITY, EFFICIENCY, AND LIFE MAY BE NEEDED TO PROPERLY DESCRIBE THE COMPONENTS EFFECT ON POWER SYSTEM PERFORMANCE.

PHILOSOPHY OF REDUNDANCY INTERNAL TO THE ALGORITHM

DUE TO THE FRAGILE NATURE OF SOFTWARE AND THE POTENTIAL CONSEQUENCES OF ERROR, A REDUNDANCY PHILOSOPHY MAY BE REQUIRED OTHER THAN THAT INVOLVED AT THE SYSTEM LEVEL.

STANDARDIZATION VS. OPTIMIZATION

IT IS IMPORTANT TO RECOGNIZE THE OVERALL SYSTEM ECONOMY IN TERMS OF SUFFICING VERSUS OPTIMIZING PHILOSOPHY – – –
A FAMILY OF "STANDARD" ALGORITHMS MAY BE ADEQUATE BUT SHOULD BE COMPARED WITH THE POSSIBILITY OF UNIQUE (OPTIMUM) ALGORITHMS FOR EACH NEED.

TECHNOLOGY ISSUES

- CONTROL REQUIREMENTS

DEPTH OF MONITORING (PENETRATION)

DEPENDING ON SYSTEM REDUNDANCY/RECOVERY PHILOSOPHY, THE DEPTH OF MONITORING MAY VARY FROM SUBSYSTEM LEVEL DOWN TO COMPONENT LEVEL. (BATTERY TO CELL)

DATA SAMPLING RATE

SINCE THE LEVEL OF COMPLEXITY AND CONTROL IS DIRECTLY DEPENDENT ON THE DATA SAMPLE RATES, VARYING SAMPLE RATES MAY BE DESIRABLE FOR OPTIMUM SYSTEM MANAGEMENT.

TECHNOLOGY ISSUES

- CONTROL PHILOSOPHY

POWER DOWN VS. LIGHT LOAD OPERATION

IT MAY BE DESIRABLE TO POWER DOWN PORTIONS OF A SYSTEM FOR LONG PERIODS OF "STANDBY" OPERATIONS AS OPPOSED TO OPERATION OF THE TOTAL SYSTEM AT A FRACTION OF ITS RATING.

LOAD SHEDDING (PRIORITIZATION)

FOR CERTAIN SITUATIONS IT MAY BE DESIRABLE TO PRIORITIZE LOADS (OR LOAD BUSES) AND ENABLE BUSES ACCORDING TO SYSTEM CAPACITY.

SELF–DIAGNOSIS AND OVERRIDE

CERTAIN SELF–DIAGNOSTICS WILL UNDOUBTEDLY BE REQUIRED; THE CONSEQUENCE OF THIS DIAGNOSIS AND THE ABILITY TO OVERRIDE AND/OR REPROGRAM AN AUTOMATED SYSTEM MAY NEED TO BE TRADED OFF AGAINST THE DEGREE OF SOPHISITICATION NECESSARY FOR "TOTAL" AUTONOMY.

SPECIFIC OBJECTIVES

DISTRIBUTED VERSUS CENTRAL CONTROL

- IDENTIFY OPTIMUM APPROACH FOR VARIOUS CLASSES OF USE (PLANETARY, EARTH ORBITAL, LARGE VS. SMALL, MILITARY)
- IDENTIFY COST VS. BENEFIT OF OPTIMUM APPROACH VS. STANDARD
- ESTABLISH LEVELS OF AUTHORITY REQUIRED IN EACH

SPECIFIC OBJECTIVES

ALGORITHM MODELING

- GENERATE ALGORITHMS
- CREATE STANDARD SET OF ALGORITHMS
- ESTABLISH COST/BENEFIT FOR USE OF STANDARD VS. OPTIMUM

SPECIFIC OBJECTIVES

ALGORITHM MODELING

IDENTIFIED ALGORITHMS

- BATTERY CHARGE CONTROL
- BATTERY STATE–OF–HEALTH
  - RECONDITIONING
  - TREND PROJECTION
- SOLAR ARRAY STATUS
- COMMAND PROCESSING
  - CIRCUIT BREAKER PROGRAMMING
- SWITCH/LOAD BUS MONITORING
  - FAULT DEFINITION
- ENERGY PLANNING/ALLOCATION
  - SOLAR ARRAY POWER REALLOCATION
- LOAD BUS ASSIGNMENTS
- POWER SUBSYSTEMS STATE–OF–HEALTH
  - REPLACEMENT SCHEDULING
  - CONTROLLER ANOMALIES

ALGORITHM TYPES

- EFFECTS ACTION
- GATHERS DATA

SPECIFIC OBJECTIVES

CONTROL REQUIREMENTS

- ESTABLISH RATES REQUIRED FOR OPTIMUM MANAGEMENT
  - GENERATION
  - STORAGE
  - DISTRIBUTION
- DETERMINE SENSITIVITY OF CHANGE IN SAMPLE RATE TO SYSTEM PERFORMANCE, RELIABILITY, AND COST
- ESTABLISH LIMITS OF DATA ALGORITHMS DETERMINATION FOR ACTION AND CONSEQUENCES OF VARIATIONS IN THOSE LIMITS

SPECIFIC OBJECTIVES

CONTROL PHILOSOPHY

- DETERMINE COST EFFECTIVE LEVELS OF REDUNDANCY (SYSTEM PAD)
- ESTABLISH LEVELS OF SYSTEM DEGRADATION WHERE SPACECRAFT HIERARCHY DECIDE WHETHER TO CONTINUE IN DEGRADED MODE FOR MAXIMUM LIFE OR TO OPERATE IN AN EARLY WEAROUT MODE TO ATTAIN HIGHER LEVELS OF PERFORMANCE
- ESTABLISH MODES OF POWER DOWN OPERATION COMMANDED BY THE SPACECRAFT HIERARCHY DUE TO POINTING CONDITIONS, THERMAL CONDITIONS, OR OTHER SPACECRAFT CONSTRAINTS.

SPACE POWER SYSTEM AUTOMATION WORKSHOP

MARSHALL SPACE FLIGHT CENTER

OCTOBER 28 & 29, 1981

REPORT OF WORKSHOP GROUP NUMBER 1

by

Sidney W. Silverman (Workshop Chairman)

Matt Immamura

Bill Brannian

Dave Peterson

Bob Giudici

Roy Lanier

John Armantrout

Doug Turner

THE QUESTION ADDRESSED

WAS

WHAT ARE THE TECHNOLOGY ISSUES INVOLVED IN THE AUTOMATION OF A SPACE POWER SYSTEM?

BACKGROUND:

The most significant factor in deriving the technology issues is to define what the word "issues" encompasses. A composite of the group's discussion is the following.

Technology issues are technical problems/questions that must be resolved prior to implementation in a spacecraft or mission in order to minimize risk criteria. The issue must meet a defined objective.

In order to be considered an issue, at least one of the following must be true:

- It has little or no history of use.
- It requires longer than 'normal' project time allowed for development.
- It has unacceptable risk (technical, cost, schedule) and value, compared to alternatives.

In addition-- a meaningful RFP can be written for the issue.

CONCLUSIONS/RECOMMENDATIONS:

In order of technical criticality the technical issues are:

1. To implement the automation and autonomous operation of the electrical power system, the primary item is the control aspect, which implies the software and the verification of the sensing and corrective action. This includes sensors to detect the selected parameters, algorithms for the component reaction, and the subsystem operation and interaction with other components and subsystems, and effectors to cover the required ranges of values (for 50-500KW spacecraft power systems). The control technique must assure that the automation of the electrical power system is fault-tolerant and can operate in programmed modes regardless of the degraded conditions encountered. Control concepts thus are the governing factors in effective automation and autonomous operation of the electrical power system.

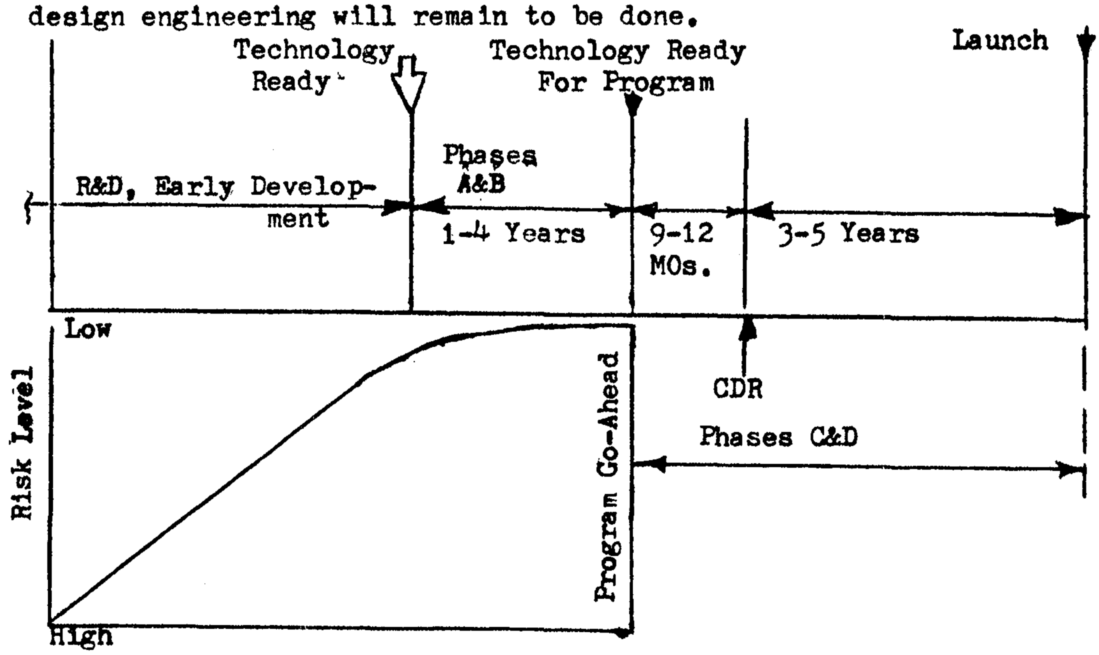
2. Once the control concept has been selected and the design initiated, the next important item is the availability of space-qualified components for high power applications. Included will be those components which are available with a past use history,

those which are logical candidates but have not been qualified, those which will have to be modified from existing designs, and those which are unavailable for various reasons. The latter will result in extensive R&D programs to conceive, fabricate, develop, and test the component within the allotted schedule. Components will have to be suitable for application to a controlled, autonomous, operational electrical power system.

3. As the power levels are increased to the multihundred kilowatt range, higher operating and distributing voltages become necessary in order to decrease system amperes, losses, and the size of the components and the distribution system, Limitations may be imposed by availability of qualified components. The voltage selection will have to be made at the electrical system level because of the interfaces with the other systems and the requirements for protection and safety. At higher power levels and higher voltages or currents, interactions with the environment become severe and significant. Special concepts must be formulated so that the electrical power system can operate.

GENERAL:

A definition of technology readiness can be described in the following program schedule chart. At the time of technology readiness, all development work will have been completed and only design engineering will remain to be done.



SPACE POWER SYSTEM AUTOMATION WORKSHOP

MARSHALL SPACE FLIGHT CENTER

OCTOBER 28 & 29, 1981

REPORT OF WORKSHOP GROUP NUMBER 2

by

NAME	ORGANIZATION
Floyd E. Ford (Chairman)	NASA/GSFC
Frederick C. Vote	JPL
John W. Lear	Martin/Marietta
Charles Sollo	TRW
Joe Navarro	McDonnell-Douglas - CA
Mike Glass	Lockheed
Wayne Hudson	NASA Headquarters
Don Routh	NASA/MSFC
Don Williams	NASA/MSFC

THE QUESTION ADDRESSED

WAS

WHAT ARE THE TECHNOLOGY ISSUES INVOLVED IN
THE AUTOMATION OF A SPACE POWER SYSTEM?

Background:

The group 2 session on Technology Issues (TI) for Automated Power Systems was initiated by addressing the following questions:

• Is the automation of power systems needed or required for future space missions requiring large (greater than 25KW) power systems?

• Is it conceivable to think in terms of an autonomous power system, supporting mission objectives for extended periods (several days to weeks) without human intervention or monitoring?

After considerable discussions on such topics as trends in power levels, complexity of large systems, user requirements for quality power, overall system cost, etc., the group achieved the following consensus:

a. Automation is required for large power systems.

b. An autonomous power system is conceivable.

The group could not agree on the level (or degree) of automation without a cost benefit analysis to illustrate the various trade-offs. There was general agreement that a fully automated power system would most likely be achieved through evolution with incremental growth from today's systems to those needed in the 1990's. However, the technology for automation is believed to be one that enables large power systems, not merely to enhance them. There seems to be no question that the large systems of the future will require a much higher degree of automation than that existing in present power systems.

Some other important considerations supporting automation technology for power systems are as follows:

• Large power systems will be extremely complex in terms of on-orbit configuration management, amount of housekeeping data, and overall energy management.

• Power and load management will require on-board intelligence to efficiently and effectively use the system's energy

• Speed of detection and correction of failures/faults will be critical for large systems.

• The need for longer periods of spacecraft autonomy is a driver for automation.

The group expressed a need for a trade-off study to establish the benefits of automation versus the degree of automation that may be achieved in a power system. To place this question in perspective, one example is given. Should a power system be completely self-correcting or should it depend on ground intervention. For instance, if a failure is detected in one of several of the power buses, is it acceptable to the users to power down and wait for ground intervention or is there sufficient cost justification to automate the diagnostic functions necessary to make decisions required to reconfigure the loads to another bus.

Conclusions/Recommendations:

The group 2 session defined five technology issues. They are as follows:

1. Establish a reference power system design from which to base the requirements for automation.

Comment

The reference system should serve as a baseline for trade-off studies, total subsystem analysis, and mission analysis. The reference design should consider the environment and user community for low earth orbit, geosynchronous, and planetary type missions. The needs of the various type payloads (high power pulse loads, long duty cycle loads, etc.) should be a strong consideration in arriving at a reference design.

2. Develop and document the architecture/methodology to be pursued in the automation of large power systems.

Comment

The group recognized that any power system consists of a multiplicity of basic components such as batteries, solar arrays and electronics. However the philosophy used in assembling these components into a system will strongly influence the approach to automation. Such issues as central vs. distributed control, type of sensor information needed, processor characteristics and storage capability, distribution of intelligence within the system (central computer vs. local microprocessors), degree of modularization of power units, and the overall system philosophy should be thoroughly investigated prior to initiating any hardware development. The early decisions made on these issues will impact development cost throughout the program. The minimum level of automation consistent with a reliable and cost effective power system should be the "first cut" design.

3. Strongly emphasize "system engineering" in the power system automation effort.

Comment

The successful outcome of an automated power system technology program will, to a large extent, depend on the amount of system engineering that goes into the decision making process. It must be recognized that the power system is only one of the several subsystems that will make up a spacecraft, vehicle or space platform. Trade-offs and/or decisions made by the power system designer can significantly influence design philosophy and/or cost of other subsystems such as mechanical, thermal, data handling, attitude control, communication, etc.

4. Develop models of power systems and system components required to generate the algorithms that accurately represent the characteristics of the individual system components.

Comment

The process of automation requires algorithms that accurately represent the characteristics of the individual system components. This requires that components such as batteries, solar arrays, electronic switches, etc., be defined in analytical terms from models that have a high degree of validity and accuracy. Both dc and ac models should be developed. Performance validation of large power systems will depend primarily on synthesizing the system using computer simulations. This is contrasted with past practices where "all up" ground system tests were conducted to demonstrate system performance prior to launch.

5. Identify and initiate development of components required for the automation of power systems.

Comments

It was generally agreed that the basic piece parts (battery cells, solar cells, transistors, etc.) for a power system currently exist. However, a number of components required for the automation process either do not exist, or are inadequate. Those specifically discussed included high power overload switches (space qualified), actuators with digital interface, electronic switchgear (non-mechanical) and accurate current sensors with large dynamic range.

General:

The overall view of the group, as perceived by the chairman, was that large space power systems will require levels of automation much greater than those being implemented in present designs. The architecture of the large power system, the philosophy of design, the methodology of hardware implementation, and the launch and operational scenarios are presently nonexistent. These are interdependent quantities and are usually studied and defined as part of a project conceptual design phase. Consequently, it is understandable that most of the issues addressed during the workshop dealt with system engineering rather than technology. Of the five recommendations presented by group 2, only numbers 4 and 5 relate to technology. What is implied by this, is that a technology program for the automation of power systems must emphasize systems engineering first. From the systems engineering a number of technology issues will emerge.

During the workshop discussions, it became apparent that there are two prevailing "schools of thought" on large power systems in space. They are as follows:

- Develop power system modules (i.e., 25KW) and use these modules as building blocks in space for growth to a 100 to 250KW capability over some period.

- Develop a "unit" power system of the size that is needed (i.e., 100 or 200KW) and place this unit in orbit.

The second approach has been referred to as a "mini-utility" system. The point of raising this issue is not to promote one concept over the other, but rather to illustrate the divergence of technical opinions, even on the basic scenario for achieving large power capabilities in space.

SPACE POWER SYSTEM AUTOMATION WORKSHOP
MARSHALL SPACE FLIGHT CENTER
OCTOBER 28 & 29, 1981

REPORT OF WORKSHOP GROUP NUMBER 3

by

Howard Weiner (Workshop Chairman)

Robert Corbett

Kent Decker

Joe Voss

Lu Slifer

Chris Carl

George Von Tiesenhausen

Lt. Ed Gjermundsen

THE QUESTION ADDRESSED

WAS

WHAT ARE THE SPECIFIC OBJECTIVES INVOLVED IN THE AUTOMATION OF A SPACE POWER SYSTEM?

BACKGROUND

Workshop Group No. 3 was assigned the task of establishing specific objectives involved in the automation of a space power subsystem. Considerable attention was also given to the "strawman" set of objectives developed by NASA-MSFC personnel. As a result of these discussions a set of recommendations, presented below, were derived. These recommendations do not necessarily represent all of the objectives required for automation. However, they do represent a well-conisdered set of initial specific objectives.

RECOMMENDATIONS

This section contains a set of recommendations arranged in order of decreasing priority (i.e. Recommendation No. 1 has highest priority). Each recommendation is also a brief description of the action needed to accomplish a specific objective.

Priority ranking was based on a temporal ranking. Thus, the specific objective of Recommendation No. 2 needed substantial completion before specific objectives of subsequent recommendations could be meaningfully attained.

RECOMMENDATION NO. 1

Identify All Potentially Useful Autonomy Functions

An Autonomy Function is defined herein as a specific capability, designed into a spacecraft which permits the spacecraft to execute a specific on-board task (with decision making) without intervention or control from the ground.

A number of autonomy functions have been identified, which are useful for power subsystem autonomy, including:

1) Battery Charge Control
2) Battery State-of-Health
   - Reconditioning
   - Trend Projection
3) Solar Array Status
4) Command Processing (Circuit Breaker Programming)
5) Switch/Load Bus Monitoring (Fault Definition)
6) Energy Planning/Allocation (Solar Array Power Relocation)
7) Load Bus Assignments
8) Power Subsystems State-of-Health
   - Replacement Schedules
   - Controller Anomalies

While these functions may appear to be sufficient, there can be more subtle considerations, based on a more global viewpoint than that of a power subsystem designer, which require additional autonomy functions be utilized for the larger more complex spacecraft. A proper understanding of these considerations can be attained by the use of a team of experts from the following spacecraft technologies:

1) Artificial Intelligence
2) Spacecraft Systems
3) Power Subsystems
4) Computer Design/Programming

Thest teams should be capable of identifying, categorizing and prioritizing all potentially useful autonomy functions. As an example, it may be useful to utilize the following categories as autonomy function discriminators.

1) Level of Control Authority
   - System
   - Subsystem
   - Local
2) Response Time Requirement
   - Fast ($\sim 10^{-6}$ Sec)
   - Moderate ($\sim 10^{-3}$ Sec)
   - Slow (~ 1 Sec)
3) Mission Impact
   - Critical
   - Non-Critical

By means of these categories, etc, the optimum methods of implementing an autonomy function can be more easily attained.

RECOMMENDATION NO. 2

Establish Design and Reliability Directives for the Power Subsystem

Another key task for the team of experts is the establishment of Design and Reliability Directives for the Power Subsystem. This task should be at as high a priority level as the first task of identifying all potentially useful autonomy functions.

The team should carefully review all mission and operations requirements in order to determine the appropriate levels of performance, reliability and autonomy for the power subsystem. Directives should then be issued for controlling design. As an example:

"Failure of an autonomy function shall not cause any degradation of power subsystem performance or lifetime"

Directives, such as the above, can then be used to determine levels of redundancy in autonomy function and power subsystem equipment as well as the type of redundancy (block, functional, standby, etc).

These directives will also serve as the basis for determining optimum monitoring approach, data sample rates and other elements of the autonomy functions.

RECOMMENDATION NO. 3

Generate Algorithms for Each Autonomy Function

An Algorithm is defined herein as a series of logical steps needed to perform an Autonomy Function.

In order to determine the optimum level of autonomy for a given power subsystem, the penalties vs benefits of various applicable autonomy function must be evaluated. Assessment of these require that an algorithm, for each function, be generated and that various methods of implementing that algorithm hardware, software, memory, data rate, sensors, data conversion, etc be evaluated. Hence, prior to the selection of any autonomy functions, for a given application, it is desirable that algorithms be generated for all potentially useful autonomy functions.

It should be noted that development of standard algorithms may be useful in terms of generating penalty information during the preliminary design process. However, algorithms and methods of implementing these algorithms should be optimized by the time the critical design review process occurs.

RECOMMENDATION NO. 4

Develop a More Rigorous Definition of Potential Computer Arrangements

As development of spacecraft autonomy proceeds, it will become necessary to develop more rigorous definitions of proposed computer arrangements. The present scheme of "Distributed", "Hybrid" or "Central Control" arrangements can lead to confusion during evaluation and trade-off processes. A proposed approach (which should be modified as more complex arrangements are developed) is shown in Figure 1. The approach is simply to indicate the numbers of computers at successively lower levels of command and control heirarchy. The arrangements shown in Figure 1 are based on the following heirarchy:

1) Spacecraft System Level
2) Subsystem Level
3) Local Level

Additional definitions of arrangements should be developed when computers are used on a ring (or circular) type of data bus.

RECOMMENDATION NO. 5

Identify Optimum Computer Arrangements Based on the Size of the Size of the Spacecraft

The "size" of a spacecraft, in terms pertinent to power system autonomy, may be the physical size of the spacecraft or the power subsystem, the power requirements of the spacecraft, the degree of "complexity" of the power subsystem or the rate of command, control and monitoring data - or any combination of the above. Essentially, the "larger" the spacecraft, the more likely a "distributed" computer arrangement will be required. As an example, if the data rate required for power subsystem autonomy is of the order of $\sim$100 KHZ, the use of the spacecraft central computer alone may be sufficient. On the other hand, a data rate of 10MHZ will require distribution of autonomy tasks between a spacecraft central computer ($\sim$3MHZ presently available), a power subsystem computer ($\sim$3MHZ) and numerous of local level processors (100KHZ - 800 KHZ).

Other considerations such as a planetary vs earth orbital spacecraft, a military vs civil spacecraft or levels of authority for each processor are relatively minor with regard to their impact on computer arrangements.

A standard computer arrangement for all spacecraft "sizes" is not indicated. Nor is it even indicated for all classes of spacecraft for a given "size". In the final analyses, an optimum computer arrangement will be used in the final design of autonomy for any power subsystem, even though a majority of the developed "standard" autonomous functions will find multiple application.

SPACE POWER SYSTEM AUTOMATION WORKSHOP

MARSHALL SPACE FLIGHT CENTER

OCTOBER 28 & 29, 1981

REPORT OF WORKSHOP GROUP NUMBER 4

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THE QUESTION ADDRESSED

WAS

WHAT ARE THE SPECIFIC OBJECTIVES INVOLVED IN THE AUTOMATION OF A SPACE POWER SYSTEM?

SPACE POWER SYSTEM
AUTOMATION WORKSHOP
INPUT FROM
GROUP 4

This document summarizes the inputs by the individual members comprising Group 4 on Automation Objectives.

Background:

With the current emphasis being placed on space platform systems, it becomes necessary to investigate new ways to make these systems affordable. That is, affordable in terms of reducing the life cycle costs, extend the operational life, and improve the performance of the systems involved. To this end, automation and autonomous systems technologies are expected to make significant and important contributions to the development and operation of these missions.

In the case of the on-board electrical power system, a program must be defined and implemented that is affordable and will ensure, in the event of a failure, that the system degrades gracefully while providing for some minimum set of useful services. Therefore, the most basic of all objectives is to define an electrical power system automation plan that will achieve the greatest early-on benefits (such as timely reconfiguration and reconstitution of itself) without adding to the complexity of a fully autonomous system.

Conclusions:

Much has been accomplished in providing new automation tools to the hardware designer that improves the performance of today's flight equipment. Microprocessors are being used to program and control system level functions with excellent results. In the case of space power systems, many of the technology issues involving distributed versus central control, algorithm modeling, control requirements/philosophy, voltage type/level, partitioning between spacecraft and ground and between hardware and man, etc. can be resolved through the application of automation techniques. To be successful, automation must be implemented as an integral part of the system design to ensure that the power demands of the users are met with the greatest reliability, flexibility and efficiency.

Recommendations:

The objectives and actions taken to evaluate and implement an agreed upon level and/or philosophy of automation for a space power subsystem must be focused so as to provide a utility type of operation. It must also reduce the ground and on-board operational burden, accommodate near-term hardware technology limitations and reduce the development, operations, and resupply costs of the system. Based upon this premise, the following recommendations are made:

1. Classify and characterize the power subsystem requirements. This includes the function, quality, type, voltage level, quantity, constraints, load profiles, etc. In addition, this action should consider all potential power utilization equipments as well as the mission phases (i.e., pre-launch, launch, orbital operations, on-orbit service/maintenance/resupply, etc.).

2. Develop a comprehensive list of all potential functions and/or activities that could impact the power subsystem and prevent it from performing an effective utility type of operation. This would include such parameters as operational environments, single point failures, insufficient redundancy, unqualified parts and components, human error, over-stressed conditions, poor design concepts, inadequate protection, inaccurate sensors, etc.

3. Generate a candidate list of automation activities that would eliminate and/or minimize all the identified impacts and would provide both a short term and long term benefit to the power subsystem if implemented. Items to be considered would include redundancy, component derating, fault management, shifting of burden from man to machines, application of algorithms for management strategies, partitioning of functions between space platform and ground and between man and machines, application of hiearchy control functions, level of monitoring, etc.

4. Conduct an indepth trade-off study to evaluate and analyze those candidate automation activities selected as having the maximum pay-off or benefits for the space power system. Questions to be addressed would include the type sensors to be used, level of redundancy to employ, derating factors, central vs distributed control, control strategies, sampling rates, fault detection methodologies, response times, operational limits, diagnosis routines, etc.

5. Develop a balanced partitioning of the automation and control functions between the ground, the space platform and the power subsystem. The partioning should be based on such factors as selected control sensors, sensor control circuitry, integration methodology, applicable control algorithms, display requirements, redline parameters, telemetry links, communication bandwidths, data pre-processing, etc.

6. Develop a fault detection, isolation, diagnosis, and protection plan. The plan should consider such parameters as interface requirements, equipment reconfiguration and recovery requirements,

"safing" for on-orbit servicing, supervisory controls for load switching, system protection for out-of-tolerance conditions, load limiters, reconditioning, trend analysis, etc.

7. Develop algorithms, as appropriate, for the following functions:

a) Battery management strategies

b) Bus power allocations

c) Power distribution management

d) Power processing management

e) Thermal management

f) Battery reconditioning

g) Monitoring health status

h) Trend analysis

i) Fault recovery/reconfiguration

j) Platform processor interfacing

k) Platform display and man interfacing

l) Ground support interfacing

m) Sensing/control parameters

n) Test and validation

These algorithms are intended to enhance and to enable the implementation of selected automation activities to improve performance, reduce costs, and to extend the useful life of the space power subsystem.

8. Develop a technology readiness demonstration program to validate and assess the automation functions and methodology employed. In addition to exercising and validating the specific automation efforts incorporated into the design and those imposed on the power subsystem, the demonstration will include a complete dynamic performance and stability characteristics of the system. Individual parameters such as the following are to be included:

a) Load switching

b) Reconfiguration

c) Fault recovery

d) Fault isolation

e) Power regulation

f) Power processing

g) Sensor response

h) Circuit protection

i) Other

9. Define, develop and verify the needed automation technology for items such as the following:

a) Sensors

b) Sensor circuits

c) Solid state circuit breakers

d) Fault isolation switches

e) Load limiters

f) Data processors

The above nine areas of activity are in priority in that they are listed in the normal sequence of events to accomplish the broad automation objectives previously stated. A carefully planned and coordinated implementation automation plan will have significant benefits making a space platform system affordable.

SPACE POWER SYSTEM
AUTOMATION WORKSHOP
AT THE
MARSHALL SPACE FLIGHT CENTER
OCTOBER 27-29, 1981

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16. ABSTRACT

With the rapidly increasing interest in the application of automation techniques to space power subsystems, the Office of Aeronautics and Space Technology decided to hold a workshop during the last week of October 1981. About 50 specialists convened at the Marshall Center for the two-day interchange. The technology issues involved in power subsystem automation and the reasonable objectives to be sought in such a program were discussed. After a full day of review of current programs, progress, and plans, the participants were divided into four workshops to discuss the different aspects of these issues and objectives. These proceedings gave insight into the complexities, uncertainties, and alternatives of power subsystem automation, along with the advantages from both an economic and a technological perspective. Whereas most spacecraft power subsystems now use certain automated functions, the idea of complete autonomy for long periods of time is almost inconceivable. Thus, it seems prudent that the technology program for power subsystem automation be based upon a growth scenario which should provide a structured framework of deliberate steps to enable the evolution of space power subsystems from the current practice of limited autonomy to a greater use of automation with each step being justified on a cost/benefit basis. Each accomplishment should move toward the objectives of decreased requirement for ground control, increased system reliability through on-board management, and ultimately lower energy cost through longer life systems that require fewer resources to operate and maintain. This approach seems well-suited to the evolution of more sophisticated algorithms and eventually perhaps even the use of some sort of artificial intelligence. On thing seems certain: Multi-hundred kilowatt systems of the future will require an advanced level of autonomy if they are to be affordable and manageable.

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