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FINAL REPORT ON

A STUDY OF SPACECRAFT TECHNOLOGY AND DESIGN CONCEPTS

NASA/LaRC Contract with

Rockwell International

NAS1 - 17758

5 March, 1985

Satellite Systems Division

Rockwell International

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FOREWORD

The Satellite Systems Division of Rockwell International has been conducting a Study of Spacecraft Technology and Design Concepts. This work was performed under Contract NAS1-17785 for the Langley Research Center, National Aeronautics and Space Administration. NASA Leadership was provided through the office of Aeronautics and Space Technology, Dr. Leonard A. Harris, Director for Space, and through the Langley Research Center, Space Systems Division, Lloyd S. Keefer, Jr., Representative of the Contracting Officer.

This report documents the findings of that study, discussing concepts for advancing the state of the art in the design of unmanned spacecraft, the requirements that gave rise to its configuration, and the programs of technology that are suggested as leading to its eventual development. Volume I contains the major technical documentation of the study. Volume II consists of 3 Appendices (Operations, Survivability, and Evaluation Criteria) that might be of particular interest to some readers.

The work was conducted under the direction of F. A. Zylius, Rockwell's Study Manager and Supervisor of Systems & Operations Analysis. The following made major contributions to this study:

C. E. Hiers, Structures & Materials

R. J. Pietka, Spacecraft Design

B. Berman, Electrical Power

T. W. Tysor, Thermal Control

E. J. Filardo, Data Management

G. C. McGee, Guidance, Navigation, Control

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TABLE OF CONTENTS

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1.0 SUMMARY

For a number of years now, it has been apparent that there has been little progress made in advancing the state-of-the-art in the design of unmanned spacecraft. Although the advent of the Space Shuttle and Space Station should have given incentive to improve the design of unmanned spacecraft, their overall conceptual design has remained much as it was 15 years ago. The dimensions, capacities and transportation services offered by the Shuttle, and the program opportunities projected by a Space Station or space platform must inevitably effect the overall design architecture of interfacing free-flying spacecraft. But that revision has not yet taken place. Neither, as it turns out, and as the reader will see later in this document, have we taken full advantage of the lessons we should have learned in 20 years of designing, manufacturing, testing and maintaining instrumented, unmanned spacecraft.

Much in response to the above, a project was instituted by Rockwell International in 1982 entitled "Spacecraft 90" - to bring the design concepts of unmanned spacecraft to a higher level of technology. This, in turn, became the basis for this contracted study with NASA/OAST-LaRC to develop a new approach to spacecraft design, and to lay down a spacecraft initiatives program for its development.

As shown in *Figure 1*, the specific tasks for this study were to (1) select a traffic model consisting of those missions and spacecraft of the 1990's and beyond that are likely to utilize the technology improvements defined in this study, and also select two or three candidates from that traffic model to illustrate the application of selected technology advancements; (2) to identify those spacecraft performance and design functions that are likely to be the source of a need for technology and design improvements; (3) to select and carefully define specific resulting requirements for improvement; (4) to determine the effect of those technology or performance improvements on spacecraft configuration and design; (5) to lay out a technology development program for the selected technology issues, and (6) prepare a "Spacecraft Initiatives" program aimed at having a test vehicle on which to demonstrate and spaceflight qualify the new, high technology functions. *Figure 2* shows a schedule for the tasks of this study.

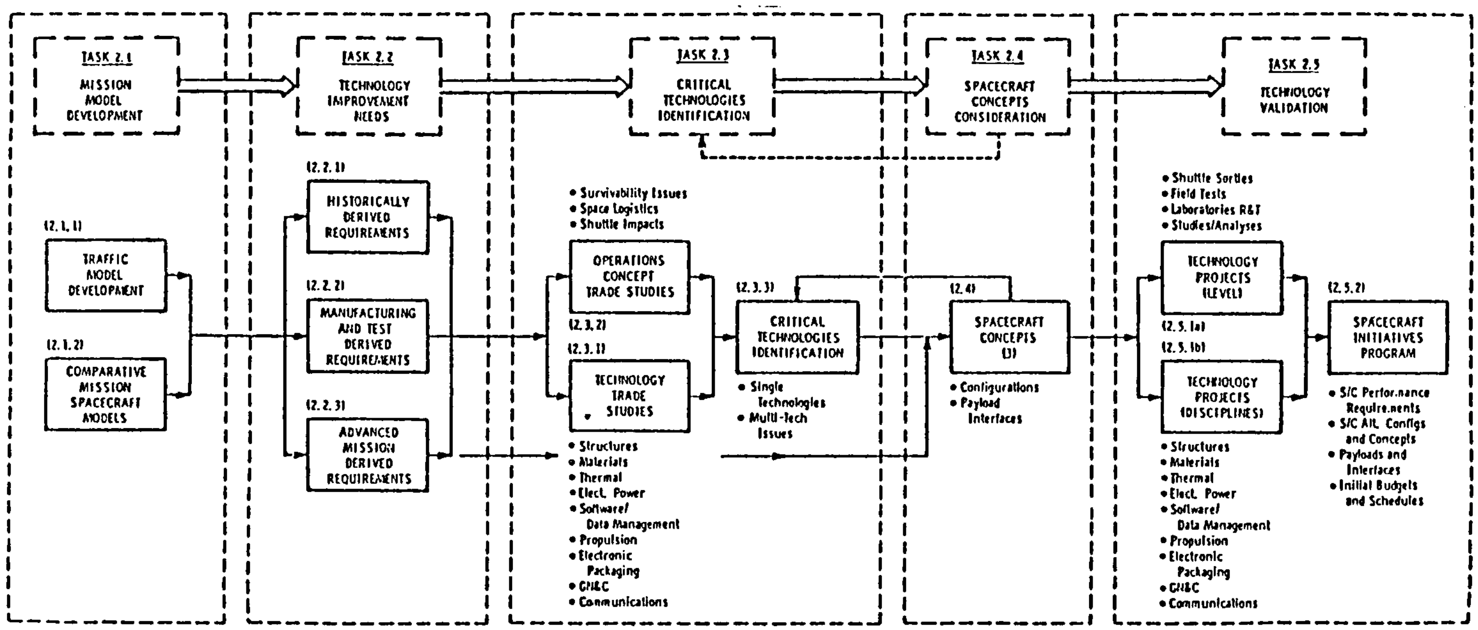


Figure 1. Project Flow Diagram

1.1 Mission Model Development:

An initial groundrule was that the study be directed not at the highly specialized, high technology payload spacecraft like a Mars orbiter or an astronomy satellite that get launched once each three or four years, but rather at the common work-a-day spacecraft that may be launched 15 to 20 times a year by government agencies, the military, or commercial enterprise. *Figure 3* develops the logic and assumptions used in selecting a proper traffic model for the study. *Figure 4* details the individual missions in the overall model and identifies those that apply to this study. The point is that the technology and spacecraft design issues addressed by this study have a new broad, significant and pertinent application to the future of the nation's unmanned spacecraft program.

1.2 Technology Improvement Needs:

The requirements for spacecraft technological advancement for the various spacecraft in that traffic model were then identified and described. It is significant to note that those requirements come from four sources, as depicted in *Figure 5;* these are (1) the

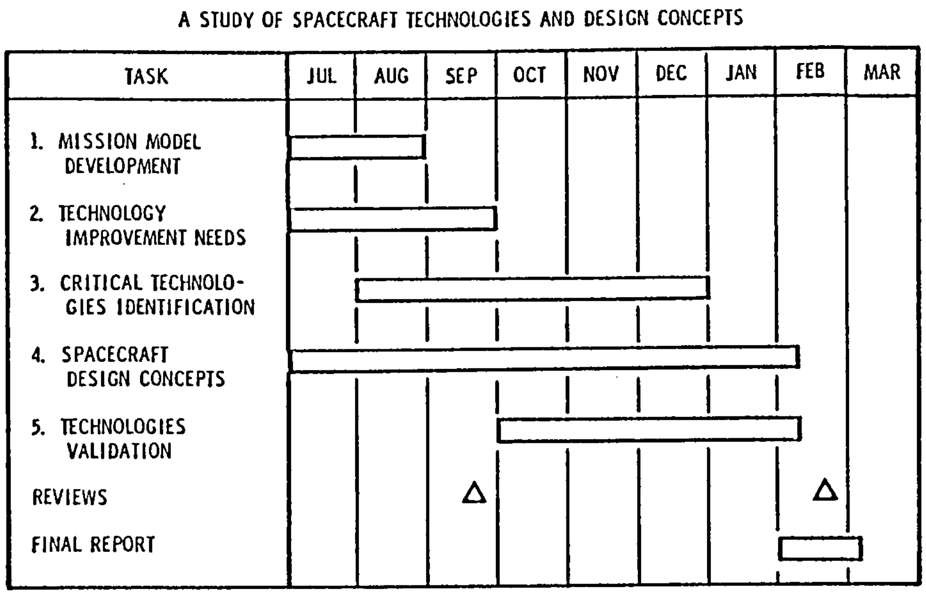


Figure 2. Schedule of Technical Activities

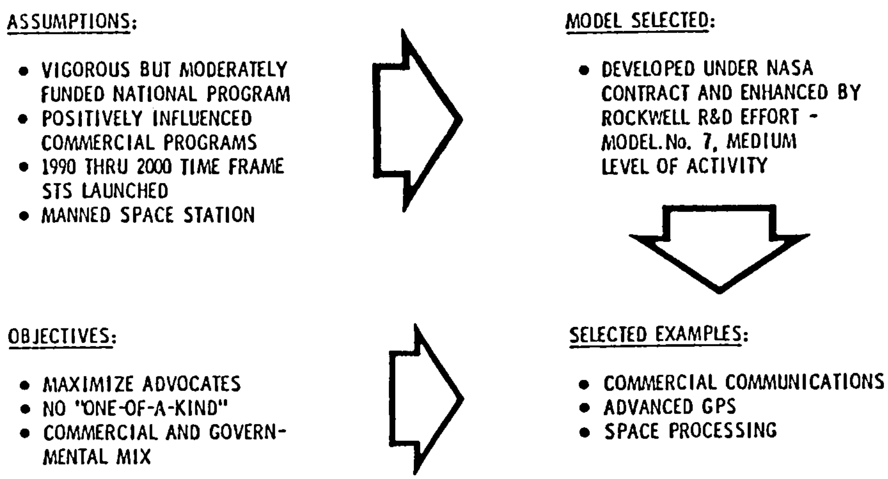


Figure 3. Mission Model Assumptions and Objectives

performance and cost history of past space satellite programs; (2) the experience gained in manufacturing and testing past spacecraft; (3) the effects that spacecraft subsystems have on each other (it is of interest to note that this source of requirements is perhaps one of the more significant, particularly when it takes a combination of technologies - e.g., thermal, structure, data management - to resolve our advanced spacecraft configuration issue); and (4) requirements imposed by the needs of an advanced mission itself.

Requirements based on the analysis of historical performance of current and past spacecraft lead to a conclusion that both costs and error-free performance require major improvement in any future spacecraft improvement program principally in the electronics disciplines, i.e., TT&C, GN&C, communications, attitude determination. Costs for these subsystems range from factors of two to ten higher than those for spacecraft structure, thermal control, interstages and propulsion. An examination of historical data reveals also that the major share of performance anomalies lie within the electronic as opposed to mechanical subsystems and subsystem elements. The lesson to be learned, then, is that if improvement in cost and performance levels is to be achieved, the improvement wants to be in the electronics spacecraft elements.

FREE FLYER TYPES	LAUNCH YEAR										TOTALS
	91	92	93	94	95	96	97	98	99	2000	
ASTRO AND SOLAR PHYSICS	2	1	2	1	1	1	2	1	0	0	11
SOLAR SYSTEM EXPLORATION	0	0	1	2	0	0	1	1	1	1	7
COMMERCIAL SPACE PROCESSING	3	2	2	2	2	1	2	1	2	2	19
COMMERCIAL COMMUNICATIONS	11	21	17	15	16	21	19	11	10	12	153
NASA LIFE SCIENCE	0	0	0	0	0	0	0	0	0	0	0
NASA SPACE PROCESSING	0	0	0	0	0	0	0	0	0	0	0
NASA COMMUNICATIONS	0	1	0	0	0	0	0	0	0	0	1
NASA RESOURCE OBSERVATIONS	1	0	0	0	0	0	0	0	0	0	1
COMMERCIAL RESOURCE OBSERVATIONS	1	2	0	1	1	2	2	1	1	0	11
NASA TECHNICAL DEVELOPMENT	1	0	1	1	0	0	1	2	3	1	10
NASA ENVIRONMENTAL SCIENCE	0	1	0	0	0	0	0	0	0	0	1
GOVERNMENT ENVIRON OBSERVAT	1	1	1	1	1	1	1	1	1	1	10
DOD	25	30	32	27	23	26	27	23	27	19	259
TOTALS	45	59	56	50	54	52	55	41	45	36	483

Figure 4. 483 Free Flyers Are Identified in the Model

The experience gained in the manufacturing and test process reveals a series of configuration sensitive drivers to spacecraft design. The more significant derived requirements are:

- The need for alternatives to a D.C. Bus and Multiple Converters which are notoriously failure prone and costly.
- Use of modularity, standardization and more stress testing to improve reliability rather than redundancy.

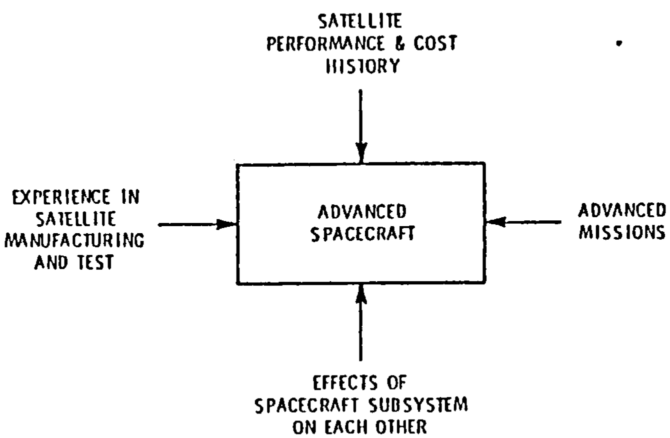


Figure 5. High Technology Spacecraft Sources of Requirements

- Reduction or elimination in the need for wire cable harnesses.
- Design or layout to improve access to spacecraft components for assembly, test, maintenance, or replacement.
- Expanded use of breadboards/brassboards testing prior to spacecraft integration.
- Improved plume impingement and contamination protection.
- Improved thermal control quality through the design and integration of structures and components.

- Improve flexibility of design in adapting to mission changes and reduction in the amount of cable harnesses by the application of distributed data processing, and high speed data bussing through the use of fibre optics.

The third major source of requirements for unmanned spacecraft design advancement is the analysis of the effects that changes in one spacecraft subsystem has on other subsystems. *Figure 6* is a simple depiction of that phenomena. It can be noted that structure, for example, is impacted by the characteristics and mission of the payload, the propulsion subsystem, thermal control and electrical power. Any change in one of these impacts structural design. It will be noted later in this document that vehicle structural change is, in fact, heavily impacted when advances are proposed in thermal management and the packaging of electronics.

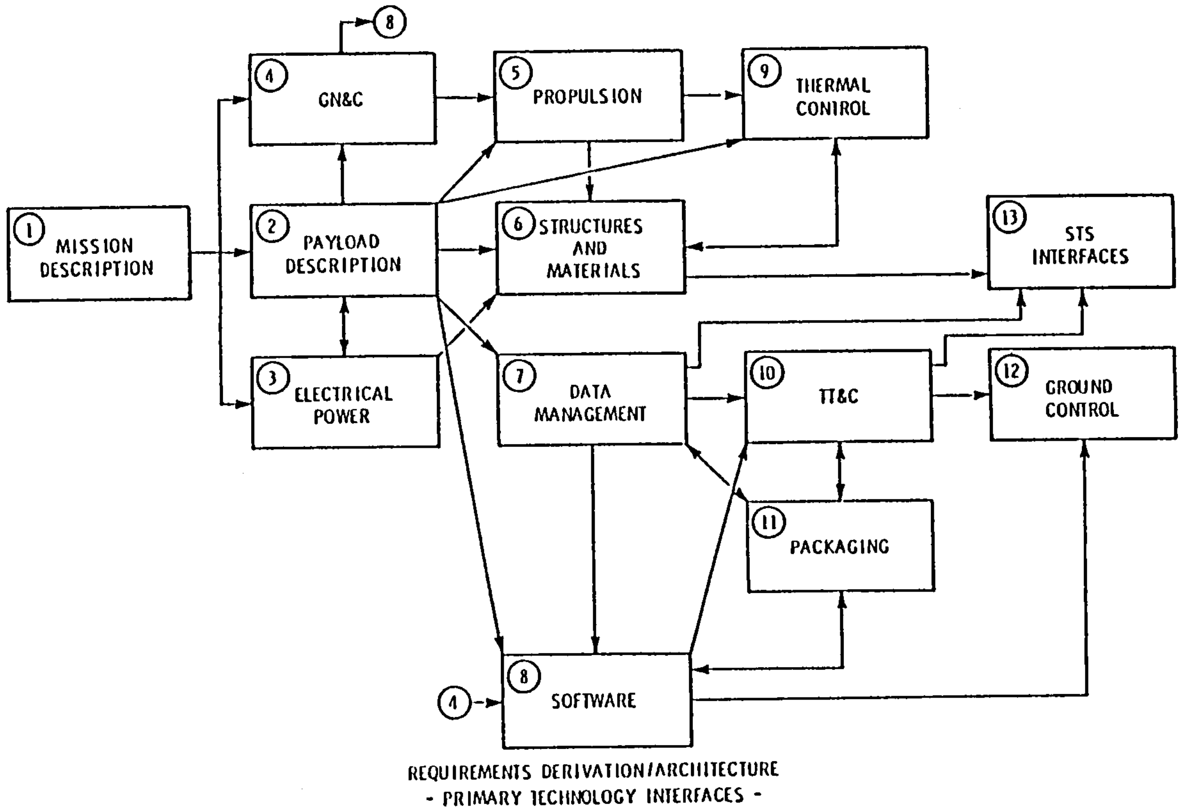


Figure 6. Spacecraft Subsystem Requirements Architecture

Finally, requirements of spacecraft design improvement are also derived from the characteristics of the mission to be performed. Earlier in Task 1 we selected a trio of advanced missions which were to be used as examples of our advanced technology development programs. One of these was a LEO-based Space Processing Satellite with the characteristics shown on *Figure 7*. Spacecraft requirements are derived from the need to support that payload.

SPACE PROCESSING PAYLOAD DESCRIPTION

- SATELLITE PRIMARY COMPONENTS - BUS AND CFES
  - BUS WEIGHT - 14,000 LBS
  - BUS POWER - 2.5 kW DAY/NIGHT CONTINUOUS
  - CFES WEIGHT - 11,000 LBS
    - PLANT WEIGHT - 6,000 LBS
    - CANISTER WEIGHT - 5,000 LBS
  - CFES POWER - 3.5 kW DAY/NIGHT CONTINUOUS
  - CFES DIMS - 15 FT DIA BY 10 FT LENGTH CYLINDER
- SATELLITE WEIGHT - 25,000 LBS
- SATELLITE POWER - 6 kW
  RESERVE POWER - 150 AMP-HR BATTERIES
- DATA STORAGE - TWO TAPE RECORDERS
- COMMUNICATIONS - 22½ MIN SINGLE ACCESS AND 45 MIN (3 AT 15 MIN) MULTIPLE ACCESS TO TDRSS
- ANTENNA - HIGH GAIN STEERABLE
- PROPELLANT - PLACE ON ORBIT AND LOWER TO STS
- SERVICING - CANISTER REPLACEMENT EVERY SIX MONTHS BY STS
- TEMPERATURE CONTROL - CFES AND CANISTER $< 300^{o}K$
- CFES VENTING - 300 LBS WATER OVER SIX MONTHS
- ATTITUDE CONTROL - BETTER THAN 10^{-3} G's IN 3 AXIS

Figure 7. Projected Space Processing Satellite Payload

1.3 Critical Technologies/1.4 Spacecraft Configuration Concepts:

Figure 8 outlines the process followed in identifying the technologies that might be critical to the development of a high-technology approach to unmanned spacecraft conceptual design, and preparing a technology program that would resolve technology deficiencies. That process consists of the following:

- Define each subsystem in terms of its components or assemblies;

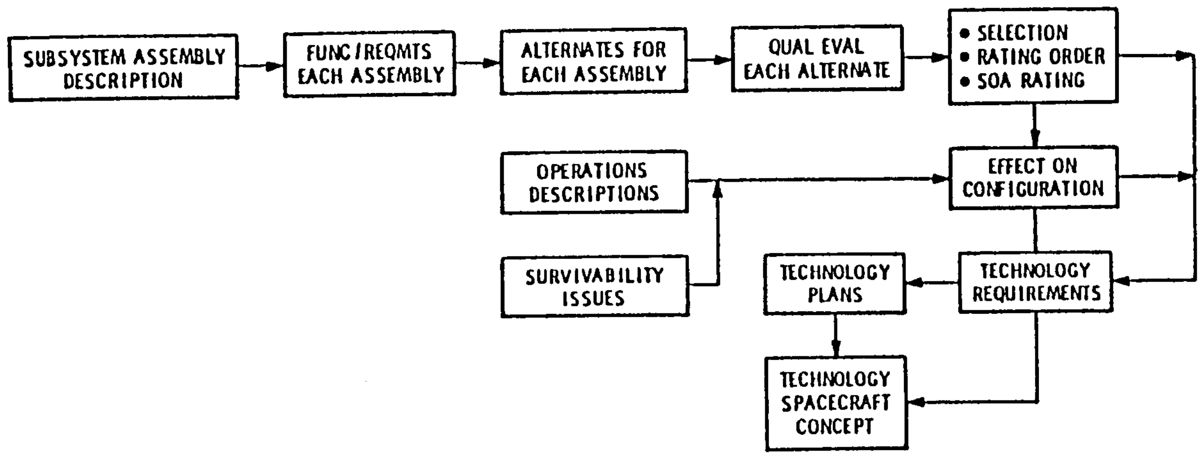


Figure 8. Phase II Study Flow

- Describe the functions and requirements associated with each of the assemblies;
- Describe alternates for each assembly;
- Carry out a qualitative evaluation of each alternate;
- Select an optimum alternate for each assembly;
- Define the effect of the chosen alternate on the spacecraft configuration;
- Identify the technology deficiency that must be corrected;
- Develop a technology plan that will resolve the deficiency.

In the course of the study, it became evident that the strongest requirements and drivers for an advanced spacecraft design concept were the following:

- A layout/configuration that would permit easy accessibility to all the spacecraft's components and subsystems;
- Elimination of the need for cables and cable harnesses;
- Reduction in the number of dedicated, customized electronic black boxes and consequent standardization of spacecraft elements and their interfaces;

- Use of a distributed/digital data management concept, using a high speed data processing architecture;

- A thermal management concept that integrates structure, thermal control and electronic packaging into a single combined unit.

It is pertinent, therefore, to examine the subsystems and technologies that were the most pertinent to those requirements. Two examples follow:

Example A: <u>Thermal Control Subsystems</u>

Subsystem Element		Selected Alternate
- Heat Transport	-	- Capillary Pump Loop
- Heat Rejection	-	- Condensing Heat Pipe
- Heat Collection	-	- Evaporative Cold Plate
- Temperature Control	-	- Capillary Pump Loop Variable Heat
- Heat Storage	-	- In-Line Flow

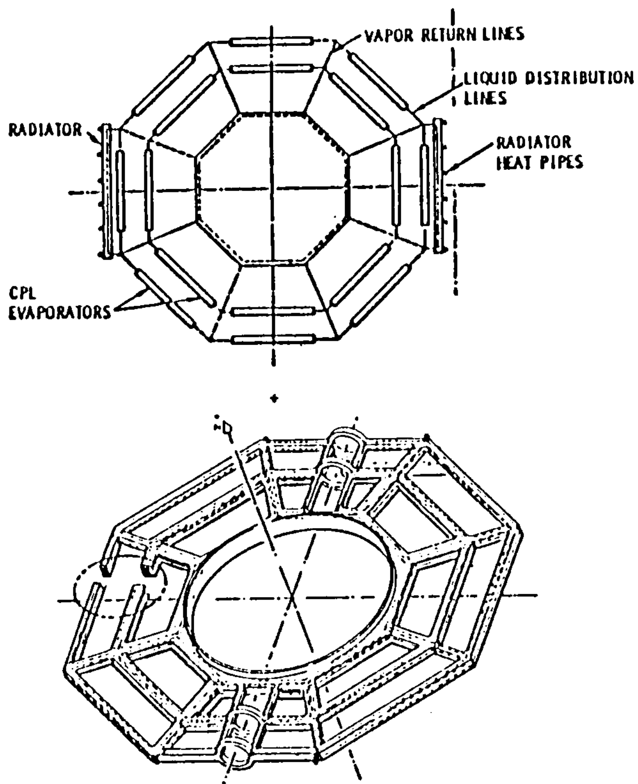
As discussed earlier, each subsystem was reduced to its principal assemblies, and then a selection made from among possible alternates to fulfill that assembly's function. Thus, in an example drawn from the above, a Capillary Pump Loop approach was the selection to fulfill the heat transport function of the Thermal Control subsystem. For that to be successfully accomplished, however, a technology project to develop a Capillary Pump Loop process that is integrated into the spacecraft's structure will be required. *Figure 9* provides a schematic and a pictorial of the capillary pump loop concept integrated into the basic spacecraft structure, and also outlines the technology project aimed at the concept's development. The total technology development program for thermal control, derived from implementing the alternate selections identified above, consists of projects to develop:

1. The integration of the Capillary Pump Loop (CPL) concept into the spacecraft's structure.

2. The development of a CPL Condenser/Radiator.

3. The design of a CPL Evaporator.

4. The integration of avionics packages into the thermal control/structure assembly.



PROBLEM

- LONG-LIFE THERMAL MANAGEMENT SYSTEM REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- TO DEVELOP AN INTEGRATED STRUCTURE/CPL LINES FOR A 12 kW-m CAPILLARY PUMPED LOOP (CPL) TRANSPORT SYSTEM

APPROACH

- COMPONENT DEVELOPMENT
- CONDUCT CPL INTEGRATION STUDY
- DEVELOP AND TEST SIMULATED SYSTEM, BREADBOARD
- PROVE 0-G FEASIBILITY WITH FLIGHT EXPERIMENT

EXPECTED RESULTS

- QUALIFIED CPL HARDWARE FOR SPACECRAFT APPLICATION

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR GROUND TEST
- SHUTTLE TEST FLIGHT

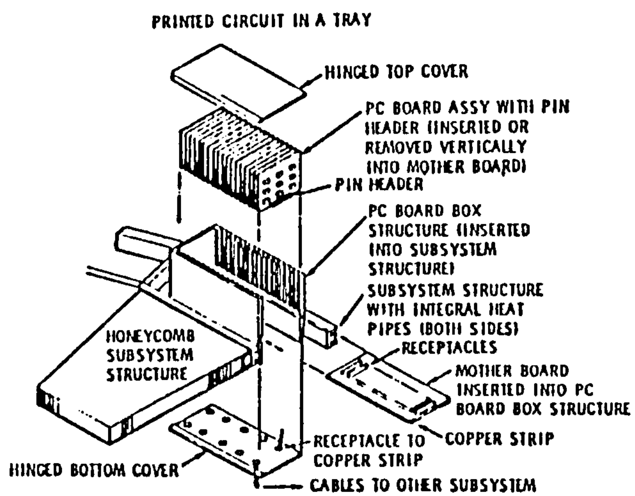
RELATED TECHNOLOGY

- STRUCTURE
- ELECTRONIC PACKAGING

Figure 9. Capillary Pumped Loop System Integrated CPL Lines/Structure

5. Development of improved modular insulation.

The fourth of the above technology advancement issues introduced yet another development discipline that interfaces with the thermal and structural subsystems, that is, electronics packaging and design. *Figure 10* depicts the problem to be resolved, i.e., conversion of electronic black boxes to PC boards, and inclusion of those heat generating elements into the structural/thermal subsystem. A further interface is discussed later in this report, i.e., with the Data Management System and potential for reducing the need for costly, dedicated electronic hardware. *Figure 11* illustrates the overall thermal control/structure/electronic package interface.



PROBLEM

- THERMAL CONTROL IS REQUIRED FOR ENHANCEMENT OF AVIONIC PACKAGE RELIABILITY

OBJECTIVE

- TO DEVELOP AN INTEGRATED THERMAL CONTROL/ PACKAGING SYSTEM FOR AVIONICS

APPROACH

- GENERATE DESIGN CONCEPTS AND CONDUCT TRADES
- DEVELOP HARDWARE BREADBOARD
- CONDUCT THERMAL-VACUUM TESTS
- DEVELOP AND QUALIFY INTEGRATED AVIONICS PACKAGE

EXPECTED RESULTS

- A QUALIFIED AVIONICS PACKAGE WITH AN INTEGRAL THERMAL CONTROL SYSTEM

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR FULL-UP GROUND TEST
- SHUTTLE TEST FLIGHT

RELATED TECHNOLOGY

- STRUCTURE
- ELECTRONIC PACKAGING

Figure 10. Thermal Technology Integrated TCS/Avionics Package

Example B: Data Management Subsystem

Subsystem Element		Selected Alternate
- Processors	-	- General Purpose
- Storage	-	- Optical
- Cables/Connectors	-	- Fibre-Optic
- Interfaces	-	- Blu-VHSIC
- Organization	-	- Distributed Resources Control
- Languages	-	- High Order
- Processing	-	- Plesiosynchronous
- Architecture	-	- Standard/Functional

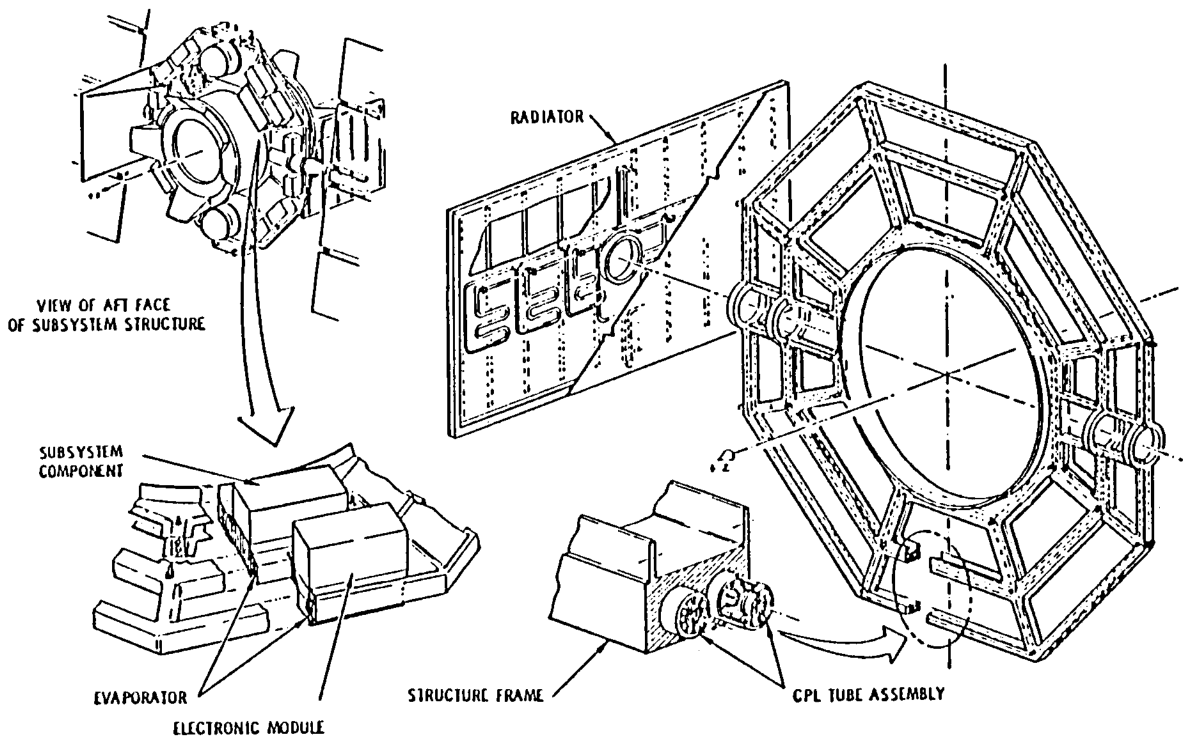
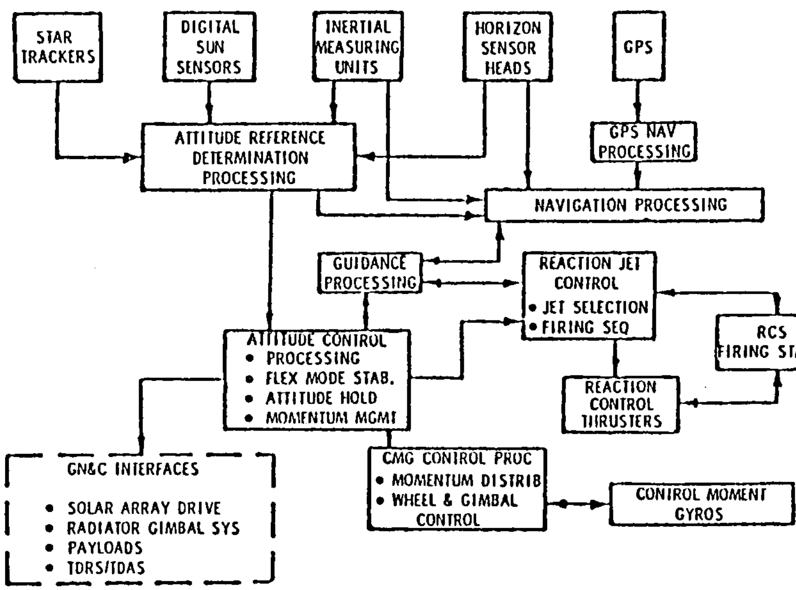


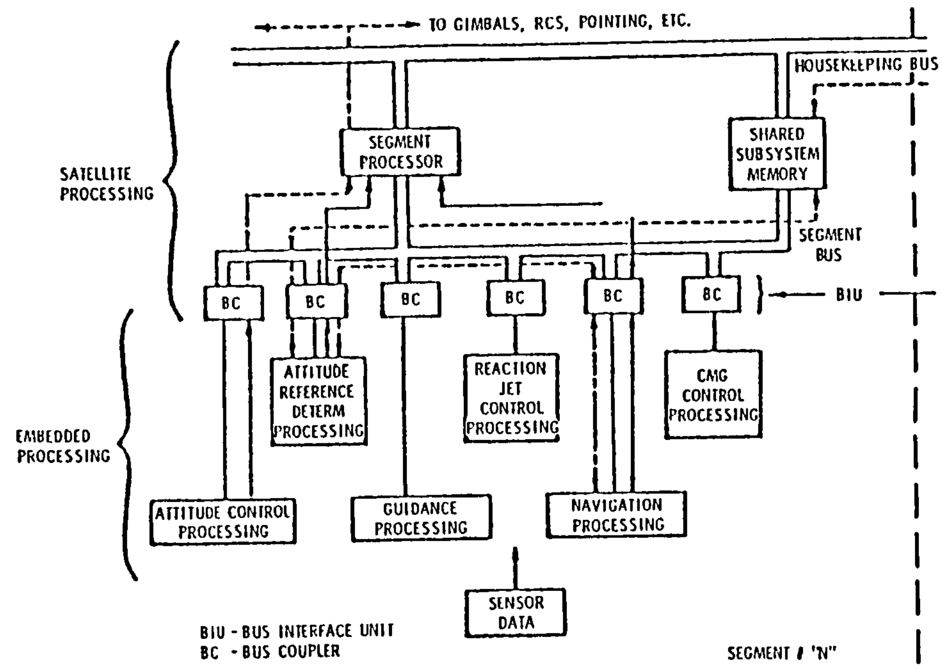
Figure 11. Thermal Management System
Capillary Pumped Loop System Integrated Into Structure

As in the discussion of a Thermal Control subsystem above, the Data Management Subsystem was reduced to its principal assemblies, and then selections made from among the alternatives to fulfill each assembly's functions. A major technology activity involves developing the architecture of the improved Data Management Subsystem. A schematic comparison of current functionally dedicated central controls, and a proposed distributed control involving local or distributed digital data processing is shown in *Figure 12* . Details of the differences between the two are discussed later in the body of this report. It's sufficient here to summarize that the advanced process results resulted in a reduction of dedicated electronic hardware, the virtual elimination of cable harnesses and the increased use of common, modular, fault tolerant components and interfaces.

SUBSYSTEM: ARCHITECTURE



FUNCTIONALLY DEDICATED, CENTRAL CONTROL



LOCAL PROCESSING, DISTRIBUTED CONTROL

Figure 12. Technology Project Plan

Figure 13 depicts the overall resulting spacecraft design concept for data management, including the basic spacecraft structure, electronic modules, fibre-optics high speed data bus, BIU cables and the like. *Figure 14* provides somewhat more detail in pictorializing the spacecraft's data management oriented subsystems.

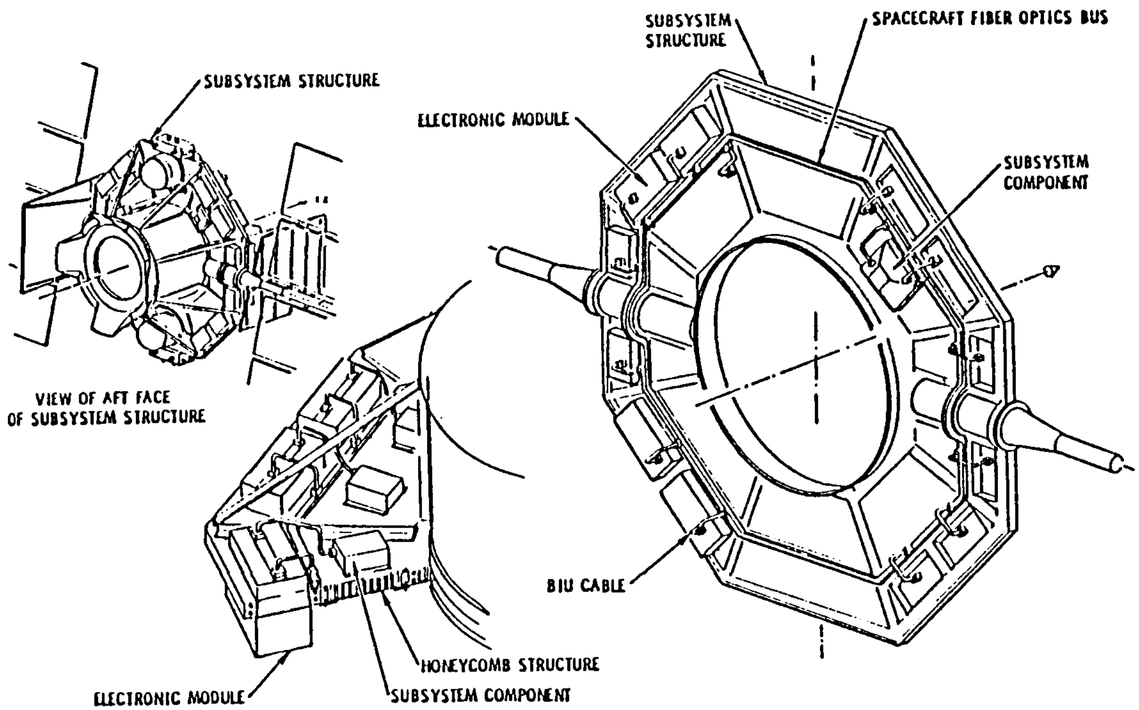


Figure 13. Spacecraft Fiber Optics Bus Interface with Electronics Modules and Subsystem Components

The Requirements/Alternatives selection/Technology planning/configuration effects process described in the two examples above were carried out for all of the Technology/ Subsystems pertinent to Advanced Spacecraft design issues. These were:

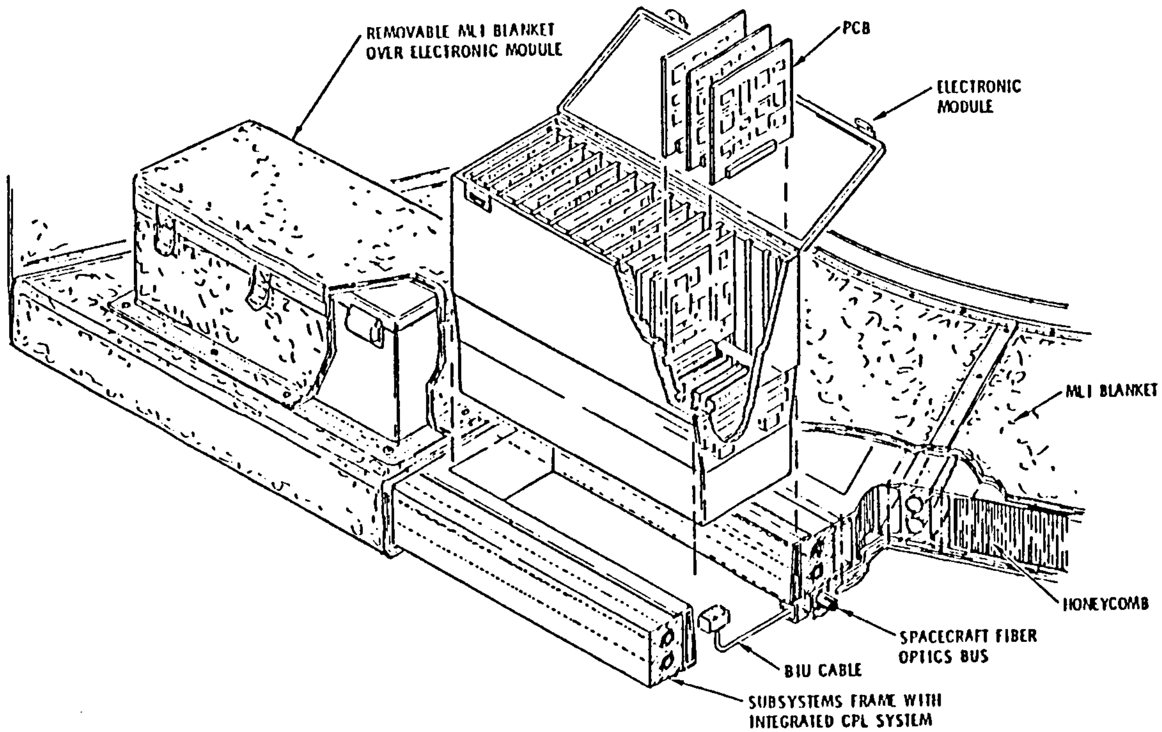


Figure 14. Integration of Data Management System with Thermal and Structural Systems

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- Structure and Materials
- Electrical Power
- Thermal Control
- Data Management
- Guidance/Navigation/Control
- Propulsion
- Communications
- Operations
- Vulnerability/Survivability

Again, the end products of the study were the spacecraft configuration concept; the technology issues pertinent to its development; plans, budgets, and schedules for technology advancement projects, and finally a concept for a High-Technology Spacecraft Initiatives program directed at an orbital test bed with and on which to test and space-qualify the advanced concepts identified in this study. Some of the principal characteristics of the spacecraft introduced by this study include

- An open structure concept
- A thermal management concept based on the use of advanced heat pipes
- An integrated thermal, structural, and electronics packaging combination
- A distributed/digital approach to data management
- The development and utilization of a high-speed data processing architecture
- A reduction of dedicated, customized electronic black boxes
- A standardization concept for spacecraft elements and their interfaces.

Figure 15 is an artist's concept of that Initiatives Spacecraft, appearing much as the spacecraft evolved in the course of the study.

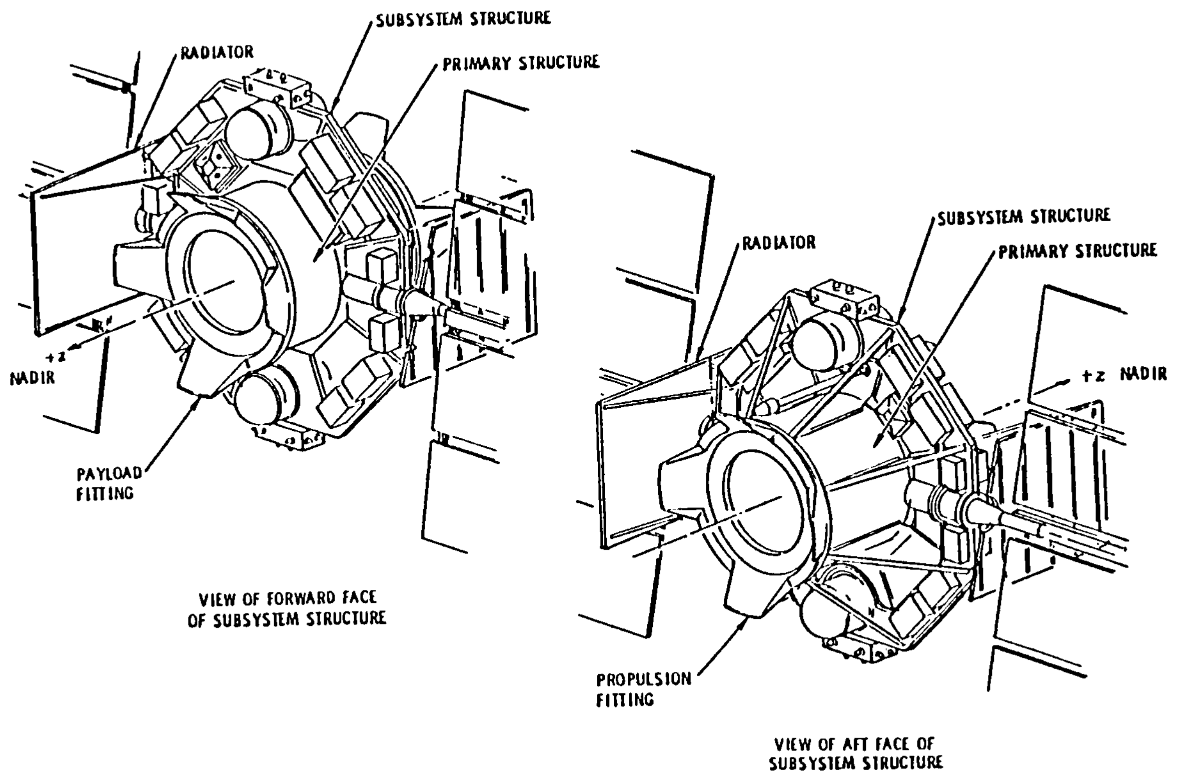

Figure 15. Test Spacecraft

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2. MISSION AND REQUIREMENTS ANALYSIS

A Study of Spacecraft Technology and Design Concepts

Guidelines and Objectives

The primary objective of this study was to develop design concepts for unmanned spacecraft of the 1990's, based on selected advances in technology and the State of the Art. This objective is arrived at in recognition of the fact that there has been no significant change or improvement in unmanned spacecraft conceptual design in the past 10 to 15 years.

The guidelines that bracket the study, then, are as shown opposite. The first is meant to ascertain that the study is directed at the high traffic, production rate families of missions that constitute the bulk of our satellite traffic - as opposed to those highly specialized missions that are carried out with a mission every year or two, or three or more. At the other extreme, the study should avoid resulting in another typical multi-mission spacecraft - tried as many times before.

It should also be noted that, where necessary, spacecraft advanced technology may have to be leap-frogged in order to satisfy a technological requirement.

GUIDELINES/OBJECTIVES

- INTRODUCE NEW UNMANNED SPACECRAFT DESIGN CONCEPTS FOR THE ROUTINE, WORKING SATELLITE
- DO WHAT SPACECRAFT PROJECT OFFICES CAN'T DO UNPRESSURED BY SPACECRAFT PROJECT OBJECTIVES
- NOT A NEW MULTI-MISSION SPACECRAFT, BUT RATHER A SELECTED/INTEGRATED APPLICATION OF ADVANCED SPACECRAFT TECHNOLOGY
- LEAP-FROG THE SPACECRAFT TECHNOLOGY STATE OF THE ART

Study Structure

The study was carried out in two phases. The first phase was dedicated to the development of requirements that would drive the new satellite design architecture toward the use of advanced technology. These requirements find their source in any of the four areas listed opposite. Also, a mission model was developed in order to get some appreciation of the traffic/mission pattern to which the new design concepts could be applicable. These are discussed further on pages 31 and 32.

Phase II concentrated on the identification and development of technology program plans for the more critical technology issues to be resolved in developing any advanced design concept. This was done in close interplay with spacecraft configuration studies that were the measure of effect of a new technology on spacecraft design. This was done on all the technology areas listed in the center box, and applied to the 3 mission applications shown.

Finally, an initial spacecraft initiatives plan was developed, including some suggestions, for immediate FY 1986/87 implementation.

Although Phase I was separately reported in September, 1984, it will be summarized here briefly in order to better understand many of the elements of Phase II of the study.

A STUDY OF SPACECRAFT TECHNOLOGY & DESIGN CONCEPTS

PHASE - I, REQUIREMENTS

PHASE - II, PROGRAMS DEVELOPMENT

MISSION MODELS

- COMMERCIAL COMSAT
- ADVANCED GPS
- IN-SPACE PROCESSING

REQUIREMENTS

- PERFORMANCE & COST HISTORY
- ADVANCED MISSIONS
- MANUF'G & TEST HISTORY
- SUBSYSTEMS INTERACTIONS

(REPORTED SEP'84)

- STRUCTURES & MATERIALS
- THERMAL MANAGEMENT
- PROPULSION
- ELECTRICAL POWER
- COMMUNICATIONS
- GUIDANCE, NAVIGATION, CONTROL
- DATA MANAGEMENT
- OPERATIONS
- RADIATION & VULNERABILITY

- TECHNOLOGY ADVANCEM'T PROJECTS
- SPACECRAFT CONFIGURATION
- CONFIGURATION APPLICATIONS
  - COMMERCIAL COMSAT
  - ADV. GPS
  - IN-SPACE MAT'LS PROCESSING
- INITIATIVES SPACECRAFT

(REPORTED FEB'85)

Traffic Model

The chart opposite summarizes the traffic model development and analysis effort that was carried out. The model is based on one developed under NASA contract and enhanced by Rockwell R&D - and known as NASA/STA Model 7, medium level of activity. It's considered to be a vigorous, but moderate funded national program, resulting in 483 unmanned spacecraft launches in the 10 year period starting in 1991, with some 212 being in the nature of the high production rate spacecraft earlier mentioned in our guidelines.

MISSION TYPES	NO. FREE FLYERS
NASA SCIENCE - (6%)	31
DOD - (54%)	259
NAVIGATION TYPES - (8%)*	40
OTHER GOVERNMENTAL - (2%)	10
COMMERCIAL - U.S. & FOREIGN - (38%)	183
COMMUNICATIONS - (32%)*	153
SPACE PROCESSING - (4%)*	19
RESOURCES OBSERVATION - (2%)	11
TOTAL MISSION SPACECRAFT IN THE TRAFFIC MODEL	483
*TOTAL NUMBER OF SELECTED MISSION SPACECRAFT (44%)	212

Air Force Space Division

Unmanned Spacecraft Cost Model - June 1981

The chart opposite is derived from a cost model developed by USAF, summarizing non-recurring and first unit cost of some 35 unmanned spacecraft programs.

It should be noted that in all cases the higher costs are incurred for electronic and sensor type components and subsystems in terms of tens and hundreds of thousands of dollars per pound of hardware delivered. Costs associated with structure, thermal, propulsion, and physical interface hardware are all factors of 5 to 10 lower.

The requirement derived from these facts is clear: any new spacecraft design concept should work at lowering the requirement for mission dedicated and mission peculiar electronic hardware and at substituting an approach less dependent on the concept of mission dedicated electronic equipment.

AIR FORCE SPACE DIVISION
UNMANNED SPACECRAFT COST MODEL - JUNE 1981

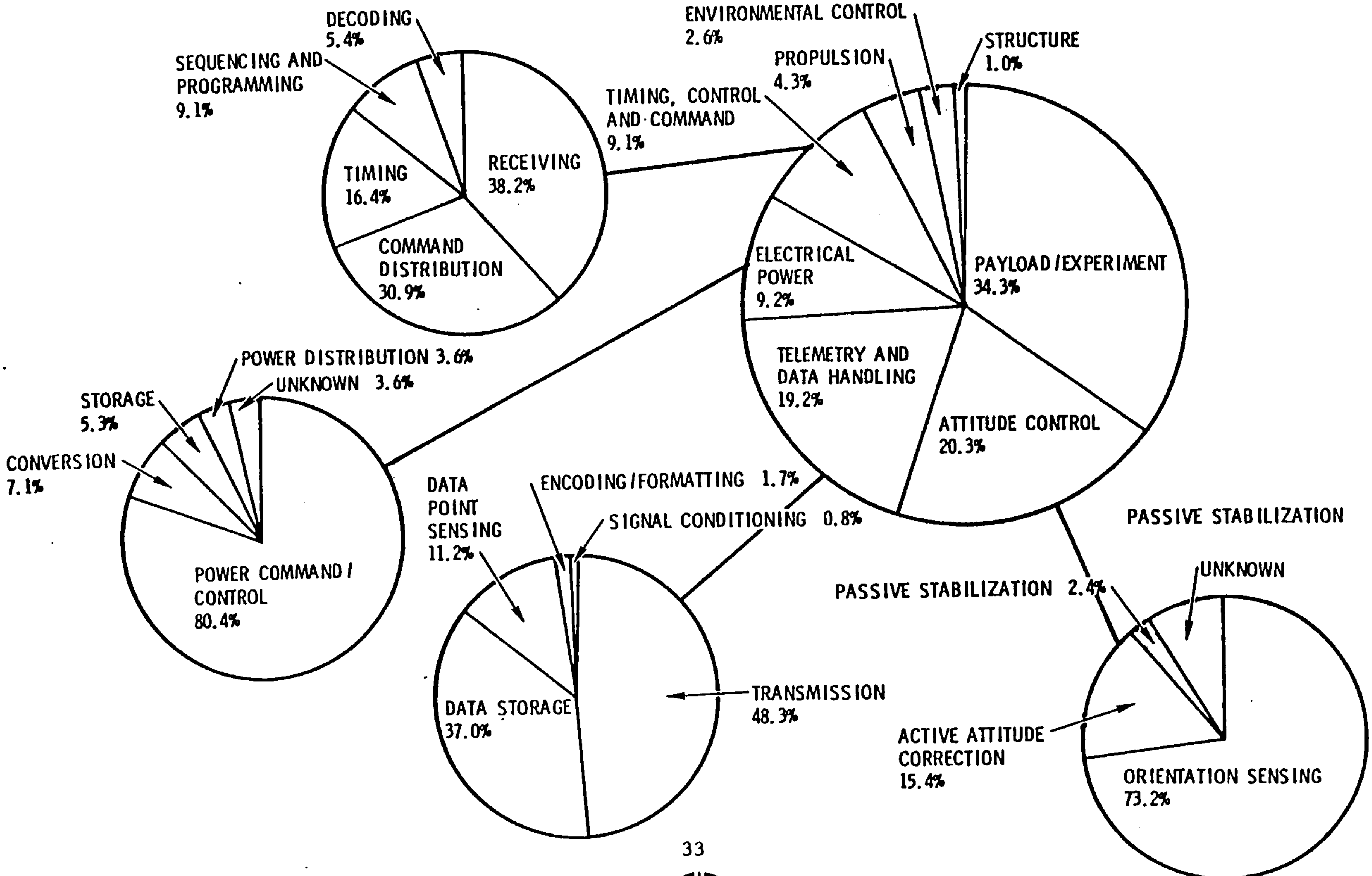
CATEGORY	NONRECURRING COST			FIRST UNIT COST		
	COST DRIVER	COST	RATE	COST DRIVER	COST	RATE
1. STRUCTURE, THERMAL CONTROL & INTERSTAGE	478.6 LB	$7.835 M	16.4 $K/LB	862.7 LB	$1.914 M	2.2 $K/LB
2. TT&C	127.5 LB	$6.141 M	48.2 $K/LB	127.5 LB	$3.304 M	25.9 $K/LB
3. COMM (PAYLOAD) - TOTAL	260.3 LB	$12.721 M	48.9 $K/LB	260.3 LB	$6.310 M	24.2 $K/LB
4. COMM ANTENNAS	96.4 LB	$4.303 M	44.6 $K/LB	96.4 LB	$0.986 M	10.2 $K/LB
5. COMM ELECTRONICS	172.8 LB	$8.876 M	51.4 $K/LB	185.9 LB	$6.904 M	37.1 $K/LB
6. COMBINED COMM & TT&C	319.3 LB	$17.153 M	53.7 $K/LB	319.3 LB	$8.179 M	26.6 $K/LB
7. ATTITUDE CONTROL - TOTAL	155.6 LB	$12.248 M	78.7 $K/LB	155.6 LB	$3.516 M	22.6 $K/LB
8. ATTITUDE DETERMINATION	76.8 LB	$9.221 M	120.1 $K/LB	70.9 LB	$2.639 M	37.2 $K/LB
9. ATTITUDE & REACTION CONTROL	97.4 LB	$3.492 M	35.9 $K/LB	193.5 LB	$2.069 M	10.7 $K/LB
10. ELECTRICAL - SUBSYNC	184,700 LB-WATT (396.6 LB)	$3.408 M	18.5 $/LB-WATT (8.6 $K/LB)	184,700 LB-WATT (396.6 LB)	$3.021 M	16.4 $/LB-WATT (7.6 $K/LB)
11. ELECTRICAL - SYNC 7 ABOVE	456,500 LB-WATT (314.4 LB)	$9.506 M	20.8 $/LB-WATT (30.2 $K/LB)	456,500 LB-WATT (314.4 LB)	$2.909 M	6.4 $/LB-WATT (9.3 $K/LB)
12. APOGEE KICK MOTOR 1-AXIS STABILIZED (TOTAL IMPULSE)	227,400 LB-SEC	$2.668 M	11.7 $/LB-SEC	71.2 LB DRY WT	$0.321 M	4.5 $K/LB
13. APOGEE KICK MOTOR 3-AXIS STABILIZED (TOTAL IMPULSE)	273,000 LB-SEC	$0.883 M	3.2 $/LB-SEC	294,400 LB-SEC	$0.311 M	1.1 $/LB-SEC
14. PLATFORM (TOTAL DRY WT W/O MISSION EQUIPMENT)	1,015 LB	$30.363 M	29.9 $K/LB	1,389 LB	$12.184 M	8.8 $K/LB
15. PROGRAM LEVEL - AS FUNCTION OF PLATFORM	$44.430 M NR COST	$20.616 M	0.464 $/$	$9.879 M FU COST	$4.513 M	0.457 $/$
16. PROGRAM LEVEL - COMSATS	$64.393 M NR COST	$22.976 M	0.357 $/$	$20.716 M FU COST	$6.818 M	0.329 $/$
17. DISPENSER	$139.7 LB	$1.265 M	9.1 $K/LB	139.7 LB	$0.197 M	1.4 $K/LB
18. AERSPACE GROUND EQUIPMENT	$66.049 K NR + FU	$7.470 M	0.113 $/$	--	--	--
19. LAUNCH OPS/ORBITAL SUPPORT WITH APOGEE KICK MOTOR	--	--	--	2,090 LB SAT NET WT	$0.653 M	0.312 $K/LB
20. LAUNCH OPS/ORBITAL SUPPORT W/O APOGEE KICK MOTOR	--	--	--	1,744 LB SAT NET WT	0.908 M	0.521 $K/LB

All Subsystem Anomalies

The chart opposite summarizes the results of a study performed by P.R.C. for the NASA to define the pattern of spacecraft performance failures and performance anomalies in flight. Some 306 spacecraft flights and 606 anomalies were examined. It again might be noted that the predominant number of anomalies were in the payloads and the electronic elements.

But the full story is somewhat more complex. Example: although anomalies in the environmental control subsystem account for only 2.6% of the incidents, that subsystem represents one of the more difficult to get through system integration and test in the development laboratories. The total requirement, then, for thermal management wants greater simplification of that subsystem, not so much to achieve higher error free flight performance ratings as to achieve simplification in development.

ALL SUBSYSTEM ANOMALIES



History Based Requirements

Page 8 and 9 showed the four sources of requirements for setting the architecture and configurations of new approaches to the design of unmanned spacecraft.

It is perhaps interesting to note that the more forceful drivers toward design change were not the anticipated refinement and increases in performance levels of spacecraft subsystems, but rather those requirements derived from our past cost and performance history; from our experience in manufacturing and test; and from observation of ineffective test and development processes brought about by having to live with an inadequate level of a technology State of the art.

Some of these more general requirement drivers are noted on pages 38, 39 and 40.

HISTORY BASED REQUIREMENTS

- DEVELOP ALTERNATIVES TO DC BUS AND MULTIPLE CONVERTERS WHICH ARE PRESENTLY LOW RELIABILITY, FAILURE PRONE, AND COSTLY, AND DEMONSTRATE DIFFICULTY IN SWITCHING AND PROTECTION
- USE MODULARITY AND STANDARDIZATION METHODS TO INCREASE RELIABILITY AND LOWER COSTS.
- INITIATE USE ANALYSIS EARLIER IN THE GN&C DEVELOPMENT CYCLE TO WRING OUT DESIGN PROBLEMS. PROVIDE CONTINGENCY PADS IN CAPABILITIES OF MAGNETS, WHEELS, AND COMPUTER.
- DEVELOP ROTATING JOINT HEAT PIPES OR FLUID LOOPS; FULFILL NEED FOR CAPILLARY PUMP LOOP HEAT TRANSPORT.
- INCREASE RELIABILITY BY COMPONENT IMPROVEMENT, INCLUDING MORE STRESS TESTING, NOT BY REDUNDANCY.
- DEVELOP HIGH TEMPERATURE SERVICEABLE GN&C SENSORS AND TT&C ANTENNAS.

MANUFACTURING AND TEST BASED REQUIREMENTS

- STANDARDIZE CIRCUITS, BOARDS, LINKS, AND INTERFACES.
- EXPAND GN&C SUBSYSTEM BREADBOARD/BRASSBOARD TESTING PRIOR TO SPACECRAFT INTEGRATION. USE NONCLEAN ROOM ENGINEERING UNITS. CONCENTRATE TESTS ON INTERFACE COMPATIBILITY. PERFORM SIMULTANEOUS SPACECRAFT FIT CHECKS USING MOCK-UP EQUIPMENT.
- DEVELOP EASIER HANDLING METHODS TO MAINTAIN CLEANLINESS OF MIRRORED SURFACES SUCH AS THERMAL RADIATORS.
- SIMPLIFY THERMAL CONTROL SYSTEM (TCS) CONFIGURATION FOR TESTING AND SERVICING; PROVIDE EASIER COMPONENT AND TEST CONNECTION ACCESS.
- REDUCE OR ELIMINATE THE NEED FOR WIRE CABLE HARNESSES.
- DESIGN TO SIMPLIFY ACCESS TO SPACECRAFT COMPONENTS FOR ASSEMBLY, TEST, MAINTENANCE, AND REPLACEMENT IN THE FACTORY, IN THE SHUTTLE, OR ON ORBIT.

GENERAL REQUIREMENTS

- IMPROVE PLUME IMPINGEMENT AND CONTAMINATION PROTECTION.
- MAINTAIN SURVIVABLE HIGH TEMPERATURE MATERIALS AND SENSORS.
- MINIMIZE LAUNCH VEHICLE COUPLING THROUGH STRUCTURAL STIFFNESS TECHNIQUES TO SURVIVE MAJOR LOAD EVENTS.
- DEVELOP VIBRO-ACOUSTIC CONTROL FOR ELECTRICAL COMPONENTS.
- DEVELOP AND SELECT POWER SUPPLIES WITH MINIMUM HEAT DISSIPATION.
- ESTABLISH THERMAL QUALITY THROUGH DESIGN AND INTEGRATION OF STRUCTURES AND COMPONENTS.
- INTERFACE DIRECTLY ALL SUBSYSTEMS WITH TT&C, DMS, & ELECTRICAL POWER SYSTEM (EPS).
- REDUCE COMMUNICATIONS DATA RATES BY TRANSMITTING MALFUNCTIONS AND CHANGES ONLY.
- PROVIDE FLEXIBILITY TO MEET FUTURE RECONFIGURATION MISSION OBJECTIVES BY DISTRIBUTIVE PROCESSING.
- REDUCE COMPLEXITIES BY DESIGNATION OF SUBSYSTEM RESPONSIBILITY FOR BOTH SOFTWARE AND HARDWARE.
- DEVELOP NETWORKING METHODS FOR REAL-TIME FAULT CORRECTION AND AUTOMATIC RECONFIGURATION.

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SPACECRAFT CONFIGURATION CONCEPTS

Principal Characteristics

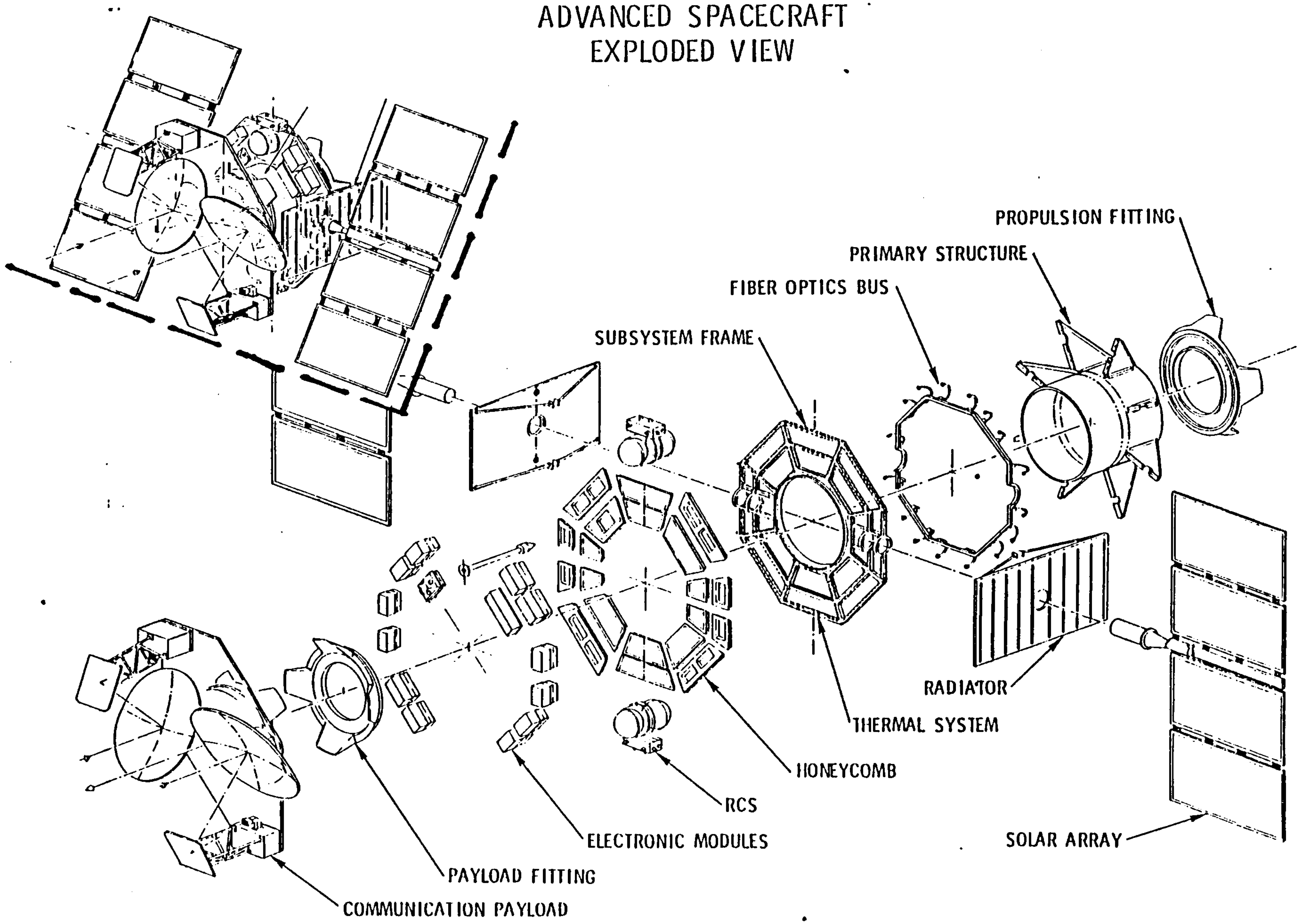
The next section of this report is dedicated to providing an advanced view of the spacecraft concept that resulted from this study. This is being done in order to be able to more completely understand the rationale behind the selection of an individual technology or subsystem elements that constitute the final spacecraft configuration concept. In the study, technology advancement needs and spacecraft configuration concepts proceeded hand-in-hand through the selection process. The chart opposite lists a few of the more critical and perhaps significant spacecraft/technology choices made.

PRINCIPAL CHARACTERISTICS

- OPEN STRUCTURE CONCEPT
- THERMAL MANAGEMENT CONCEPT BASED ON THE USE OF ADVANCED HEAT PIPES
- INTEGRATED THERMAL, STRUCTURE, AND ELECTRONIC PACKAGING
- DISTRIBUTED/DIGITAL DATA MANAGEMENT
- DEVELOPMENT AND UTILIZATION OF A HIGH-SPEED DATA PROCESSING ARCHITECTURE
- REDUCTION OF DEDICATED, CUSTOMIZED ELECTRONIC BLACK BOXES
- STANDARDIZATION OF SPACECRAFT ELEMENTS AND THEIR INTERFACES

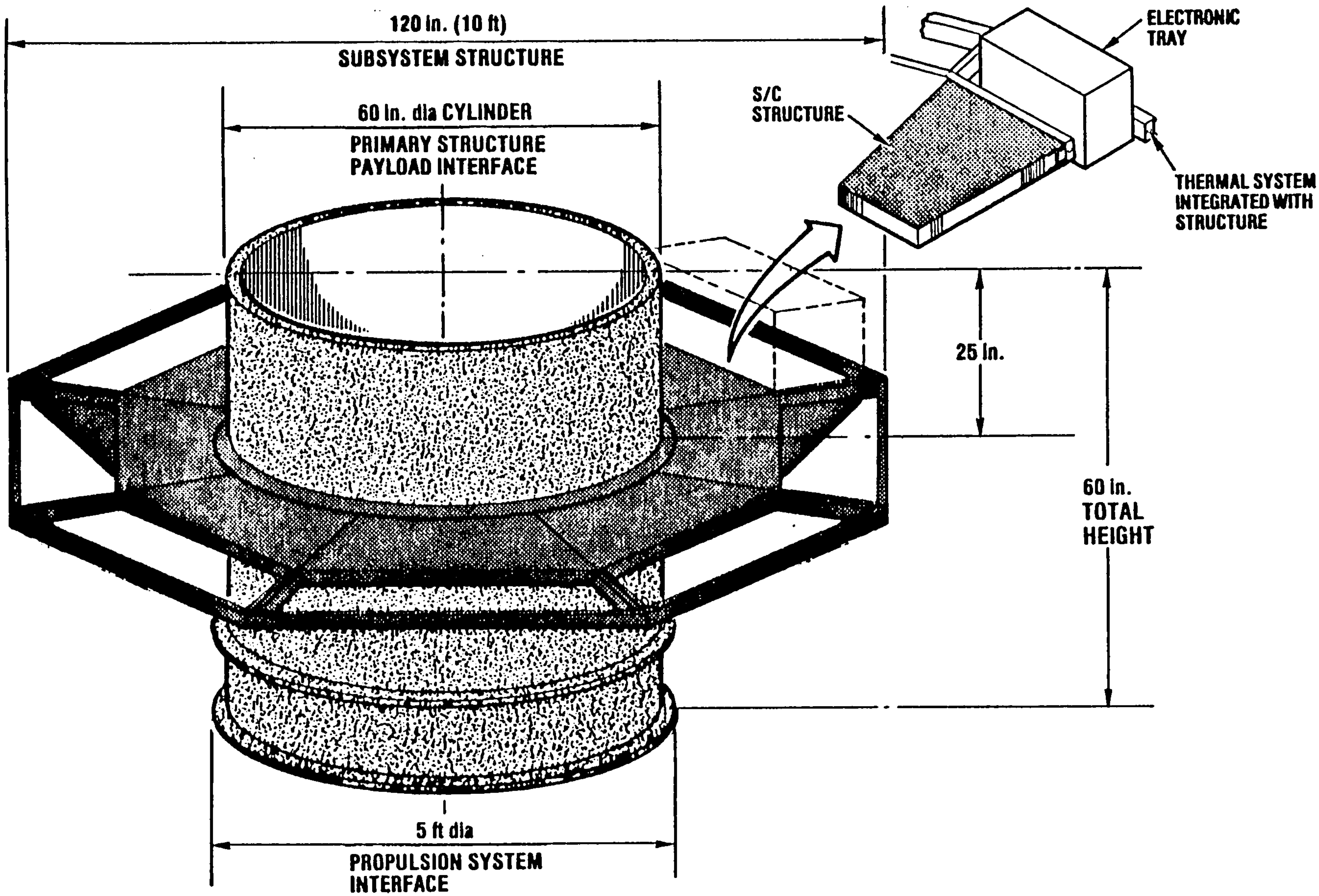
This overview of the spacecraft with the subsystems components is intended to serve as a road-map for the spacecraft systems description. The primary features of this concept include the reduction of cables by the introduction of a distributed data management system and a quasi-active thermal control system mounted on an open-type structure designed to be easily accessible.

ADVANCED SPACECRAFT
EXPLODED VIEW



The open-type structural architecture makes it possible to satisfy the majority of the spacecraft requirements. It is sized to fit the 15 ft. diameter orbiter payload bay in the horizontal position. The central 5 ft. diameter aluminum honeycomb cylinder is the primary load-carrying member and interfaces with the instrument payload at the top and with the propulsion system at the bottom. The octagon shelf structure is 10 ft. across the flats and is the key element that satisfies the installation of all the remaining subsystems. The electronic tray installed along the periphery of the structure represents the first key element in the data management systems, and makes it possible to eliminate a large number of cables.

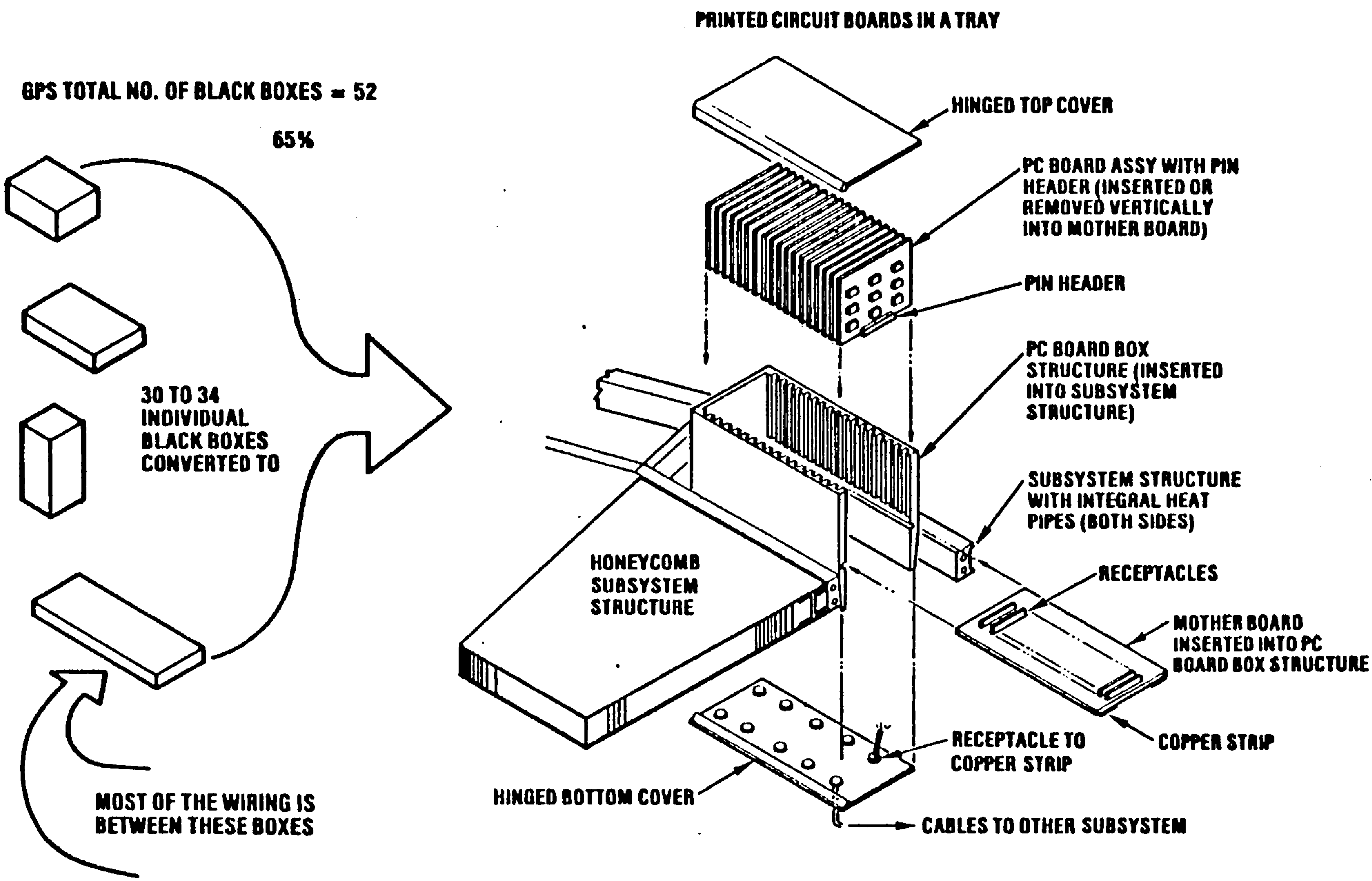
ADVANCED SPACECRAFT BASIC STRUCTURE



ELIMINATION OF CABLES BY APPLICATION OF CURRENT TECHNOLOGY TO GPS

Using the GPS as an example of the current spacecraft technology, it was found that most of the wiring is between 52 black boxes mounted at various locations on the structure. Reducing the number of cables led to the concept of converting 65% of the black boxes into 6 x 9 printed circuit boards which are inserted into larger trays. This modular tray system permits self-test and fault isolation at the card level; the modules are inserted into the periphery of the structure and cooled with a thermal system integrated into the structure.

ELIMINATION OF CABLES BY APPLICATION CURRENT TECHNOLOGY TO GPS

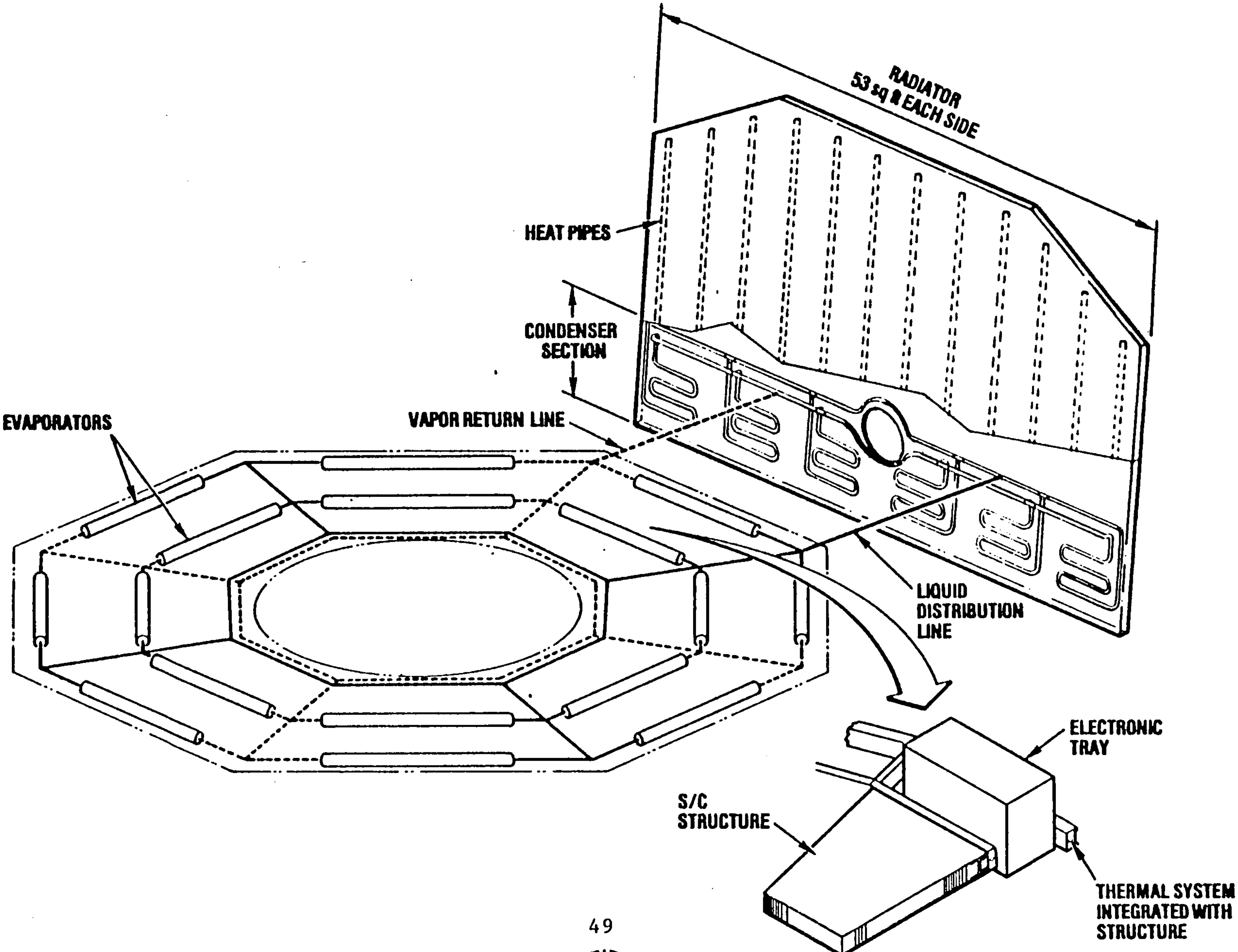


CAPILLARY PUMPED LOOP SYSTEM

A two-phase capillary pumped loop system and radiator are the primary elements of the thermal management system. The electronic trays fit between the evaporators which are integrated into the frame of the structure as are vapor and liquid distribution lines.

Heat generated by the electronic trays is transmitted to the evaporators where a pumping pressure is created by the wicking in the evaporators. The vapor is pumped to the radiator where it is condensed and then returned to the evaporators.

THERMAL MANAGEMENT SYSTEM
CAPILLARY PUMPED LOOP SYSTEM

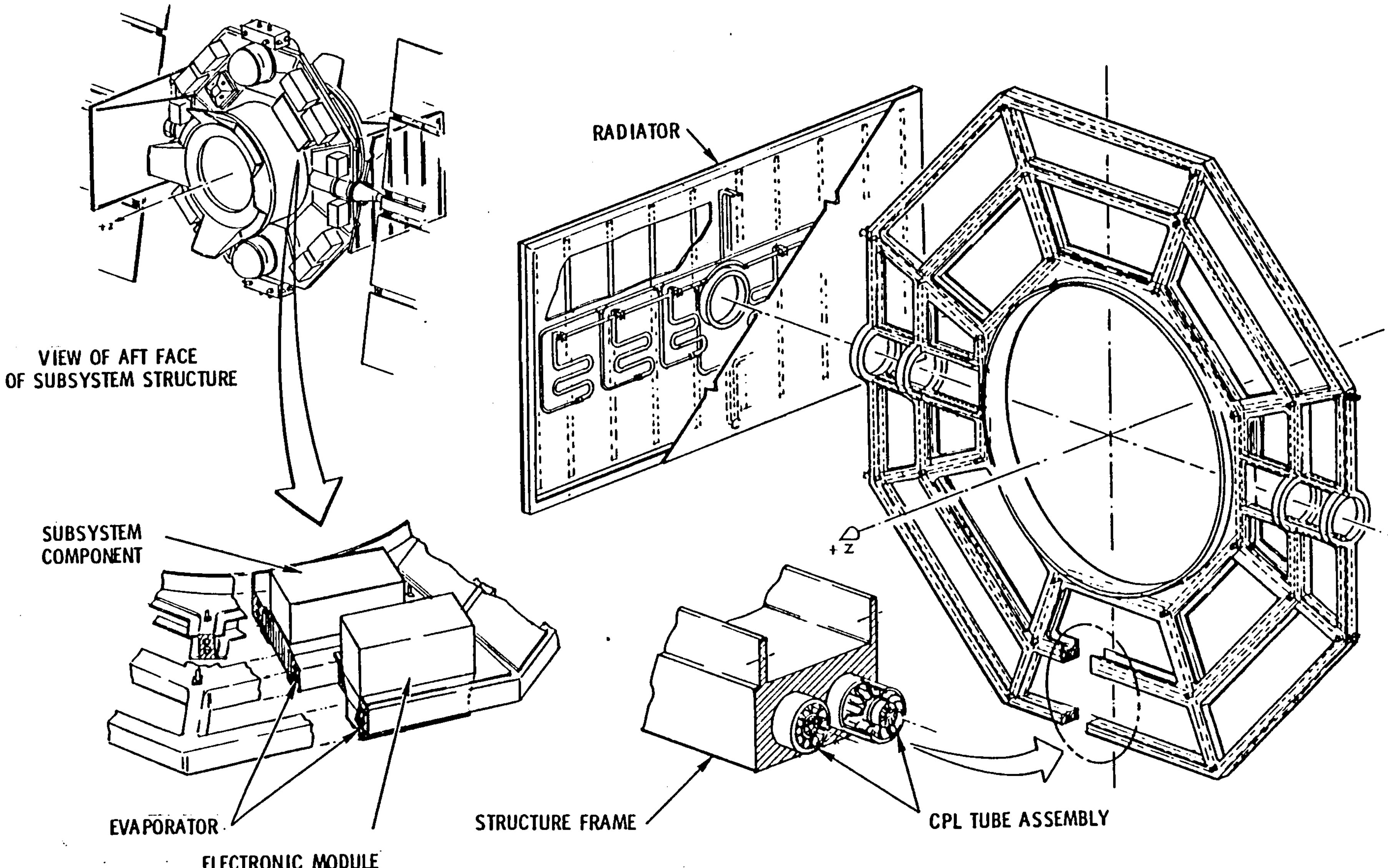


CAPILLARY PUMPED LOOP SYSTEM INTEGRATED INTO STRUCTURE

The redundant thermal system is integrated into the frame of the octagonal structure. A capillary pumped loop tube assembly or evaporator is manufactured into the tangential members of the structural frame. The radial members and those adjacent to the cylinder contain ports for the distribution of the fluid.

The electronic module, which in this case could not be converted into standard PC boards, is installed between the evaporators and the subsystem components.

THERMAL MANAGEMENT SYSTEM
CAPILLARY PUMPED LOOP SYSTEM INTEGRATED INTO STRUCTURE

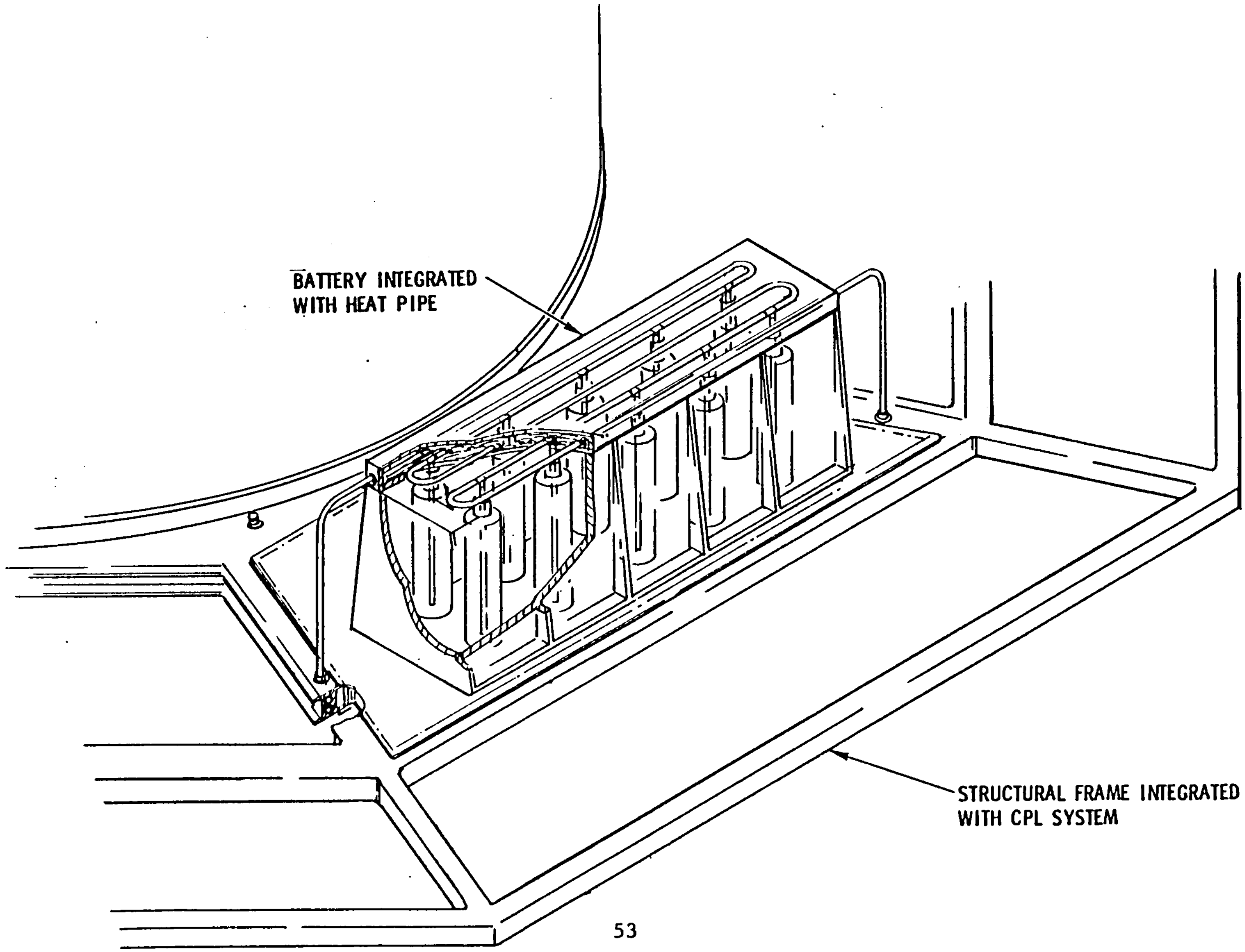


THERMAL INTERFACE WITH SUBSYSTEM COMPONENT

A battery is integrated with a heat pipe system. This concept permits the use of a single spacecraft radiator instead of a special low temperature radiator for the battery as currently required of conventional spacecraft.

The battery thermal system is connected to the spacecraft thermal system with fittings located at various points in the structure. This approach can be used for other components that require special treatment.

THERMAL INTERFACE WITH SUBSYSTEM COMPONENT

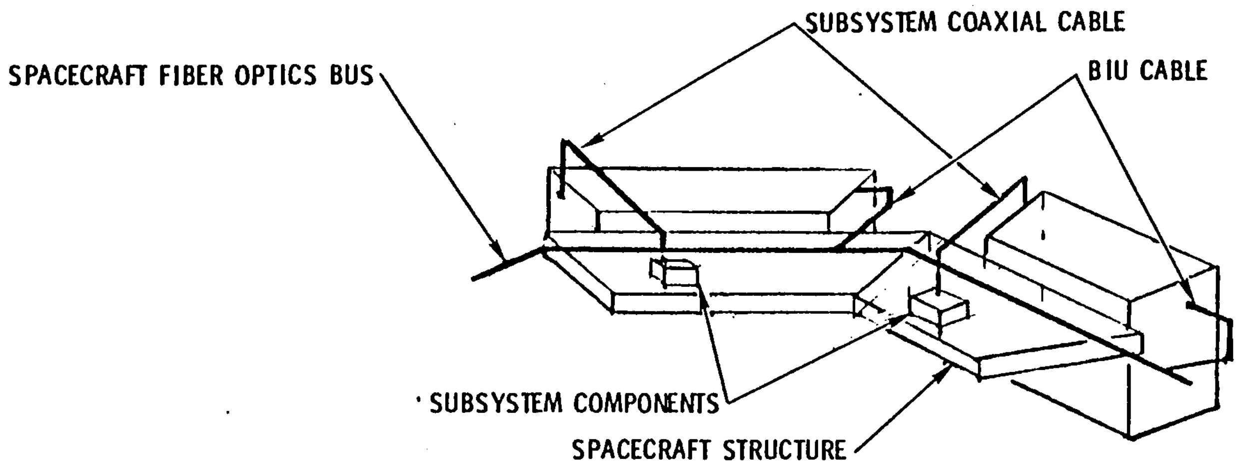


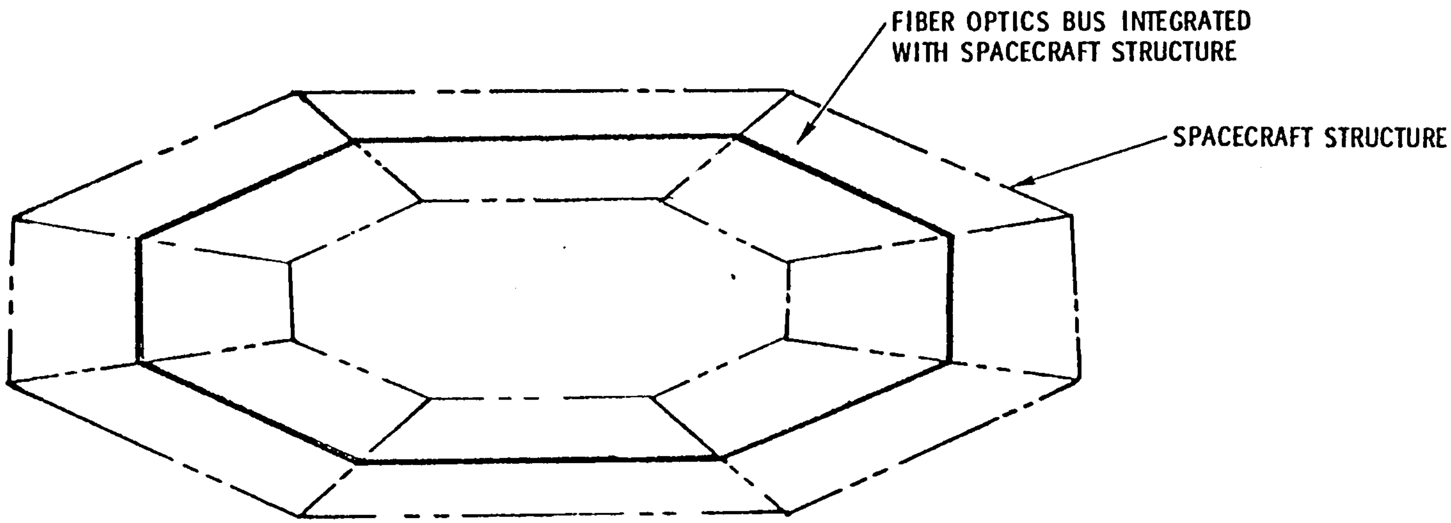
SCHEMATIC OF DISTRIBUTED DATA

MANAGEMENT SYSTEM

A fiber optics bus is installed on the octagon structure and is the basis for the distributed management system. Electronic modules and subsystems components tap into the fiber optics bus.

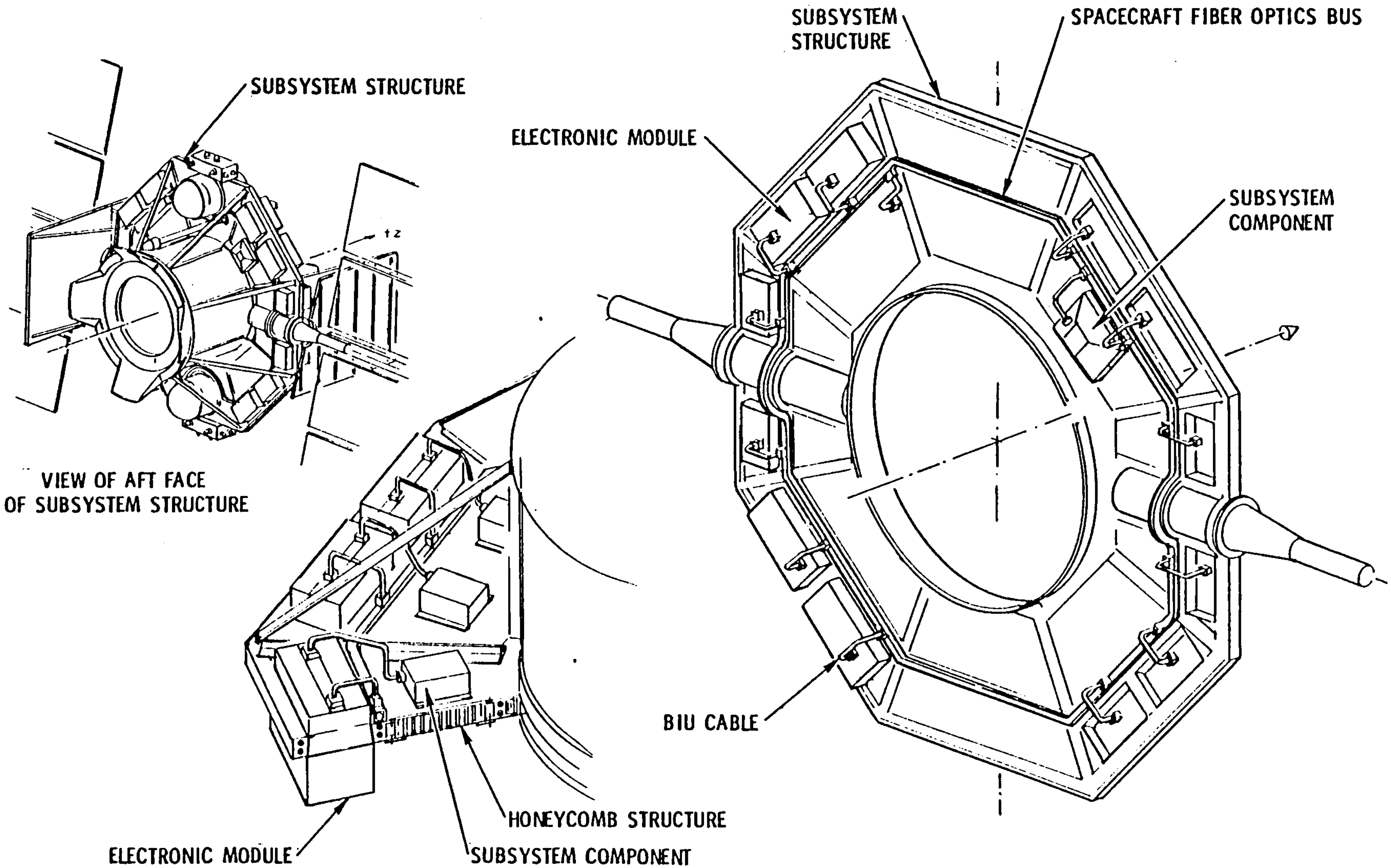
SCHEMATIC OF DISTRIBUTED DATA MANAGEMENT SYSTEM





The spacecraft fiber optics bus is integrated with the octagon structure completely around the periphery. Bus Interface Unit (BIU) cables are connected to the electronic modules. Communication between modules and between subsystem components is conducted through BIU cables and subsystem cables.

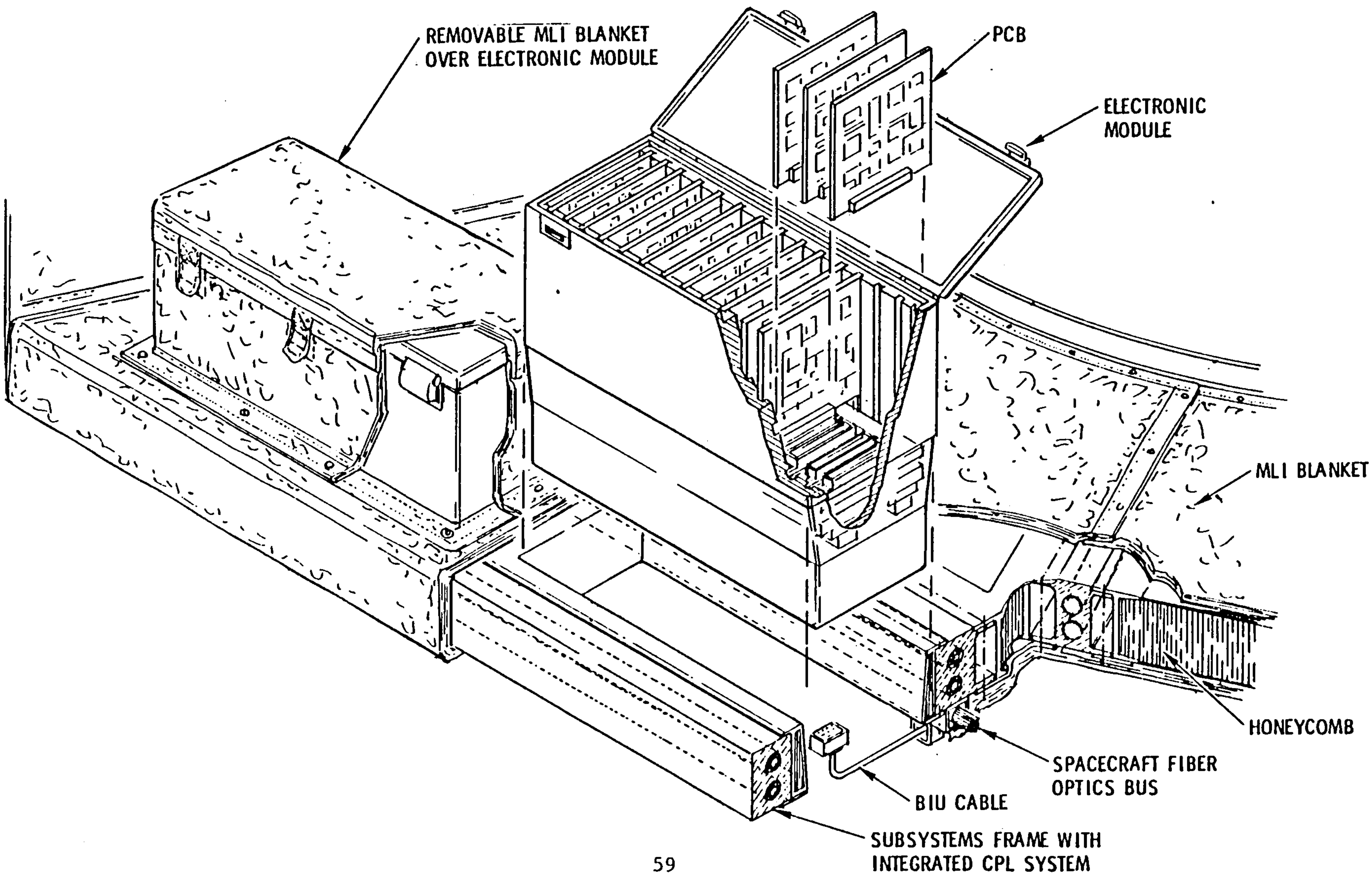
SPACECRAFT FIBER OPTICS BUS INTERFACE WITH ELECTRONICS MODULES AND SUBSYSTEM COMPONENTS



INTEGRATION OF DATA MANAGEMENT WITH THERMAL & STRUCTURAL SYSTEMS

The spacecraft fiber optic bus and BIU cable are integrated into the structure of the subsystem frame. The electronic module is shown being integrated with the thermal and structural frame members of the subsystem frame. The thermal MLI blankets are permanently mounted on the structure, and removable blankets are installed over the electronic modules to permit servicing.

INTEGRATION OF DATA MANAGEMENT SYSTEM WITH THERMAL AND STRUCTURAL SYSTEMS

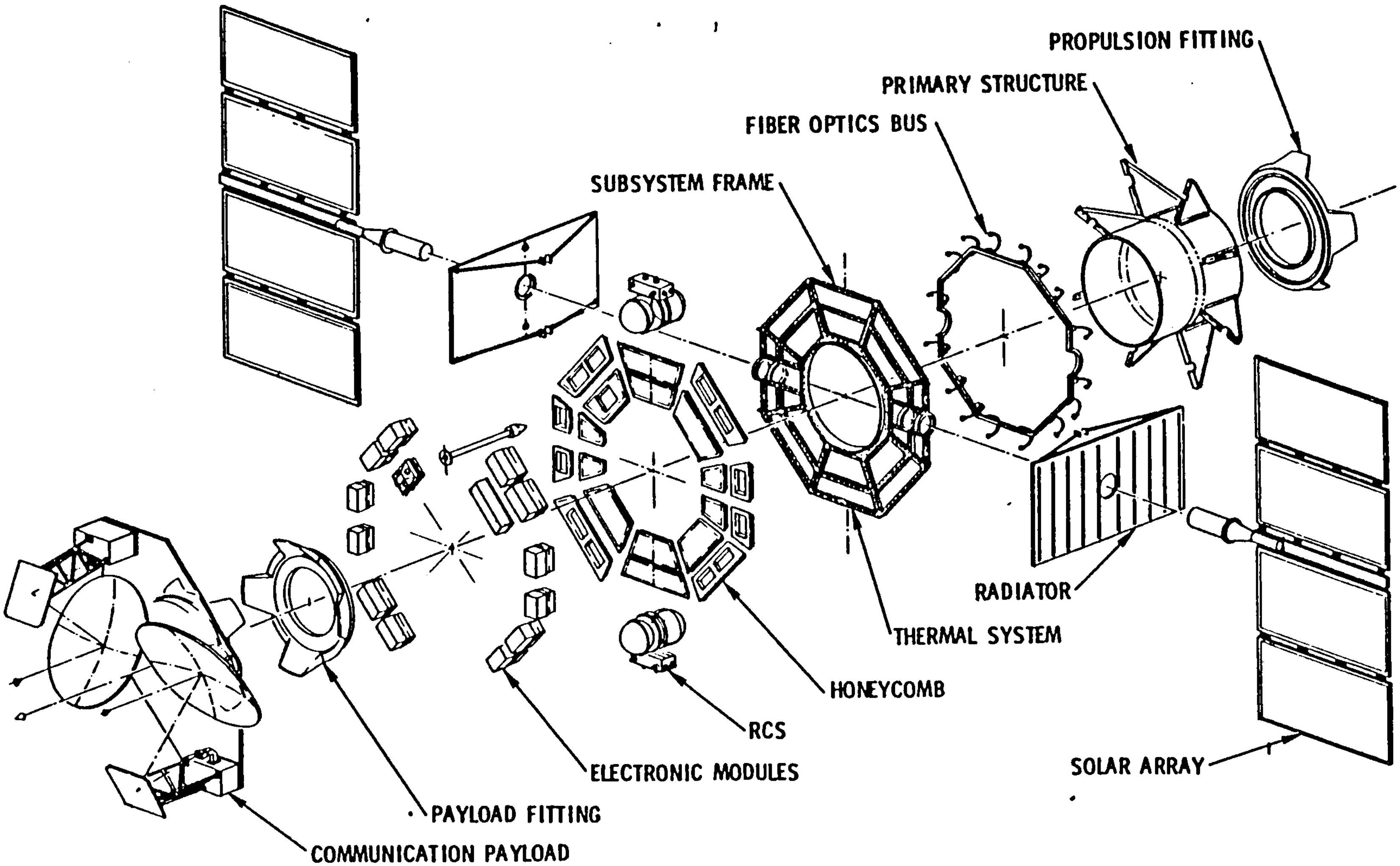


Summary:

The open-type spacecraft architecture concept satisfies the primary requirements of the program. The following is a summary.

The central cylinder is the primary load carrying structure and supports the payload at the forward interface and the propulsion system at the aft interface. All the remaining subsystems are installed on the subsystem frame which is supported by the primary structure. The two elements of thermal system, the CPL and radiator, are made integral with, and supported by, the frame. The two elements of the data management system consist of: (1) the electronic modules integrated with the structure and the thermal system, and (2) the fiber optics bus installed into the structure of the frame. The reaction control system is supported by the frame as are the solar array panels and various components of the remaining subsystems.

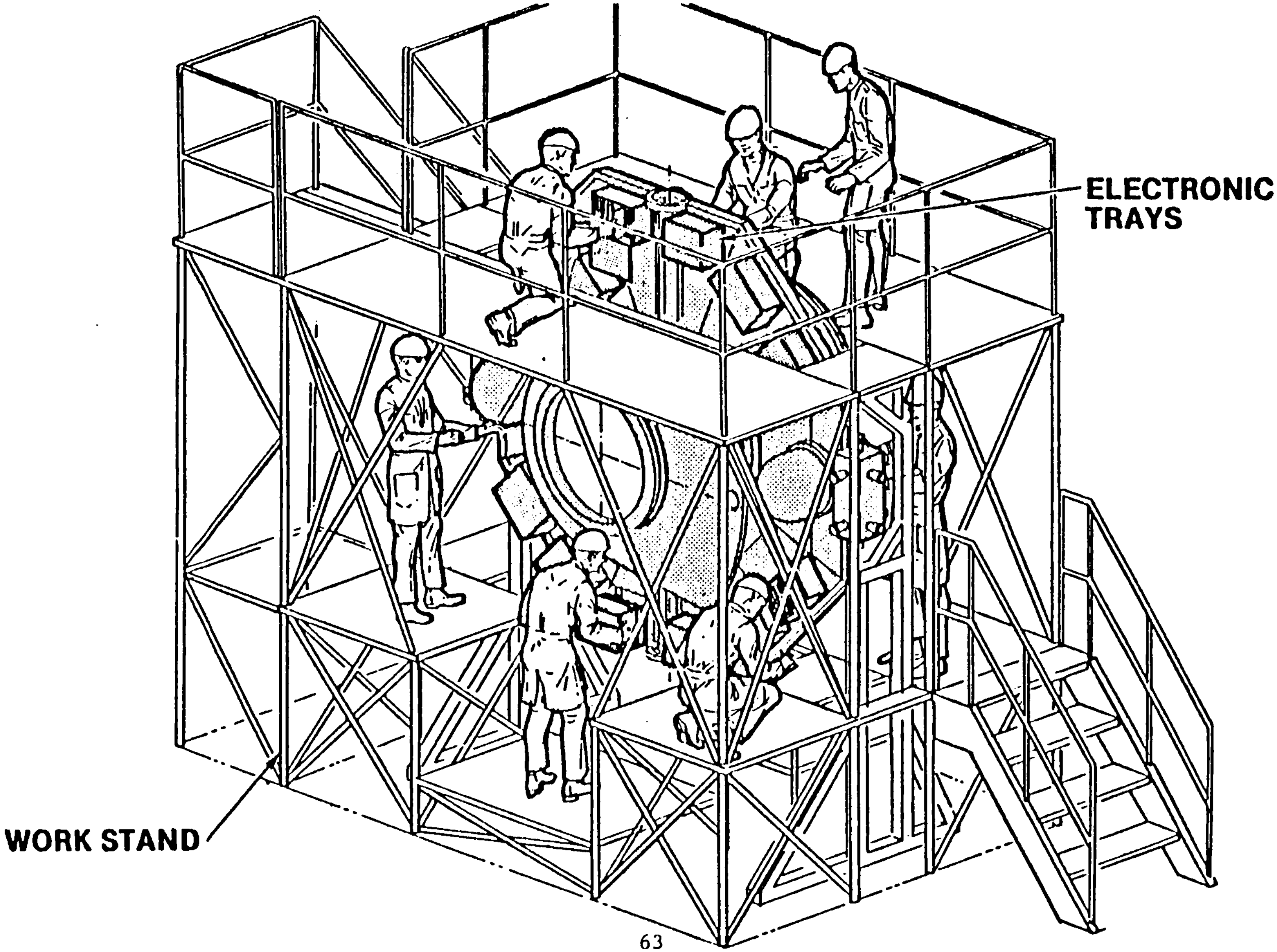
ADVANCED SPACECRAFT EXPLODED VIEW



MANUFACTURE & TEST

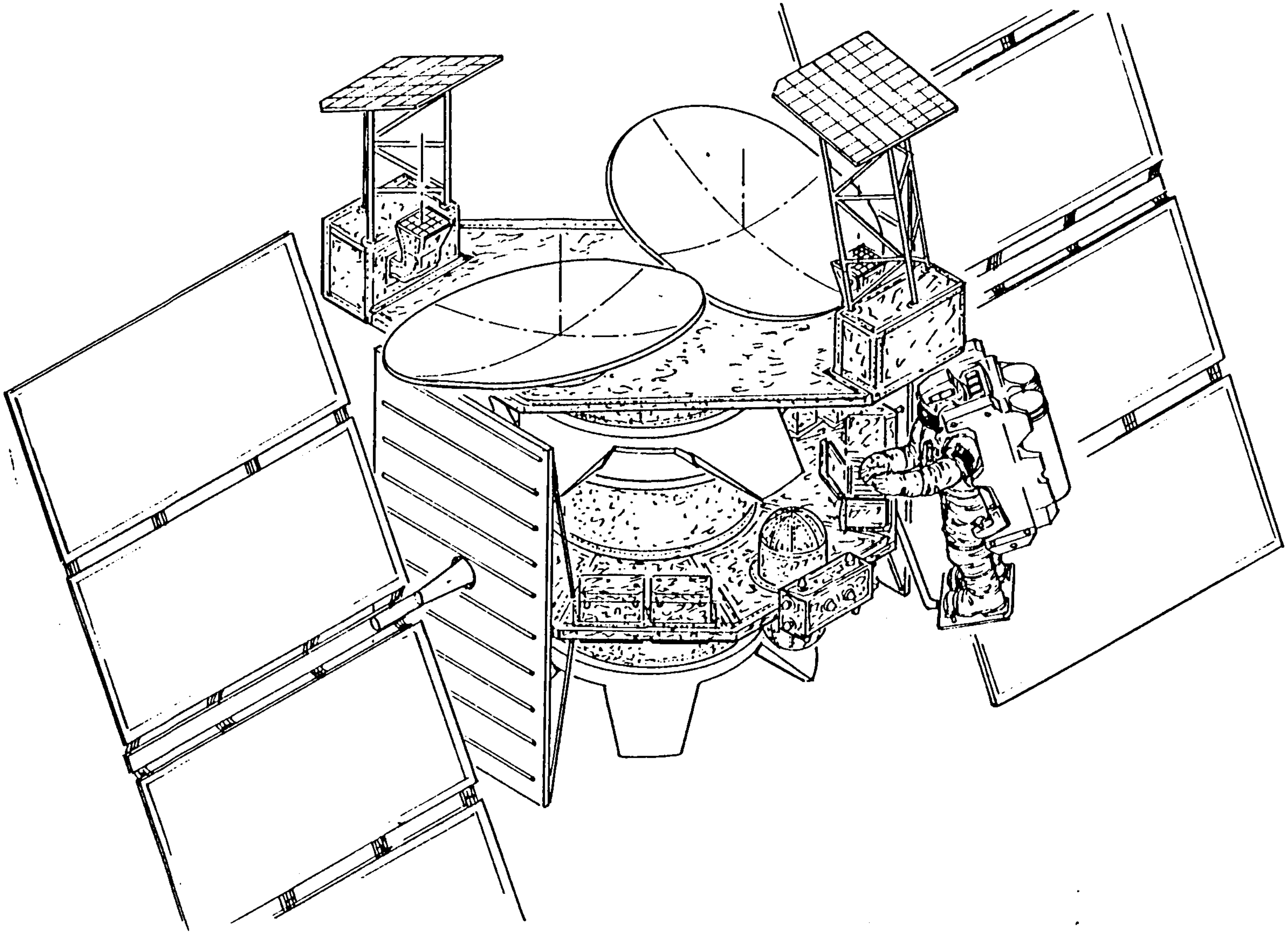
Manufacturing operations are simplified when an open-type structure is used. Subsystem components are easily accessible and may be installed in parallel operations by several mechanics. Testing of individual components and of the entire system will be significantly improved.

ADVANCED SPACECRAFT ACCESSIBILITY
MANUFACTURING AND TEST



An astronaut is shown servicing the data management electronic modules located at the periphery of the open structure. The thermal blankets are removable as are other components that may require servicing.

ADVANCED SPACECRAFT EVA
MAINTENANCE, REPAIR OR TEST IN ORBIT

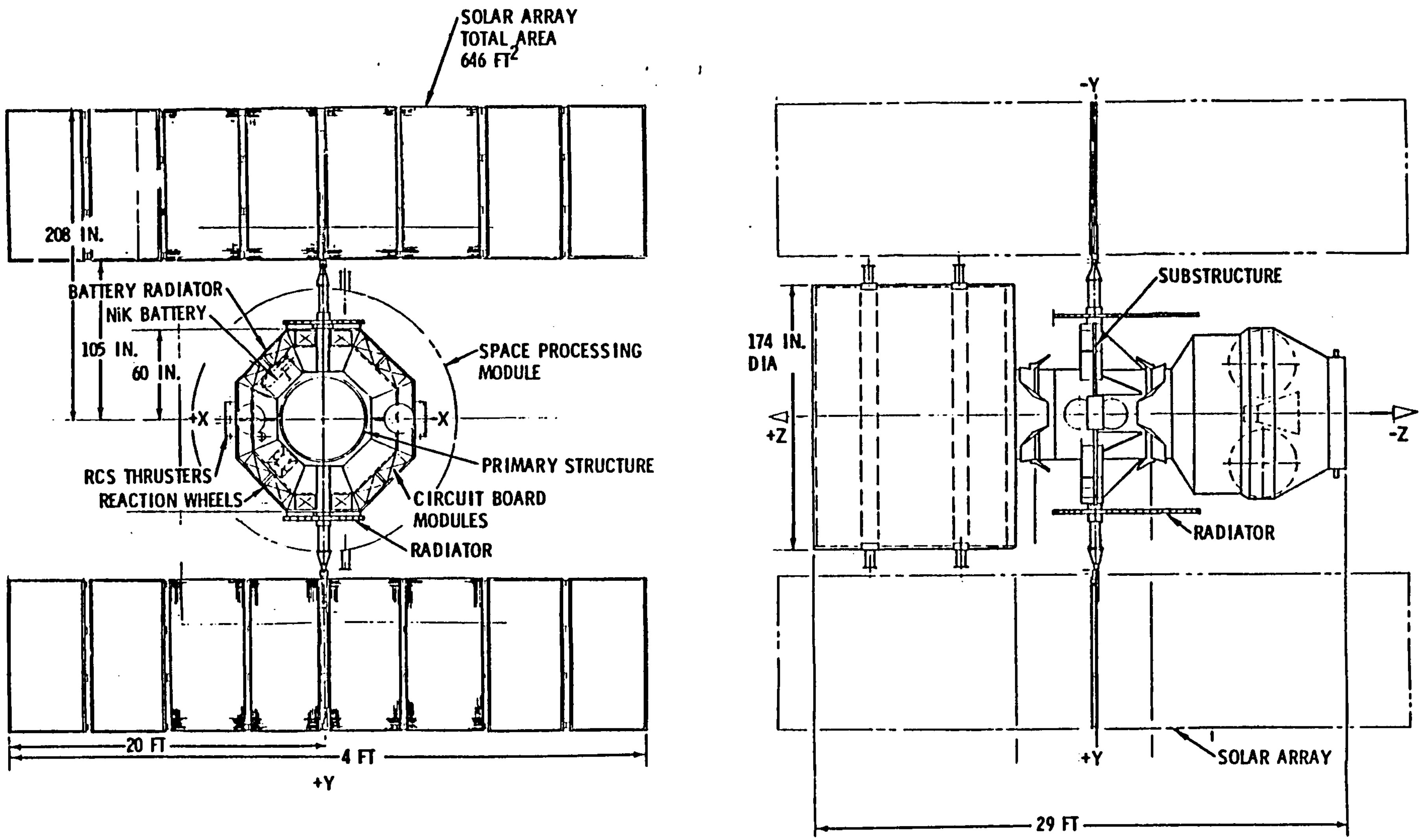


During the study three applications payloads were examined to determine their effects on advanced spacecraft concepts: (1) space processing in low earth orbit, (2) communications in geosynchronous earth orbit, and (3) geopositioning navigation in one-half earth geosynchronous orbit.

The 11,000-lb. space processing satellite was installed into the Shuttle payload bay supported by cradles at the propulsion module and by direct attachment at the space processing payload. The spacecraft configuration was sized to fit the 15-ft. diameter of the payload bay installed in the horizontal position. Because of the potential use of the space station, a docking and berthing port fitting can be used at the forward and aft interfaces of the cylindrical structure for attachment of the propulsion system and payload.

This is a 160 N.M. orbit configuration showing the installation of the space processing payload on the octagon-cylinder structure. The payload is located at the forward end of the structure, and the Orbital Sciences Corp./Apogee Maneuvering Stage (OSC/AMS) propulsion system located at the aft end is designed to be retrievable from low earth orbit to the Shuttle orbit. The octagonal structure is connected to the cylinder and houses all of the other subsystems.

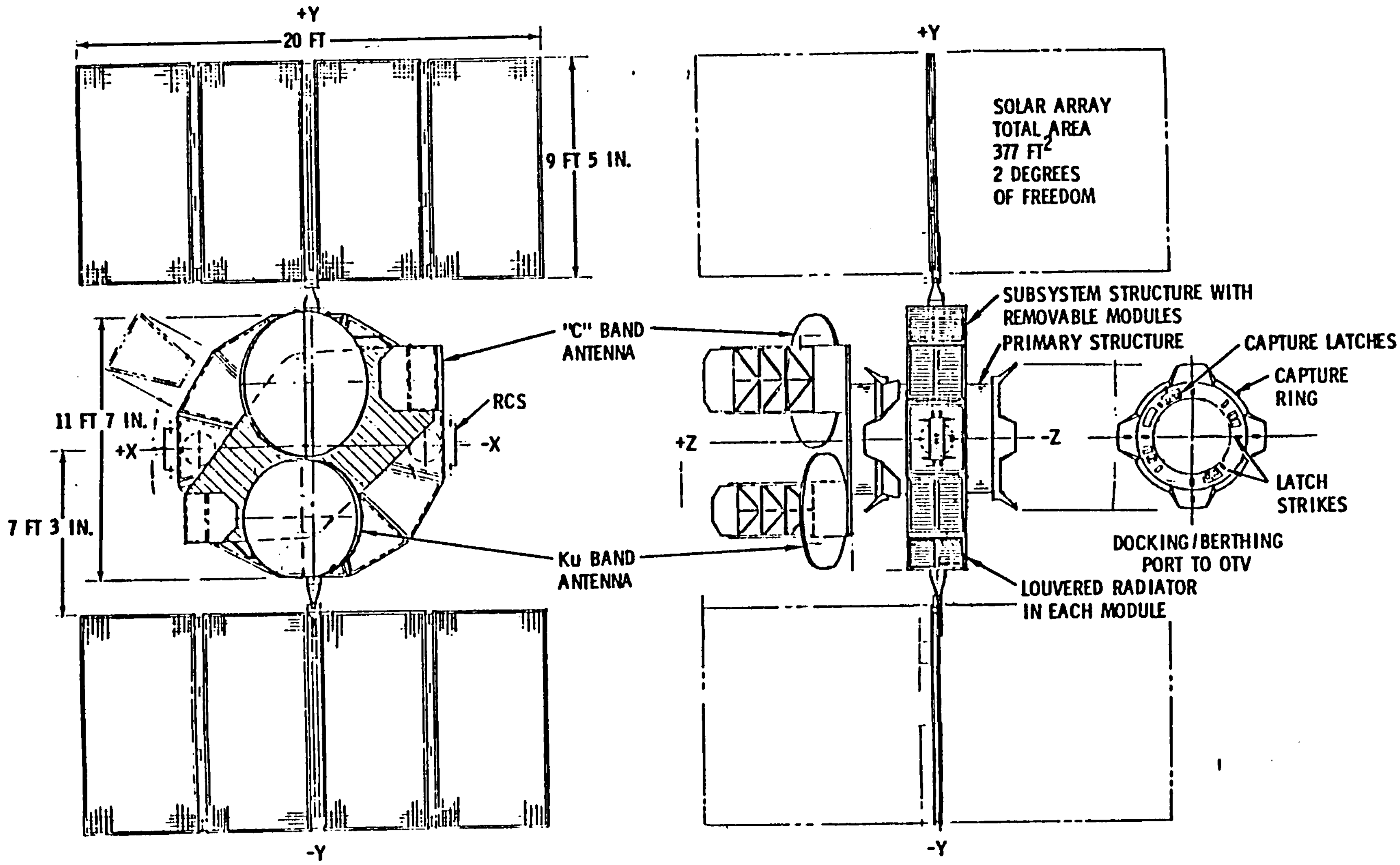
SPACE PROCESSING SPACECRAFT ORBIT CONFIGURATION



The communication satellite in the STS stowed configuration is cantilevered from a Centaur G prime which carries it to geosynchronous orbit. The Centaur propulsion system includes an integrated support system which consists of a cradle, a rotation trunnion and ejection system.

A flight concept is shown of the communication payload with two antennas mounted at the forward end with a docking and berthing fitting for possible use with the space station. The structural concept consists of the same primary load-carrying cylindrical structure; however, the subsystems are installed inside a 12-sided polygon with removable modules at each face. Each module contains its own louvered radiator. This approach was investigated as an alternate to the open structure octagon; however, this subsystem structure proved to have too many disadvantages.

COMMUNICATION SATELLITE ORBIT CONFIGURATION



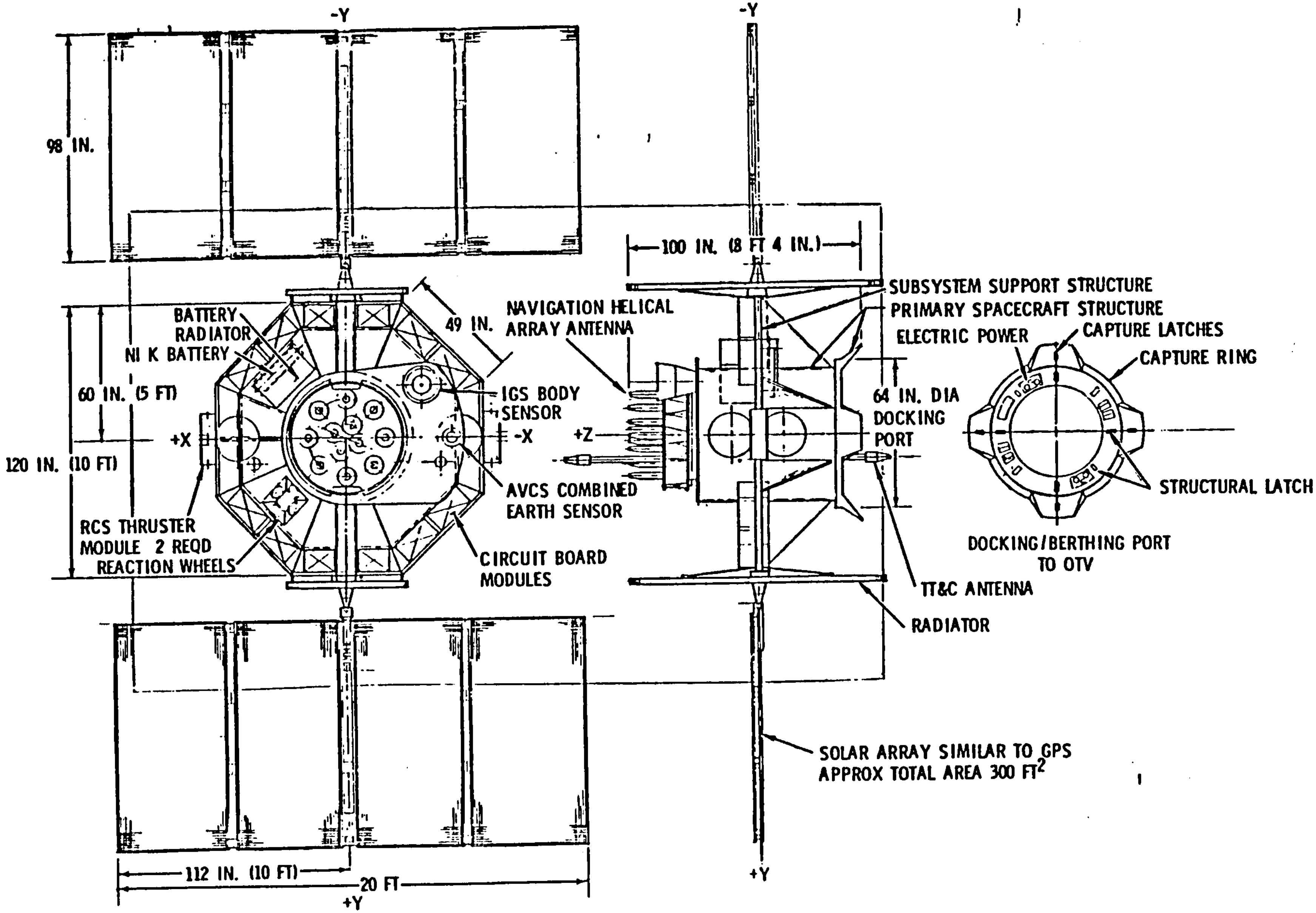
The advanced GPS, with its navigation payload in the STS, is cantilevered from a Centaur G which carries it to a one-half geosynchronous orbit. The Centaur also includes an integrated support system which consists of a cradle, a rotation trunnion and ejection system.

The flight configuration of an advanced GPS payload is shown attached permanently to the forward face of the cylindrical structure with the same octagonal subsystems structure used with the space processing payload.

Summary:

An evaluation of the installation of the three payloads indicates that the open-type structural concept, when integrated with the Thermal and Data Management System, is adaptable to a wide range of Earth oriented missions. The concept offers a balanced design that satisfies the reduction of cables, an efficient thermal system, accessibility during manufacture, and a simplified testing procedure.

ADVANCED GPS CONCEPT
ORBIT CONFIGURATION



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TECHNOLOGY ISSUES

This section addresses the subsystem technology issues and delineates technology project plans for each of the listed subsystems.

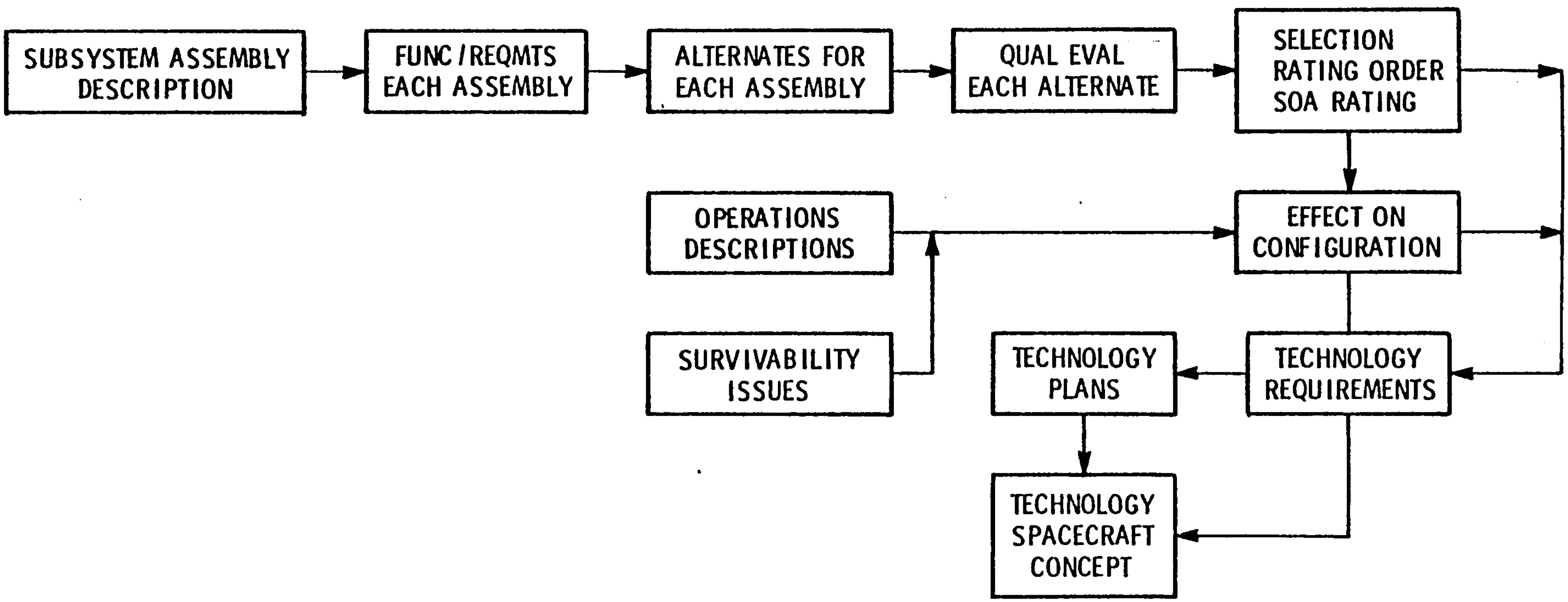
TECHNOLOGY ISSUES

- STRUCTURES AND MATERIALS
- THERMAL CONTROL
- PROPULSION
- ELECTRICAL POWER
- COMMUNICATIONS
- GUIDANCE, NAVIGATION AND CONTROL
- DATA MANAGEMENT

The process listed opposite was performed on each subsystem/technology area. Consideration of both subsystem advanced technology needs and their effects on the spacecraft design/configuration concepts proceeded hand in hand through the selection process. The end results were a selected approach to each spacecraft element, a definition of the effect that the choices had on spacecraft design and configuration, and the description of a technology project to resolve spacecraft technology issues and a concept for a technology spacecraft.

The next section of this report addresses the subsystem choices and delineates the technology project plans. The major effects of the subsystem choices on the spacecraft design concept and configuration have already been discussed in the previous section. The final section of this volume of the report addresses the technology spacecraft issues. Three important but somewhat peripheral issue areas, (1) the effect of new spacecraft operations associated with the space station, (2) spacecraft survivability under somewhat low level security threats, and (3) some detail of various technology evaluation processes, are included as appendices in Volume II of this report.

PHASE II STUDY FLOW



4.1 STRUCTURES AND MATERIALS

A number of structure types and materials were considered for the vehicle. From these honeycomb structure, made from aluminum, was chosen. The other alternatives are detailed on the following charts.

The more significant technology projects chosen are listed on the facing chart. Fabricating the electronic box chassis' integral with the structure gives promise for great gains in simplifying electronic box fabrication and test, eliminating a large portion of cabling, and reducing vibration levels on the components.

Development of composite material, including bonds, gives promise of advances in reliability, weight savings, and greater ranges of temperature compatibility.

STRUCTURES AND MATERIALS

SUBSYSTEM ELEMENT	SELECTED ALTERNATE
STRUCTURES	HONEYCOMB
MATERIALS AND PROCESSES	ALUMINUM

STRUCTURES AND MATERIALS TECHNOLOGY PROJECTS

- ELECTRONIC BOX CHASSIS INTEGRATION INTO BASIC SPACECRAFT STRUCTURE
- COMPOSITES HONEYCOMB STRUCTURE DEVELOPMENT
- OPEN STRUCTURE STATIC/DYNAMIC ANALYSIS

This chart lists and ranks the three combinations of structure and material deemed best as candidates for the advanced technology spacecraft. The first ranked, aluminum honeycomb, is being commonly used in spacecraft and thus needs no development work. The second ranked, composite honeycomb, is being used but requires some development to improve performance in areas such as out-gassing and greater temperature range applicability.

STRUCTURES AND MATERIALS

SELECTION

RANKING	S.O.A.
1. Honeycomb, aluminum	3
2. Honeycomb, composite	2
3. Semi-monocoque aluminum	3

This chart presents examples of the items that were considered in the process of evaluating and selecting the proper structural concept and materials.

The listed requirements were compiled from information from previous spacecraft programs, from manufacturing inputs, and from requirements established for STS payloads.

The issues listed are those which are typical subjects when considering development or composite honeycomb, such as low out-gassing and room temperature curing adhesives.

STRUCTURES & MATERIALS FUNCTIONS AND REQUIREMENTS

MATERIALS AND PROCESSES

FUNCTION:
- PROVIDE MATERIALS FROM WHICH SPACECRAFT IS FABRICATED

INTERFACES:
- SOLAR ENVIRONMENT
- DATA MANAGEMENT SYSTEM
- ELECTRICAL POWER SUBSYSTEM
- TELEMETRY, TRACKING AND COMMAND
- GUIDANCE, NAVIGATION AND CONTROL
- THERMAL CONTROL

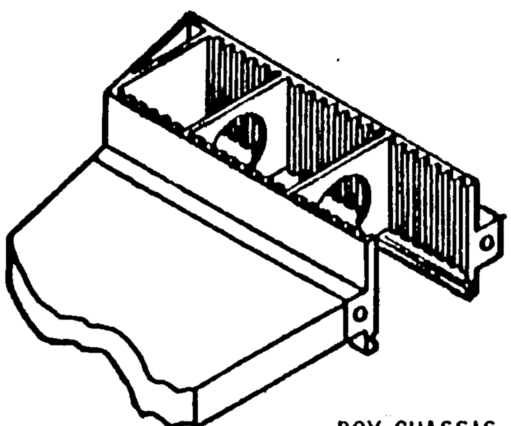
REQUIREMENTS:
- HIGH TEMPERATURE STRUCTURAL ADHESIVES AND COMPOSITE MATERIAL
- HIGH STIFFNESS/WEIGHT MATERIALS
- HIGH STRENGTH/WEIGHT MATERIALS
- STABLE THERMAL CONTROL COATINGS
- HIGH THERMAL CONDUCTANCE MATERIALS FOR THERMAL DOUBLERS
- LOW THERMAL CONDUCTANCE MATERIALS FOR THERMAL ISOLATION
- LOW OUT-GASSING, VACUUM COMPATIBLE MATERIAL

ISSUES:
- ROOM TEMPERATURE-CURING ADHESIVES
- MATCH MATERIAL TEMPERATURE RANGE TO S/C TEMPERATURE REQUIREMENTS
- NO USE OF STRESS CORROSION SUSCEPTIBLE MATERIAL
- SIMPLIFICATION OF MANUFACTURING AND TEST PROCESSES
- INCREASED USE OF ROOM TEMPERATURE CURE ADHESIVES
- LONG-LIFE THERMAL COATINGS

ELECTRONIC BOX CHASSIS INTEGRAL WITH SPACECRAFT STRUCTURE

The development program required to integrate the electronic box chassis into the spacecraft structure is outlined in the facing chart. The current practice for electronic box design requires severe vibration requirements be imposed upon the boxes, due to uncertainties about the vibroacoustic environment. The integrated box design minimizes vibration amplification to the PCBs, with resulting less severe design requirements. Also, it has the advantage of qualifying PCBs at the board level, thus simplifying qualification/requalification due to design changes.

STRUCTURES AND MATERIALS
TECHNOLOGY PLAN
ELECTRONIC BOX CHASSIS INTEGRAL WITH SPACECRAFT STRUCTURE



BOX CHASSIS INTEGRAL WITH SPACECRAFT STRUCTURE

PROBLEM

- ELIMINATE SEPARATE DEVELOPMENT OF ELECTRONIC EQUIPMENT. REDUCE CONSERVATIVE RANDOM VIBRATION REQUIREMENTS CURRENTLY PLACED ON ELECTRONIC BOX CHASSIS

OBJECTIVE

- INTEGRATE ELECTRONIC TRAY WITH PCB's BOX CHASSIS AND INTERFACE OF BOX CHASSIS WITH SPACECRAFT STRUCTURE TO MAKE EFFICIENT VIBRO-ACOUSTIC STRUCTURE

APPROACH VIBRO-ACOUSTIC CONCEPT

- COMBINE SPACECRAFT STRUCTURE WITH BOX CHASSIS
- INTEGRAL DAMPING ON PCB's
- DETAILED ANALYSIS AND DESIGN TRADES
- PROTOTYPE TESTING - FLIGHT VEHICLE

EXPECTED RESULTS

- REVISION OF ELECTRONIC CHASSIS SPECIFICATION
  - MINIMIZATION OF THE AMPLIFICATION TO PCB's
  - ESTABLISH VIBRO/ACOUSTIC DESIGN REQUIREMENTS RESULTING IN MAJOR WEIGHT REDUCTION
  - VERIFY STRUCTURAL CONFORMITY OF ELECTRONIC COMPONENT TO VIBRO/ACOUSTIC REQUIREMENTS BY TEST
  - PCB's HAVE BEEN QUALIFIED AT BOARD LEVEL (SIMPLIFIES QUAL/RE-QUAL OF DESIGN CHANGES)

SPECIAL FACILITIES/EQUIPMENT

- NONE REQUIRED

FIELD OR SHUTTLE FLIGHT TEST

- FLIGHT TEST ON INTEGRATED SPACECRAFT

RELATED TECHNOLOGY AREAS

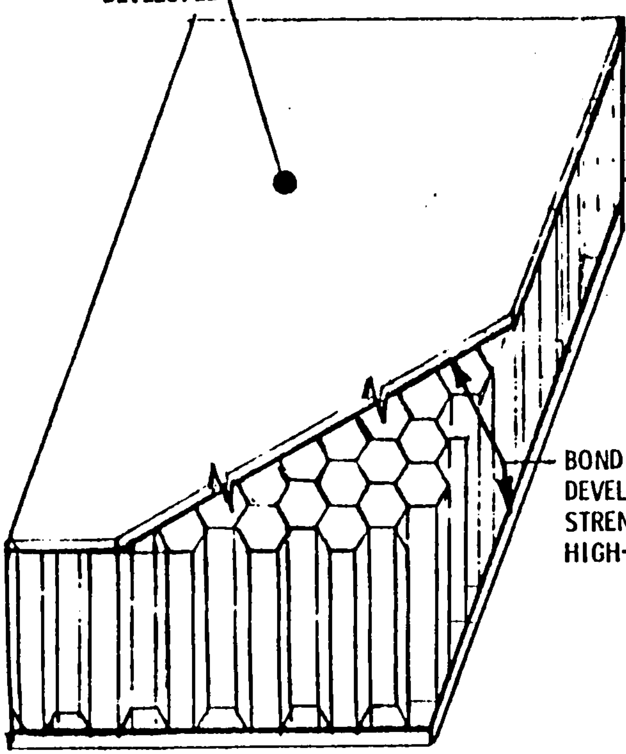
- ALL ELECTRONIC SUBSYSTEMS
- STRUCTURAL DESIGN ANALYSIS AND TEST

COMPOSITE HONEYCOMB DEVELOPMENT

The structure/material combination baselined for the flight test vehicle is aluminum honeycomb. The facing chart outlines the development program to be undertaken to advance the composite honeycomb state of the art so it may be used advantageously for future spacecraft.

Low out-gassing resins with high strength and temperature range are to be developed.

STRUCTURES AND MATERIALS
TECHNOLOGY PLAN
COMPOSITE HONEYCOMB DEVELOPMENT



PROBLEM

- MEET THE REQUIREMENT FOR A LIGHT WEIGHT, STIFF, CHEMICALLY STABLE HONEYCOMB STRUCTURE TO PROVIDE MOST EFFICIENT PLATFORM FOR 1990's SATELLITE SYSTEM

OBJECTIVE

- DEVELOP A LIGHT WEIGHT, STRONG SATELLITE STRUCTURAL MATERIAL CAPABLE OF WITHSTANDING INDUCED LOADS AND SPACE ENVIRONMENT FOR THE USEFUL LIFE OF THE SPACE VEHICLE WITHOUT UNDUE DEGRADATION

APPROACH

- CONDUCT CHEMICAL LABORATORY PROGRAM TO DEVELOP RESINS FOR COMPOSITE STRUCTURE WITH LOW OUTGASSING HIGH STRENGTH AND INCREASED ELASTICITY AND HEAT RESISTANCE
- USE NEW RESINS TO OPTIMIZE COMPOSITE MATERIAL PROPERTIES THROUGH LABORATORY TEST
- DEVELOP AUTOMATED MANUFACTURING METHODS FOR COMPOSITE STRUCTURE FABRICATION

EXPECTED RESULTS

- LOW OUTGASSING HIGH-STRENGTH ELASTIC LIGHT WEIGHT COMPOSITE STRUCTURAL MATERIAL

SPECIAL FACILITIES/EQUIPMENT

- EXPERIMENTAL CHEMISTRY LABORATORY
- R&D STRUCTURAL TEST LABORATORY

FIELD OR SHUTTLE FLIGHT TEST

- SHUTTLE TEST FLIGHT DEPLOYMENT WITH FULL-UP SYSTEMS AND PAYLOAD

RELATED TECHNOLOGY AREAS

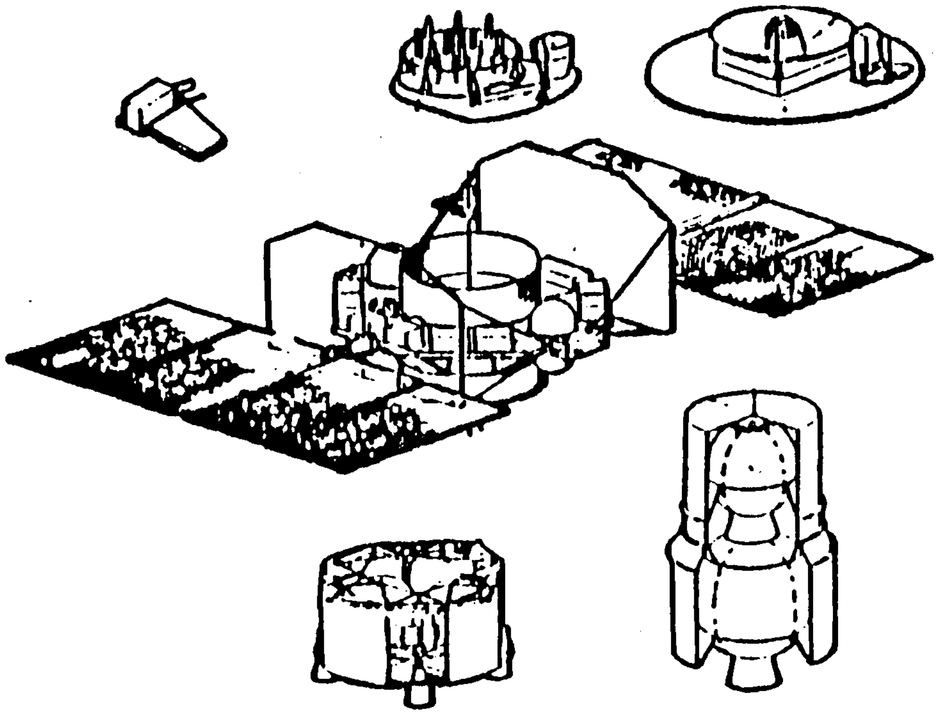
- DYNAMICS AND STRUCTURAL ANALYSIS AND TEST
- THERMAL SUBSYSTEM
- ELECTRONICS SUBSYSTEMS

CANDIDATE FOR FLIGHT TEST VEHICLE-STRUCTURAL CONCEPT

In order to validate the advanced design concepts, a flight test vehicle is required. The development program for structure/materials bus is outlined on this chart. Included is the requirement for developing static and dynamic loads analysis and test. The analysis/test program is to be developed to qualify the open-structure concept, and also the new integrated chassis approach to electronic packaging.

The noted analysis/test program will fully qualify the advanced spacecraft bus for the space flight test program.

STRUCTURES AND MATERIALS
TECHNOLOGY PLAN
CANDIDATE FOR FLIGHT TEST VEHICLE - STRUCTURAL CONCEPT



PROBLEM

- PROVIDE MATERIAL DESIGN AND ANALYSIS FOR ADVANCED TECHNOLOGY SPACECRAFT BUS

OBJECTIVE

- QUALIFY ADVANCED TECHNOLOGY OPEN-STRUCTURE DESIGN AS MULTI-USE SPACECRAFT BUS OF THE FUTURE

APPROACH

- PERFORM STATIC AND DYNAMIC ANALYSES OF ADVANCED TECHNOLOGY DESIGN SPACECRAFT
- PERFORM STATIC AND VIBRO-ACOUSTIC TESTS AS APPROPRIATE
- INCORPORATE NEW APPROACH TO ELECTRONIC PACKAGING

EXPECTED RESULTS

- EFFICIENT, LOW-PRICED, ADVANCED TECHNOLOGY SPACECRAFT BUS QUALIFIED FOR MULTIPLE MISSION USE

SPECIAL FACILITIES/EQUIPMENT

- STS ORBITER FLIGHT VEHICLE

FIELD OR SHUTTLE FLIGHT TEST

- FLIGHT VEHICLE FROM STS WITH FULL-UP SYSTEMS AND PAYLOAD

RELATED TECHNOLOGY AREAS

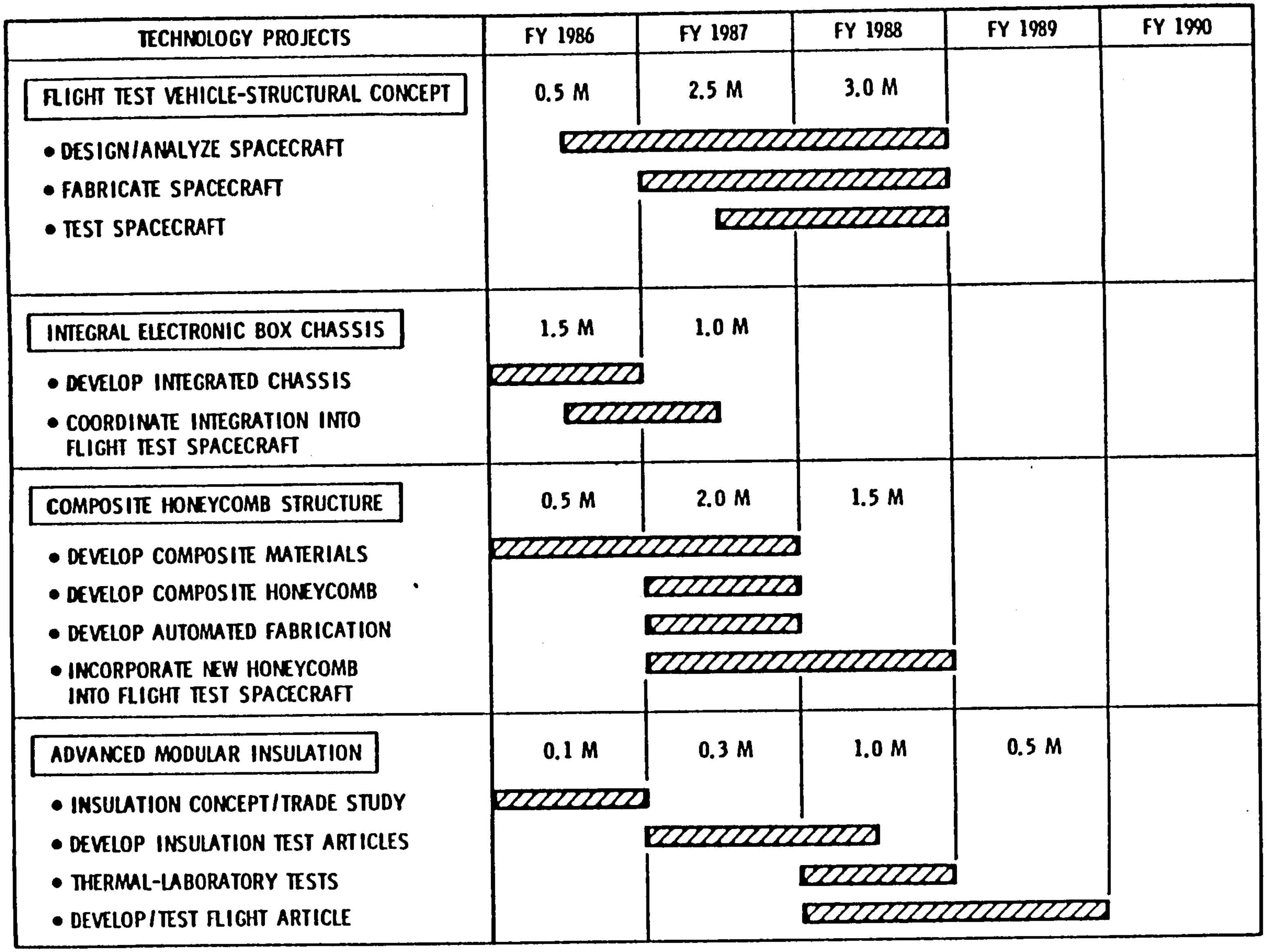
- STRUCTURE AND DYNAMIC ANALYSES AND TEST
- ALL SPACECRAFT SUBSYSTEMS
- PAYLOAD (TO BE DETERMINED)

STRUCTURES AND MATERIALS

TECHNOLOGY PLAN

The budgets and schedules shown opposite are very preliminary in nature, but can be revised and updated as the actual technology program is more precisely defined and point designs for test hardware and processes are developed.

STRUCTURES AND MATERIALS TECHNOLOGY PLAN



4.2 THERMAL CONTROL SUBSYSTEM SUMMARY

The selected alternate for each subsystem element is summarized. Key TCS technology projects are identified.

THERMAL CONTROL SUBSYSTEM SUMMARY

SUBSYSTEM ELEMENT	SELECTED ALTERNATE
HEAT TRANSPORT	CAPILLARY PUMP LOOP
HEAT REJECTION	CONDENSING HEAT PIPE
HEAT COLLECTION	EVAPORATIVE COLD PLATE
TEMPERATURE CONTROL	CAP PUMP LOOP VARIABLE HEAT
HEAT STORAGE	IN-LINE FLOW

THERMAL CONTROL TECHNOLOGY PROJECTS

- INTEGRATED CPL LINES/STRUCTURE
- CPL CONDENSER/RADIATOR DEVELOPMENT
- CPL EVAPORATOR/COLD PLATE DEVELOPMENT
- INTEGRATED TCS/AVIONICS PACKAGING

THERMAL CONTROL SUBSYSTEM

ELEMENT SELECTION

The chart opposite identifies the alternatives that were considered for each element of the thermal control subsystem, the ranking order of the selection, and a first measure of the State of the art of each alternative: (1 being the most advanced technology alternative; (2 being a known State of the art but still requiring major R&D; (3 being a well developed technology, but yet requiring hardward development for a particular mission.

THERMAL CONTROL SYSTEM

ELEMENT SELECTION

	S.O.A.
HEAT TRANSPORT	
1. Capillary Pumped Loop	1
2. Single-Phase Pumped Fluid Loop	3
3. Heat Pipe Loop	2
4. Two-Phase Compression	1
5. Louver Control	3
6. Cold Bias Spacecraft	3
7. Two-Phase Pump Fluid Loop	1
HEAT REJECTION	
1. CPL Condenser	1
2. Fluid Loop	3
3. Heat Pipes	2
HEAT COLLECTION	
1. Cold Plates - Evaporative	1
2. Cold Plates - Convective	3
3. Cold Plates - Component Mounting Structure	1
4. Heat Exchanger	3
CONTROLLER	
1. CPL Evaporator	1
2. Variable Flow, Fixed Temperature	2
3. Fixed Flow, Variable Heat Addition	2
HEAT STORAGE	
1. In-Line Flow Capacitor	1
2. Radiator Mount Capacitor	2
3. Component Mount Capacitor	2
ENVIRONMENT CONTROL	
1. Modular MLI Blankets	2

TCS ASSEMBLY REQUIREMENTS/FUNCTIONS

HEAT TRANSPORT AND DISTRIBUTION

The function, interfaces, requirements, and issues are defined for the heat transport and distribution assembly. This assembly transports waste heat/component dissipation from various sources to heat rejection radiators. Two key issues affecting spacecraft design are long life operation and better access to components and test connections.

TCS ASSEMBLY REQUIREMENTS/FUNCTIONS
- HEAT TRANSPORT AND DISTRIBUTION -

FUNCTION: THIS ASSEMBLY TRANSPORTS WASTE HEAT/COMPONENT DISSIPATION FROM VARIOUS SOURCES TO HEAT REJECTION RADIATORS AND MAINTAINS S/C COMPONENTS WITHIN SPECIFIED TEMPERATURE

INTERFACES: COOLANT INLET AND OUTLET CONNECTIONS AT HEAT REJECTION RADIATORS AND AT VARIOUS HEAT COLLECTION DEVICES

REQUIREMENTS:

COMSAT	5 KW
ADV GPS	1.2 KW
MANUF'G	2.5-6 KW

ISSUES:

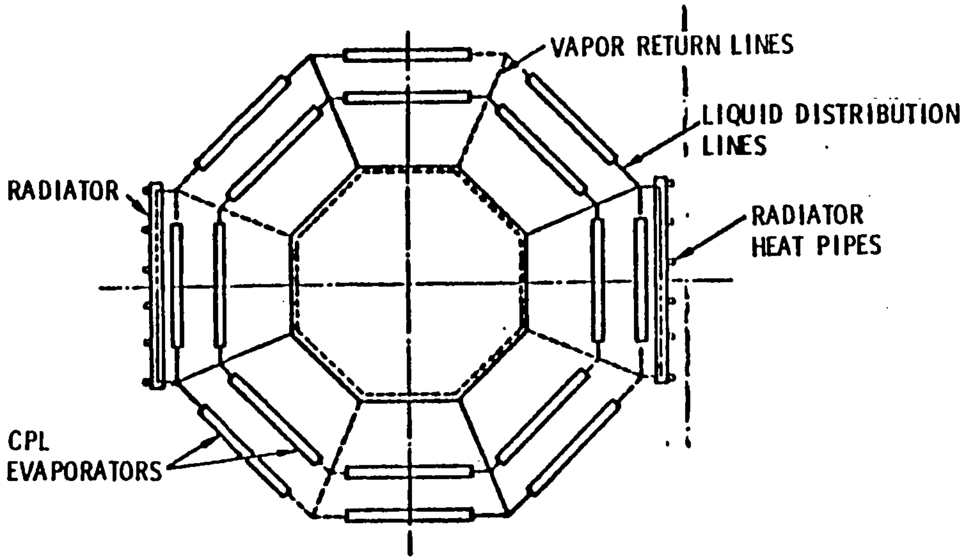
- OPERATE FOR LONG LIFE (10-12 YRS)
- MINIMIZE WEIGHT PENALTY
- PROVIDE BETTER ACCESS TO COMPONENTS AND TEST CONNECTIONS
- SIMPLIFY TEST PROCEDURES
- CAPILLARY TECHNOLOGY DEVELOPMENT

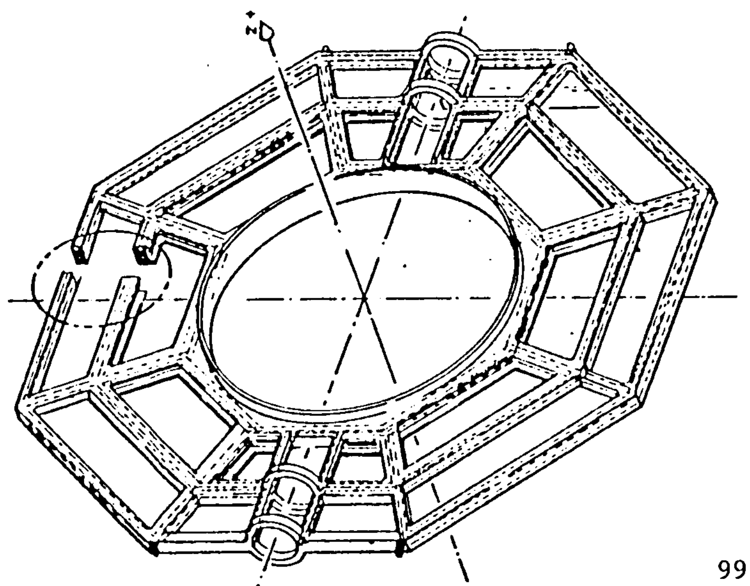
CAPILLARY PUMPED LOOP SYSTEM

INTEGRATED CPL LINES/STRUCTURE

An important TCS component technology project is identified. This project deals with the integration of fluid transport lines into the spacecraft structure.

CAPILLARY PUMPED LOOP SYSTEM
INTEGRATED CPL LINES/STRUCTURE





PROBLEM

- LONG-LIFE THERMAL MANAGEMENT SYSTEM REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- TO DEVELOP AN INTEGRATED STRUCTURE/ CPL LINES FOR A 12 kW-m CAPILLARY PUMPED LOOP (CPL) TRANSPORT SYSTEM

APPROACH

- COMPONENT DEVELOPMENT
- CONDUCT CPL INTEGRATION STUDY
- DEVELOP AND TEST SIMULATED SYSTEM BREADBOARD
- PROVE 0-G FEASIBILITY WITH FLIGHT EXPERIMENT

EXPECTED RESULTS

- QUALIFIED CPL HARDWARE FOR SPACECRAFT APPLICATION

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR GROUND TEST
- SHUTTLE TEST FLIGHT

RELATED TECHNOLOGY

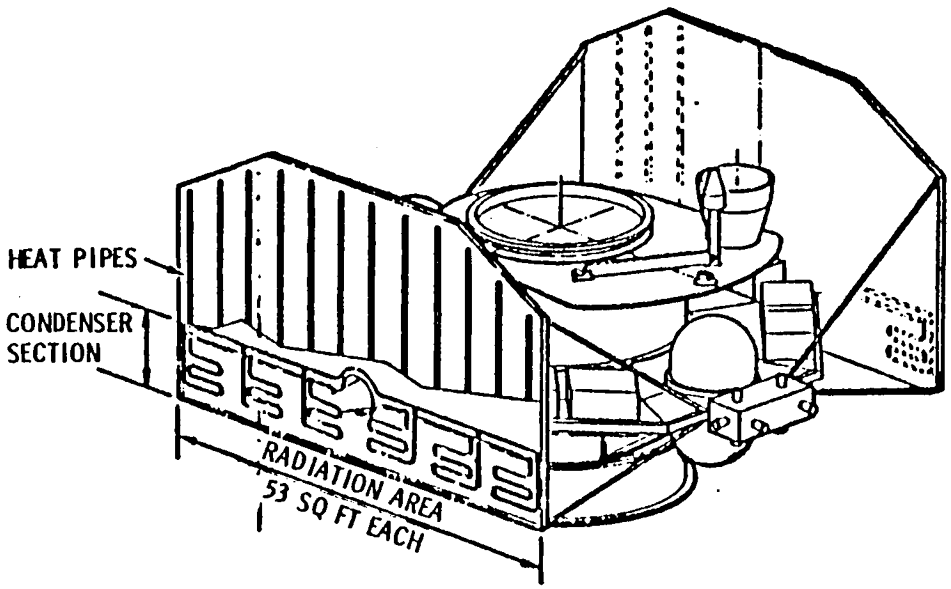
- STRUCTURE
- ELECTRONIC PACKAGING

CAPILLARY PUMP LOOP ASSEMBLY

CPL CONDENSER/RADIATOR

An important TCS component technology project is identified. This project deals with the development of a condensing radiator for the CPL.

CAPILLARY PUMPED LOOP ASSEMBLY
CPL CONDENSER/RADIATOR



PROBLEM

- LONG-LIFE THERMAL MANAGEMENT SYSTEM REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- TO DEVELOP A CONDENSING/RADIATOR FOR A 12 kW-m CAPILLARY PUMPED LOOP (CPL) TRANSPORT SYSTEM

APPROACH

- CONTINUE COMPONENT DEVELOPMENT
- CONDUCT CPL INTEGRATION STUDY
- DEVELOP AND TEST SIMULATED SYSTEM BREADBOARD
- PROVE 0-G FEASIBILITY WITH FLIGHT EXPERIMENT
- EXPAND TRANSPORT CAPABILITY

EXPECTED RESULTS

- QUALIFIED CPL HARDWARE FOR SPACECRAFT APPLICATION

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR FULL-UP GROUND TEST
- SHUTTLE TEST FLIGHT

RELATED TECHNOLOGY

- STRUCTURE
- DEPLOYABLE ARRAYS

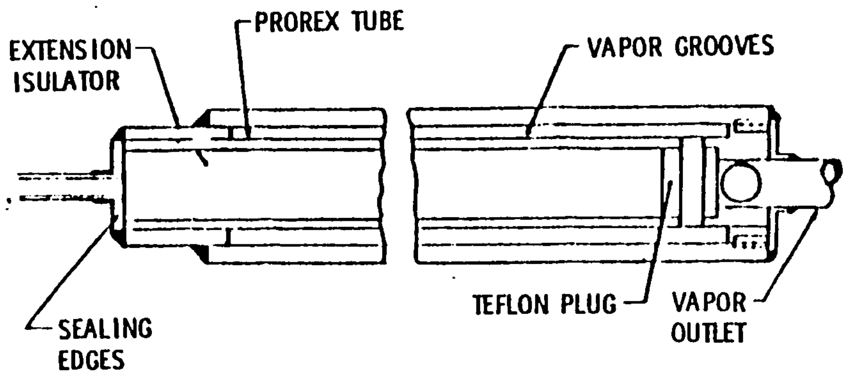
THERMAL CONTROL TECHNOLOGY

CAPILLARY PUMPED LOOP SYSTEM EVAPORATOR DESIGN

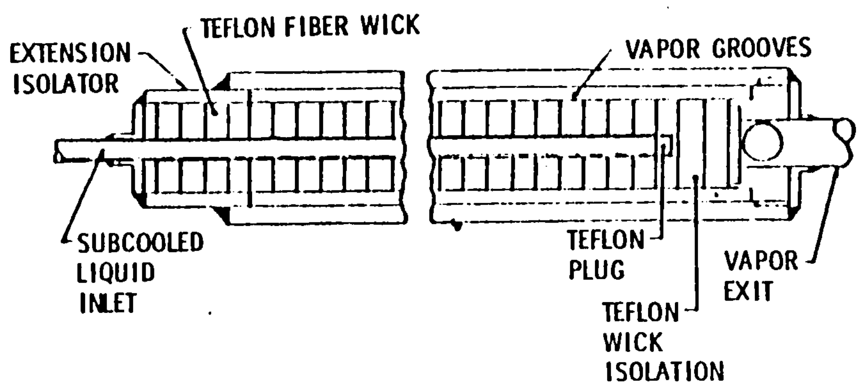
An important TCS component technology project is identified. This project deals with development of cold plates and heat exchangers using CPL evaporators.

THERMAL CONTROL TECHNOLOGY
CAPILLARY PUMPED LOOP SYSTEM EVAPORATOR DESIGN

PROREX TUBE EVAPORATOR



TEFLON-WIKED EVAPORATOR



PROBLEM

- LONG-LIFE THERMAL MANAGEMENT SYSTEM REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- TO DEVELOP A CPL EVAPORATIVE COLD PLATE FOR A 12 kW-m CAPILLARY PUMPED LOOP (CPL) TRANSPORT SYSTEM

APPROACH

- CONTINUE COMPONENT DEVELOPMENT
- CONDUCT CPL INTEGRATION STUDY
- DEVELOP AND TEST SIMULATED SYSTEM BREADBOARD
- PROVE 0-G FEASIBILITY WITH FLIGHT EXPERIMENT

EXPECTED RESULTS

- QUALIFIED CPL HARDWARE FOR SPACECRAFT APPLICATION

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR FULL-UP GROUND TEST
- SHUTTLE TEST FLIGHT WITH SPECIAL COOLING FACILITIES

RELATED TECHNOLOGY AREAS

- STRUCTURE
- ELECTRONIC PACKAGING

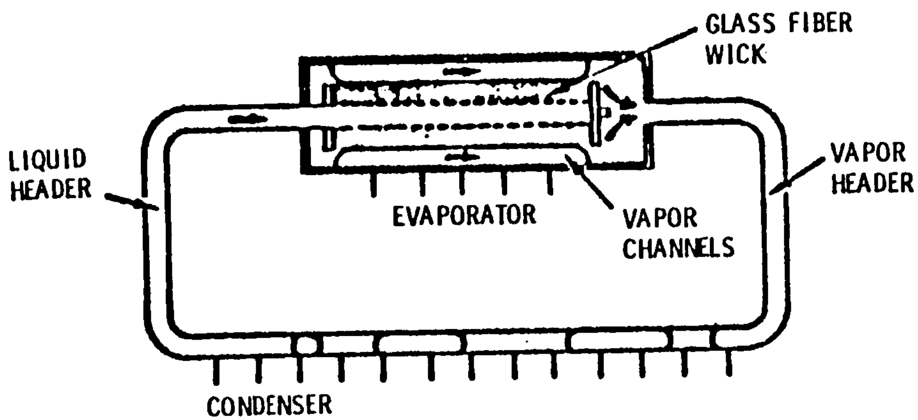
THERMAL CONTROL TECHNOLOGY

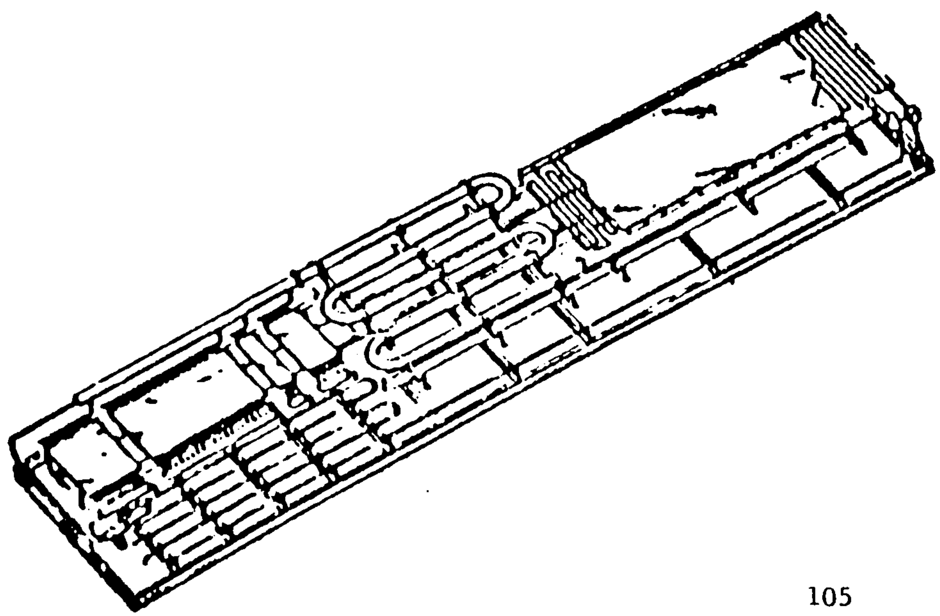
CAPILLARY PUMPED LOOP SYSTEM

SPACE QUALIFICATION

An important space qualification test is identified for CPL technology. This test assembles the evaporator, condenser, and transport line into a single test assembly for a shuttle test flight.

THERMAL CONTROL TECHNOLOGY
CAPILLARY PUMPED LOOP SYSTEM
SPACE QUALIFICATION





PROBLEM

- LONG-LIFE THERMAL MANAGEMENT SYSTEM REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- TO DEVELOP A 12 kW-m CAPILLARY PUMPED LOOP (CPL) TRANSPORT SYSTEM

APPROACH

- CONDUCT CPL INTEGRATION STUDY
- DEVELOP AND TEST SIMULATED SYSTEM BREADBOARD
- PROVE 0-G FEASIBILITY WITH FLIGHT EXPERIMENT/SHUTTLE SORTIE FLIGHT
- INCORPORATE INTO SPACECRAFT TEST SATELLITE

EXPECTED RESULTS

- QUALIFIED CPL HARDWARE FOR SPACECRAFT APPLICATION

SPECIAL FACILITIES/EQUIPMENT

- COOLING TEST FACILITY
- THERMAL/STRUCTURAL TEST FACILITY

FIELD OR SHUTTLE SORTIE FLIGHT TESTS

- VACUUM SYSTEM FOR FULL-UP GROUND TEST
- SHUTTLE TEST FLIGHT

RELATED TECHNOLOGY

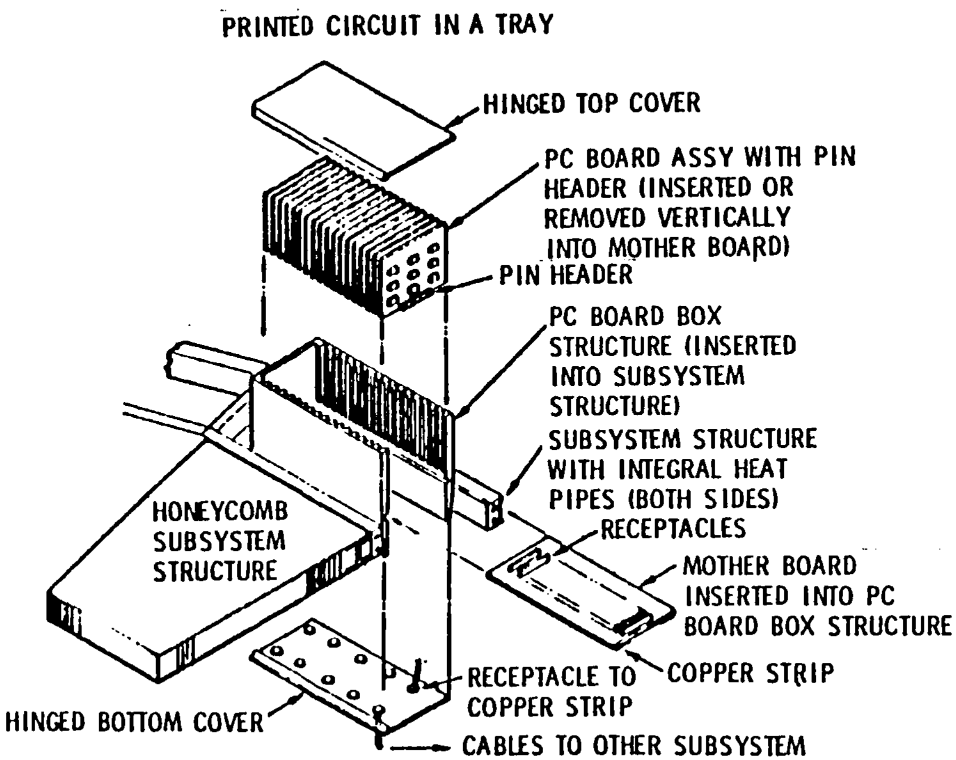
- STRUCTURES
- ELECTRONIC PACKAGING

THERMAL TECHNOLOGY

INTEGRATED TCS/AVIONICS PACKAGE

A key TCS technology project is identified. This project deals with the integration of TCS devices and techniques into compact avionics packages to minimize temperature gradients and to enhance heat rejection.

THERMAL TECHNOLOGY
INTEGRATE TCS/AVIONICS PACKAGE



PROBLEM

- THERMAL CONTROL IS REQUIRED FOR ENHANCEMENT OF AVIONIC PACKAGE RELIABILITY

OBJECTIVE

- TO DEVELOP AN INTEGRATED THERMAL CONTROL/ PACKAGING SYSTEM FOR AVIONICS

APPROACH

- GENERATE DESIGN CONCEPTS AND CONDUCT TRADES
- DEVELOP HARDWARE BREADBOARD
- CONDUCT THERMAL-VACUUM TESTS
- DEVELOP AND QUALIFY INTEGRATED AVIONICS PACKAGE

EXPECTED RESULTS

- A QUALIFIED AVIONICS PACKAGE WITH AN INTEGRAL THERMAL CONTROL SYSTEM

SPECIAL FACILITIES/EQUIPMENT

- COOLING FACILITY
- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- VACUUM SYSTEM FOR FULL-UP GROUND TEST
- SHUTTLE TEST FLIGHT

RELATED TECHNOLOGY

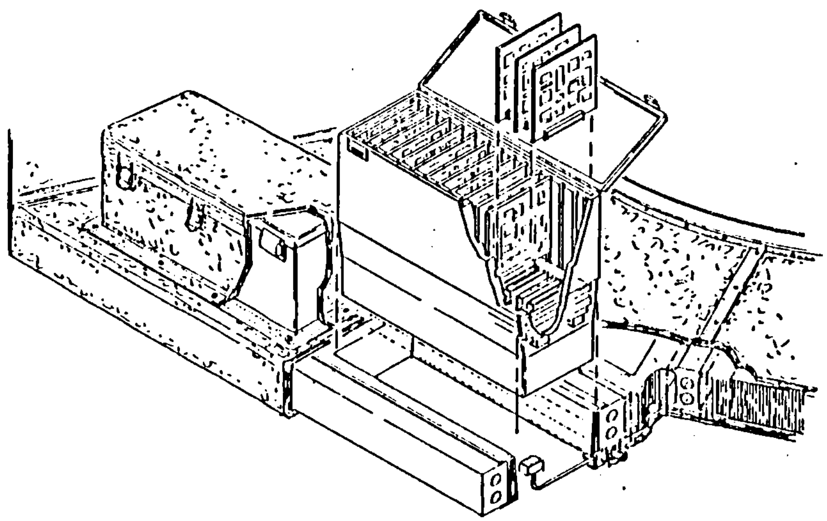
- STRUCTURE
- ELECTRONIC PACKAGING

THERMAL CONTROL TECHNOLOGY

ADVANCED MODULAR INSULATION

An important TCS technology project is identified. This project deals with the identification and development of modular insulation approaches which simply component access, testing, and maintenance procedures.

THERMAL CONTROL TECHNOLOGY
ADVANCED MODULAR INSULATION



PROBLEM

- SIMPLIFY INSTALLATION, TESTING, AND MAINTENANCE OF INSULATION ON SPACECRAFT STRUCTURE

OBJECTIVE

- TO DEVELOP LIGHT-WEIGHT, MODULAR INSULATION SYSTEM FOR EACY INSTALLATION, AND SIMPLIFIED TESTING AND MAINTENANCE

APPROACH

- CONDUCT INSULATION TRADE STUDY
- DEVELOP INSULATED SPACECRAFT TEST ARTICLE
- CONDUCT THERMAL-VACUUM TEST

EXPECTED RESULTS

- IDENTIFICATION OF MODULAR INSULATION APPROACHES

SPECIAL FACILITIES/EQUIPMENT

- THERMAL/STRUCTURE TEST FACILITY

FIELD OR SHUTTLE FLIGHT TEST

- INCORPORATE INTO INITIATIVES SPACECRAFT TEST PROGRAM

RELATED TECHNOLOGY AREAS

- STRUCTURE

THERMAL CONTROL TECHNOLOGY PLANNING

Estimated development schedules and funding for the identified TCS technology projects are summarized.

THERMAL CONTROL TECHNOLOGY PLANNING

	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992
INTEG CPL LINES/STRUCTURE	$100 K	$300 K	$250 K	$125 K			
INTEGRATED DESIGN							
HARDWARE BREADBOARD							
THERMAL VACUUM TEST							
CPL CONDENSER/RADIATOR	$100 K	$200 K	$350 K	$500 K	$600 K	$200 K	
INTEGRATION STUDY							
SIMULATED TEST ARTICLE							
FLIGHT EXPERIMENT							
INTEGRATE INTO SPACECRAFT							
CPL EVAPORATOR/COLD PLATE	$100 K	$250 K	$250 K	$550 K	$550 K	$300 K	$150 K
INTEGRATION STUDY							
SIMULATED TEST ARTICLE							
SORTIE FLIGHT EXPERIMENT							
FLIGHT EXPERIMENT/SPACECRAFT							
INTEGRATED TCS/PACKAGE	$100 K	$200 K	$175 K	$200 K	$300 K	$500 K	
CONCEPTS AND TRADES							
HARDWARE BREADBOARD							
THERMAL-VACUUM TEST							
INTEGRATED HARDWARE							
MODULAR INSULATION	$175 K	$200 K	$200 K	$200 K			
TRADES							
TEST ARTICLE							
THERMAL-VACUUM TESTS							

The propulsion subsystem can be subdivided into five elements: (1) the pressurization subsystem, (2) the propellant tank assembly, (3) the propellant feed system assembly, (4) the thruster assembly, and (5) the pressure relief assembly. Each assembly presents its own design/concept problems when developing the best propulsion system for the given application.

For the Spacecraft 90 study, the preferred reaction control system (RCS) elements are shown on a chart. The selections imply a small RCS impulse velocity requirement (100 - 300 ft/sec) with no on-orbit servicing. Should the impulse velocity requirement become large, a GN_2 or GH_e pressure-regulated pressurization system and large propellant tanks with vane or screen-type propellant management devices may be the better choices. If maneuvering for survivability is to be part of the on-orbit propulsion system, strong consideration would be given to pump-fed bipropellant thrusters for maneuvering and pressure-fed RCS thrusters. If on-orbit servicing is a requirement, the manual fill and drain valves would be replaced with quick disconnects capable of being remotely engaged and disengaged.

The orbit transfer vehicle for the Spacecraft 90 study can be either a tandem of solid rocket motors or a cryogenic propellant stage such as the Centaur G vehicle. For the small payloads (less than 5,000 lbm) the available solid rocket motor designs (payload assist modules (PAMs) Thiokol STAR motors, Shuttle compatible orbit transfer stage (SCOTS), inertial upper stage (IUS), etc.) offer a cost-effective solution. However, for the heavier payloads (greater than 5,000 lbm), the Centaur G and G' vehicles are the better choices. A possible intermediate alternative between an IUS and Centaur vehicle is the combination transfer orbit stage and apogee and maneuvering stage (TOS/AMS) developed by Orbital Sciences Corporation and Martin-Marietta. The TOS is essentially the same as the first stage of the IUS and the AMS is a bipropellant propulsion system which could also be used as the on-orbit RCS or as the retrieval stage. The final selection is based on vehicle lifting capability and overall cost. Should retrieval or de-orbiting be a requirement, an AMS concept is almost mandatory.

The zero-g propellant transfer technology has to be fully developed if refueling in space is to occur. In 1984, the orbital refueling demonstration test and the storable fluid management demonstration test involving water and hydrazine propellant confirmed the Shuttle capability to provide this service. However, more work has to be done; not only with hydrazine propellant, but with MMH/N_2O_4 and LOX/LH_2 propellants as well.

PROPULSION SUBSYSTEM

SUBSYSTEM ELEMENT	SELECTED ALTERNATIVE		
	FOR RCS	FOR OTV	
		SRM	LIQUID
PRESSURIZATION S/SYST	GN_2 BLOW-DOWN	NA	AUTOGENOUS, PR. REG.
PROPELLANT TANK ASSY	SPHERICAL W. ELASTOMER DIAPHRAGM	FIL WOUND CASINGS	ELONGATED TANKS W. ELLIP. ENDS
PROPELLANT FEED SYST. ASSY	SMALL TUBING/MANUAL F/O VALVES	NA	VAC. JACKETED W. QUICK DISCONNECT
THRUSTER ASSY	N_2H_4 OR MMH/N_2O_4	SOLID	LOX/LH_2
PRESSURE RELIEF ASSY	BURST DISC/RELIEF VALVE	NA	RELIEF VALVE ASSY

PROPULSION SUBSYSTEM TECHNOLOGY PROJECT

- ZERO-G PROPELLANT TRANSFER - HYDRAZINE, MMH/N_2O_4, LOX/LH_2

PROPULSION SUBSYSTEM SELECTION

These two charts are intended to show the preferred choices of each subassembly of the propulsion subsystem. However, these selections are generalizations and for a particular application, a lower ranking subassembly selection presented herein may be the better choice.

A blowdown or pressure-regulated pressurization system is the top choice for this assembly. Total propulsion system weight normally is used to select the desired option between these two concepts. By way of contrast, an autogenous ("bootstrap") pressurization system is the best choice for a LOX/LH_2 booster during thruster operation. Cost, complexity as well as system weight are used as discriminators in making the final selection. The pressurization system assemblies presented are well developed, or nearly so; thus the state-of-the-art (SOTA) rankings given are either a "3" or "2".

The propellant tank assembly selection is subdivided into two parts: tank shape and propellant management device (PMD). Packaging constraints, manufacturing capability, whether the system is 3-axis stabilized or a spinner, costs and availability are the selection drivers for tank shape. All tank shapes may have a cylindrical section added to its design to increase its propellant volume capacity. The teardrop shape is a popular RCS tank choice for spinning spacecraft while a common bulkhead tank design has been used on LOX/LH_2 boosters. The PMD design and cost become very significant for spacecraft. Elastomeric diaphragms are the preferred choice; however, because of size or material incompatibility, screens or vanes or propellant settling via exterior thrusting may be the superior choice. An advantage of the spinning spacecraft is that it does not need a PMD for its tank since the centrifugal force causes the propellant to be oriented to the outer portion of the tanks. Finally, the tank material selection is driven by material compatibility with the propellant and cost.

PROPULSION SUBSYSTEM SELECTION

ASSEMBLY: Pressurization Subsystem (Liquid and Gas Systems Only)

Ranking	Description	SOTA
1	Blowdown	3
1	Pressure-Regulated	3
2	Autogenous*	3
3	Self-Pressurized*	3
4	Piston/Bellows	2
5	Combustion Products	2

NOTE: SOTA = State-of-the-Art

*Liquid Systems Only

ASSEMBLY: Propellant Tank

Ranking	Shape Description	SOTA
1	Sphere	3
1	Ellipsoid	3
1	Teardrop	3
2	Common Bulkhead	3
3	Torus	2
4	Regular Polygon	1

Propellant Management Device

Ranking	Description	SOTA
1	Elastomers	3
2	Screens/Vanes	3
2	Spinning System	3
2	Ext. Thrusting	3
3	Pistons/Bellows	2
4	Baffles	3

The propellant feed system material selection is a function of propellant compatibility. The line size of the assembly is governed by the permissible pressure drop within the assembly. The available valving and thermal control designs for the propellant feed system are well developed and the best choice is a function of the application. For example, if the vehicle is not to be re-serviced, a manual fill and drain valve is usually the best choice; however, if the spacecraft is to be re-serviced, a quick disconnect (pneumatically or mechanically actuated) is the better selection. If zero leakage is a requirement, pyrotectic (squib) valves become the obvious choice. The same applies to the method of thermal control for the assembly. Cryogenic systems usually use vacuum-jacketed lines and insulation while earth-storable propulsion systems use heaters to maintain the system above a lower temperature limit. Nearly all of the assembly elements have mature, flight-proven designs.

The thruster assembly selection is the key element that drives the design of the propulsion system. For example, if a liquid chemical engine is chosen, a propellant feed system assembly is required and nearly always, a pressurization system assembly is required. By way of contrast, if a solid rocket motor assembly is used, the propellant tank assembly selection is the only other real propulsion system assembly selection. The designs of the liquid chemical thrusters, the solid rocket motors, and inert gas thrusters are flight-proven, mature concepts, while the designs of the electric (pulsed plasma or magnetoplasmadynamic) and nuclear thrusters need additional development to be used as frequently as the liquid chemical thrusters. It should be mentioned that some electric thruster designs have already been used in flight, but the thrust is small (less than 0.002 lbf) and the required specific power (electric power per unit of thrust) is high. Lastly, the laser and solar thermal engine designs show much promise, but these thrusters need a lot of development before they are ready for flight usage.

The pressure relief assembly is a safety feature used in liquid or pneumatic systems to prevent an excessive overpressure condition within the system. Most pressure relief assembly designs are flight-proven and mature. Typical assemblies are a relief valve, burst disk, vent valve, or expanding volume configurations. A favorite design for spacecraft is a burst disk in series with a relief valve; thus, the assembly will not allow leakage until its first usage.

PROPULSION SUBSYSTEM SELECTION (CONTINUED)

ASSEMBLY: Propulsion Feed System (Liquid or Gas Systems Only)

Ranking	Material Description	SOTA	Ranking	Valves Description	SOTA	Ranking	Thermal Control Description	SOTA
1	Aluminum	3	*	Electrically-Operated	3	*	Passive	
1	Stainless Steel	3	*	Pneumatically-Operated	3		o Insulation	3
2	Other	2	*	Manual	3		o Vacuum-Jacketed	3
			*	Pyrotectic	3	*	Active	
							o Heaters	3
							o Shunts	3
							o Vapor-Film Cooling	3

* Ranking Dependent Upon Application

ASSEMBLY: Thrusters (Engines)

Ranking	Description	SOTA	Ranking	Description	SOTA
1	Solid Rocket Motor	3	3	Magnetoplasmadynamic Engines	2
1	Liquid Chemical Engines	3	3	Nuclear Engines	2
1	Inert Gas Thrusters	2	4	Laser Thrusters	1
2	Pulsed Plasma Engines	2	5	Solar Thermal Engines	1

ASSEMBLY: Pressure Relief

Ranking	Description	SOTA
1	Burst Disc/Relief Valve Comb.	3
2	Burst Disc	3
2	Relief Valve	3
2	Vent Valve	3
3	Expending Volume	2

PRESSURIZATION ASSEMBLY
(APPLIES TO LIQUID OR GAS SYSTEMS ONLY)

The purpose of the pressurization system (PS) is to supply sufficient ullage pressure to meet the engine inlet or pump inlet pressure requirements during thruster operation. For those propulsion systems with zero NPSH pumps and propellant with relatively high vapor pressures, the ullage space is sufficient and no other hardware is required. Some liquid propulsion system concepts utilize a separate inert gas PS to supply the pressure either in an ullage-pressure-regulated mode or a ullage-blowdown mode. Still other concepts use an inert gas system to supply the ullage pressure initially and subsequently switch to superheated propellant vapor extracted from the engine during operation (autogenous mode). For cold gas systems, the propellant and pressurization system are one and the same.

Regardless what type of PS is used, it must interface with the propellant tank assembly. If the PS contains gas tanks and other supporting hardware, the PS is usually serviced through its own fill and drain system and generally required to interface with a pressure relief assembly to protect the subsystem from over pressure. The PS may require active thermal control to maintain it within desired temperature limits. Typically, the PS is instrumented to monitor the supply pressure in the gas tanks and the ullage pressure. Temperature readout instrumentation is normally optional for the PS even with active thermal control.

If the PS is to be serviced in orbit, quick or remotely-actuated disconnects are used in lieu of manual fill and drain valves. In addition, it is advantageous to mount all of the pressurization system supporting hardware (disconnects or fill and drain valves, regulators, relief valve subassembly, transducers, etc.) on an easily-accessable panel for ease of maintenance and checkout.

PROPULSION SUBSYSTEM REQUIREMENTS AND FUNCTIONS
PRESSURIZATION ASSEMBLY
(APPLIED TO LIQUID OR GAS SYSTEMS ONLY)

FUNCTION: SUPPLY THE DRIVING FORCE TO MOVE THE PROPELLANT FROM ITS TANKS TO THE PUMP OR ENGINE INLET

INTERFACES: PROPELLANT TANK ASSEMBLY
PRESSURE RELIEF ASSEMBLY
THERMAL CONTROL SUBSYSTEM
INSTRUMENTATION, DISCONNECTS
ELECTRICAL POWER SUBSYSTEM

REQUIREMENTS: TO PROVIDE SUFFICIENT ULLAGE PRESSURE TO MEET THE ENGINE INLET OR PUMP INLET PRESSURE REQUIREMENTS DURING THRUSTER OPERATION

ISSUES: SYSTEM TYPE: AUTOGENOUS, COLD GAS, SELF-PRESSURIZED, OTHER. AVAILABLE THERMAL CONTROL & PRESSURANT CONTROL. RESERVICING, PACKAGING (TANK QUANTITY), OPERATING PRESSURE

The purpose of the propellant tank assembly (PTA) is to contain and manage the propellant during all phases of flight. For a gas propulsion system, the PTA is normally one or more spherical tanks. For a liquid propulsion system, the PTA shape selection is generally dictated by the packaging constraints. Some of the more common tank shapes are spherical, elliptical, or toroidal. Each one of these shapes may have a cylindrical mid-section. Almost all liquid tanks have a propellant management device (PMD) (diaphragms, bladders, screens, vanes, etc.) for zero-g control. Those liquid tanks that don't have a PMD tend to be spinners, i.e., the use of centrifugal force for propellant control or tend to use the propellant settling technique with the aid of an auxiliary propulsion system (cold gas, monopropellant, etc.). For solid rocket motors (SRMs), the PTA is typically a filament-wound casing which holds the solid propellant, propellant liner, and propellant ignitor subsystem. For electric propulsion systems which use teflon or other solid material, there is no PTA, per se, while those with liquid propellants, e.g., mercury, typically have a PMD.

Almost all PTAs require thermal control, either passive or active, and a pressure relief assembly. SRMs do not require a pressure relief assembly. Generally, there is pressure and temperature monitoring of the propellant. The pressure and temperature transducers may be part of the feed system assembly rather than within the PTA.

As seen in the enclosed graph, the PTA has several issues which must be resolved before the final tank configuration and quantity are selected. Although tank servicing-in-flight is a new technology, the envisioned requirements do not cause any radical changes in existing tank concepts.

PROPULSION SUBSYSTEM REQUIREMENTS AND FUNCTIONS
PROPELLANT TANK ASSEMBLY

FUNCTION: PROVIDE STORAGE VOLUME FOR PROPELLANT(S)

INTERFACES:
- PRESSURIZATION SYSTEM
- PRESSURE RELIEF ASSEMBLY
- THERMAL CONTROL SYSTEM
- ELECTRICAL POWER SUBSYSTEM
- FEED SYSTEM ASSEMBLY
- INSTRUMENTATION (GAGING, TEMP., PRESSURE)

REQUIREMENTS: TO PROVIDE SUFFICIENT PROPELLANT TO THE THRUSTER ASSEMBLY VIA THE FEED SYSTEM UNDER ALL GRAVITY CONDITIONS FOR ALL MISSION MANEUVERS

ISSUES:
- TANK QUANTITY
- AVAILABLE THERMAL CONTROL
- SLOSH CONTROL
- TANK VOLUME
- TANK CONFIGURATION (SPHERES, CYLINDERS, COMBINATION)
- PROPELLANT MANAGEMENT DEVICE (LIQUID SYSTEM ONLY)
- SERVICE LIFE, RESERVICING
- OPERATING PRESSURE

PROPULSION SUBSYSTEM REQUIREMENTS AND FUNCTIONS
PROPELLANT FEED ASSEMBLY
(LIQUID OR GAS SYSTEM ONLY)

The purpose of the propellant feed assembly (PFA) is to provide the fluid path between the propellant tank assembly and the thruster assembly. The PFA also provides the fluid path between the PTA and the ground or airborne support equipment. The PFA typically consists of the fluid lines, tank isolation valves, filters, quick disconnects or manual fill and drain valves, pressure and temperature transducers, and, in some applications, an in-line pump assembly. In addition, the PFA usually has a pressure relief assembly to protect the PFA from over pressure and a thermal control subsystem to keep the PFA within desired temperature limits.

For cryogenic propellants, the fluid lines are normally vacuum-jacketed, while the earth-storable propellants, the fluid lines are wrapped with insulation and/or have an active thermal control subsystem. The permissible pressure drop within the PFA, temperature limits and redundancy requirements drive the PFA design. In-flight remote-servicing requirements add complexity to the fluid disconnect design.

PROPULSION SUBSYSTEM REQUIREMENTS AND FUNCTIONS
PROPELLANT FEED ASSEMBLY
(LIQUID OR GAS SYSTEM ONLY)

FUNCTION: PROVIDE THE PHYSICAL LINK BETWEEN THE PROPELLANT TANKS (OR PUMPS) AND THE THRUSTER ASSEMBLY

INTERFACES:
- PROPELLANT TANKS (OR PUMPS)
- PRESSURE RELIEF ASSEMBLY
- THRUSTER ASSEMBLY
- DISCONNECTS, THERMAL CONTROL SUBSYSTEM
- ELECTRICAL POWER SUBSYSTEM

REQUIREMENTS: PROVIDE FLUID PATH TO THRUSTER ASSEMBLY. PROVIDE FLUID PATH TO TANKS FOR PROPELLANT FILL. PROVIDE TANK ISOLATION AND REDUNDANT FLUID PATHS.

ISSUES:
- ISOLATION VALVE TYPE (GAS, ELECTRICAL, PYRO, ETC.)
- PERMISSIBLE PRESSURE DROP (LINE SIZE, FLEX LINES, ETC.)
- REQUIRED REDUNDANT FLUID PATHS
- THERMAL CONTROL REQUIREMENTS

The purpose of the pressure relief assembly (PRA) is to protect the subassembly from over pressure. The PRA may be a vent valve, a relief valve, a burst disk, or a combination of two of these components. For example, a vent valve/relief valve concept has been used for cryogenic propellant tanks. The vent valve portion for ground operations during propellant loading/off loading and the relief valve portion during pressurized tank conditions. A relief valve in series with a burst disk is typical of spacecraft designs which do not permit gas leakage until the initial over pressure condition occurs. Some spacecraft may not want the resulting thrust force that a PRA would give; thus, a non-propulsive vent system is the usual design solution. The PRA concept that is finally selected is dependent upon the permissible leakage requirements of the system, whether the PRA is to function on the ground or in-flight, and if the mission has any non-propulsive venting requirements.

PROPULSION SUBSYSTEM REQUIREMENTS AND FUNCTIONS
PRESSURE RELIEF ASSEMBLY
(LIQUID OR GAS SYSTEMS ONLY)

FUNCTION: TO PROTECT THE SUBASSEMBLY FROM EXCEEDING ALLOWABLE INTERNAL PRESSURE LEVELS

INTERFACES:
- PRESSURIZATION SUBSYSTEM ASSEMBLY
- PROPELLANT TANK ASSEMBLY
- PROPELLANT FEED SYSTEM

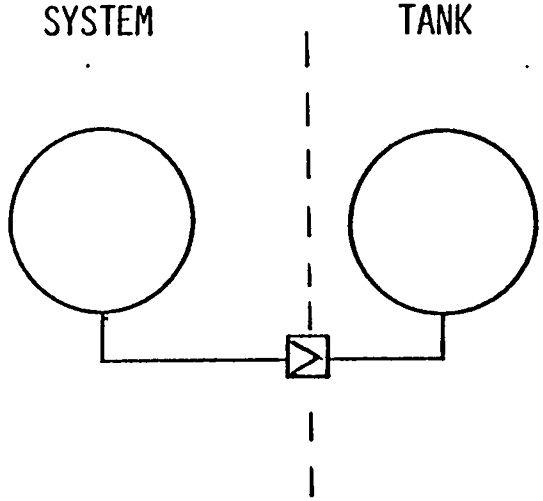
REQUIREMENTS: TO PREVENT THE SUBASSEMBLY INTERNAL PRESSURE FROM EXCEEDING THE MAXIMUM OPERATING PRESSURE (M-O-P) BY A GIVEN RATIO, NORMALLY 110 PERCENT OF THE M-O-P

ISSUES:
- PERMISSIBLE LEAKAGE
- NON-PROPULSIVE VENTING

If refueling in orbit is to become a reality, the technology associated with zero-g fluid transfer of all the popular propellant combinations must be fully developed. Propellant management, thermal control, and minimizing propellant spillage (disconnect design) are a few of the problems related to this technology. The NASA organization has already demonstrated zero-g fluid transfer of water inside the Shuttle cabin and has performed a zero-g propellant transfer test of liquid hydrazine in the cargo bay. However, these plans must be extended to encompass the popular earth-storable bipropellant, MMH/N_2O_4, and the cryogenic bipropellant combination of LOX/LH_2 as well as demonstrating the engaging and disengaging of the propellant disconnects remotely. Other propellant combinations, such as LH_2/LF_2, may require a proof-of-concept demonstration test in space. The hydrazine test called out on the chart denotes the simulation of a retrieved satellite with an N_2H_4 RCS which must be refueled.

The goal is to have a universal propellant transfer set which can accommodate all the fluids. This may not be possible, nonetheless, it is the goal. As seen in the Shuttle testing schedule chart, by the year 1992, the more popular propellant combinations should have been transferred in a zero-g environment. The funding shown on the chart are estimates and do not necessarily reflect the NASA budget for these tests.

TECHNOLOGY PROJECT PLAN
PROPULSION SUBSYSTEM
PROPELLANT TANK ASSEMBLY



PROBLEM

THE TECHNOLOGY OF ZERO-G PROPELLANT TRANSFER HAS NOT BEEN FULLY DEVELOPED. WITHOUT THIS DISCIPLINE, ON-ORBIT SERVICING OF FUELS WILL NOT BE ACCOMPLISHED.

OBJECTIVE

DEVELOP AN EFFICIENT METHOD OF TRANSFERRING PROPELLANTS IN SPACE WITHOUT EXCESSIVE OVERBOARD SPILLAGE.

APPROACH

DEVELOP PROTOTYPE AND GROUND TEST.
USE SHUTTLE FOR IN-SPACE PROOF-OF-CONCEPT EXPERIMENT.

EXPECTED RESULTS

A TRANSFER SYSTEM WHICH CAN BE USED TO DISPLACE ALL TYPES OF PROPELLANTS FROM ONE TANK TO ANOTHER.

SPECIAL FACILITIES/EQUIPMENT

ORBIT TRANSFER SYSTEM WITH SHUTTLE-COMPATIBLE PALLET.

FIELD OR SHUTTLE TEST FLIGHT

SHUTTLE TEST FLIGHT WITH ORBIT REFUELING SYSTEM IN CARGO BAY

- HYDRAZINE
- MMH/N_2O_4
- LOX/LH_2

RELATED TECHNOLOGY AREAS

- STRUCTURES
- THERMAL
- ELECTRICAL POWER

SCHEDULE (SHUTTLE TESTING)

	1984	1985	1986	1987	1988	1989	1990	1991
	▲ H_2O TRANSFER TEST		△ N_2H_4 TRANSFER TEST		△ MMH/N_2O_4 TRANSFER TEST			△ LOX/LH_2 TRANSFER TEST
FUNDING		300K	500K	300K	1M	500K	1M	2M

Blank

4.4 Electrical Power Subsystem (EPS)

The Electrical Power Subsystem consists of five (5) major assemblies as delineated on the chart. The requirements imposed on each assembly is derived from the definition of the three (3) S/C selected and their missions.

The study flow established a prudent methodology for deriving the requirements, listing plausible alternative, rating the alternatives for compatibility with the mission, their technology status, SOA and projected into the 1990's, and their merits within the study's guidelines.

Investigations, analysis and tradeoffs were performed.

The preferred alternatives were selected and the resulting option is shown facing each major assembly.

For each option selected, the technology status and needs were reviewed with governmental agencies, scientific bodies, industrial entities, and Rockwell internal programs and technical specialists.

Technology issues, plans and projects were defined and are recommended for the five EPS assemblies to assure an improved and advanced capability for the S/C of the 1990's.

Ranking highest is the development of the efficiency of GaAs retractable boom/array.

ELECTRICAL POWER SUBSYSTEM

SUBSYSTEM ELEMENT	SELECTED ALTERNATE
POWER SOURCE	SOLAR PHOTOVOLTAIC/PLANAR, GaAs
ENERGY STORAGE MGMT.	SWITCHING TYPE
ENERGY STORAGE	N1H2 BATTERY
POWER PROCESSOR	D.C. TO A.C. INVERTERS
POWER DIST'N AND MGM'T	A.C. - MEDIUM VOLTAGE, 3Ø, SINUSOIDAL

ELECTRICAL SUBSYSTEM TECHNOLOGY PROJECTS

- POWER SOURCE/ENERGY CONVERSION
- ENERGY STORAGE MANAGEMENT
- ENERGY STORAGE
- POWER PROCESSOR
- POWER DISTRIBUTION AND MANAGEMENT

ELECTRIC POWER SYSTEM

ELEMENT SELECTION

The chart opposite identifies the alternatives that were considered for each element of the thermal control subsystem, the ranking order of the selection, and a first measure of the State of the art of each alternative: (1 being the most advanced technology alternative; (2 being a known State of the art but still requiring major R&D; (3 being a developing technology, but yet requiring hardware verification for a particular mission.

ELECTRIC POWER SYSTEM

ELEMENT SELECTION

	S.O.A.
POWER SOURCE/ENERGY CONVERSION	
1. SOLAR PHOTOVOLTAIC - PLANAR, GaAs	3
2. SOLAR PHOTOVOLTAIC - HIGH CONCENTRATION (100) GaAs	3
3. SOLAR THERMAL - THERMOELECTRIC	3
4. SOLAR THERMAL - DYNAMIC	2
5. CHEMICAL - CRYO, STORABLE, SOLID - NO COMPATIBILITY WITH SC MODEL	n/a
6. NUCLEAR - RADIOISOTOPES, REACTOR - NO COMPATIBILITY WITH SC MODEL	n/a
ENERGY STORAGE MANAGEMENT	
1. BATTERY CHARGERS - SWITCHING TYPE, ADAPTIVE HYBRID PEAK POWER, SERIES	3
2. FUEL CELLS (SOLID STATE) - SWITCHING TYPE, ADAPTIVE HYBRID PEAK POWER, SERIES	3
3. BATTERY CHARGERS - SWITCHING TYPE, ADAPTIVE, SHUNT	3
4. FUEL CELLS - SWITCHING TYPE, DYNAMIC, ADAPTIVE HYBRID PEAK POWER, SERIES	3
5. FLY WHEELS - MAGNETIC SUSPENSION, REGENERATIVE INERTER	2
6. SOLAR THERMAL THERMOELECTRIC/DYNAMIC - ADAPTIVE TEMP., PRESSURE, VOLUME	2
7. INDUCTORS, CAPACITORS - NO COMPATIBILITY WITH SC MODEL	n/a
ENERGY STORAGE	
1. NiH2 BATTERY, CPV	3
2. REGENERATIVE FUEL CELLS, SOLID STATE	2
3. LiTiS2	1
4. FLYWHEELS	4
5. THERMAL	2
6. Ag H2	3
7. INDUCTORS CAPACITORS	n/a
POWER PROCESSOR	
1. D.C. to A.C. INVERTERS, HARMONIC CANCELLATION, INTEGRATED POWER CHIPS	3
2. D.C. to A.C. INVERTS, RESONANT CONTROLLED TYPE, INTEGRATED POWER CHIPS	2
3. D.C. to D.C. CHOPPERS/CONVERTERS - NOT COMPATIBLE WITH POWER MANAGEMENT SYS.	3
POWER DISTRIBUTION AND MANAGEMENT	
1. A.C., MEDIUM VOLTAGE, 3 PHASE, SINUSOIDAL, REDUNDANT CENTRAL INVERTERS	3
2. D.C., MEDIUM VOLTAGE, 3 WIRE, REDUNDANT CENTRAL CHOPPERS, D.C. PROTECTION	2
3. HYBRID DERIVATIVE OF A.C. SYSTEM FOR BOTH D.C. AND A.C.	2

The selected power/energy source is a GaAs planar photovoltaic array.

The functions, interfaces, requirements and issues of the power source /energy conversion are shown in summarized format.

A power recap for the three specified satellites is:

COMSAT - 1.2 KWe to the SC and payload

Advanced GPS - 5 KWe to the SC and payload

Material processing - 6 kWe to the SC and payload.

The material processing in space imposes the heaviest load, has most severe battery requirements and is subjected to environmental perturbations. However, the three EPSs retain the same generic functions and the tradeoffs resulted in commonality of the preferred selection.

The list of issues shown supplants the above in great detail.

EPS SUBASSEMBLY REQUIREMENTS AND FUNCTIONS
POWER SOURCE/ENERGY CONVERSION

FUNCTION:	GENERATE & CONVERT POWER AND ENERGY FROM AVAILABLE PRIMARY SOURCE--SOLAR PHOTOVOLTAIC INTO ELECTRIC ENERGY DURING LIGHT PERIODS.
INTERFACES:	SOLAR ENVIRONMENT ENERGY STORAGE MANAGEMENT SYSTEM POWER PROCESSOR/DISTRIBUTION INSTRUMENTATION
REQUIREMENTS:	FOR COMMERCIAL COMMUNICATION SATELLITE-- SUPPLY POWER TO SC AND ENERGY FOR BATTERY (~23 HRS.) FOR ADVANCED GPS--SUPPLY POWER TO SC AND ENERGY TO BATTERY (10 HOURS EVERY 11 HOUR PERIOD) FOR MATERIAL PROCESSING IN SPACE--SUPPLY POWER TO SC AND CHARGING ENERGY TO BATTERY FOR 68 MIN EVERY 103 MIN.
ISSUES:	VOLTAGE LEVEL, LONG LIFE, LOW DEGRADATION, HIGH EFFICIENCY, LOW DEVELOPMENT RISK, RELATIVE RADIATION RESISTANCE, LOW LIFE CYCLE COST, HIGH POWER AND VOLUMETRIC DENSITY, EASE OF ASSEMBLY, TESTING, SERVICING AND INTERCONNECTS.

The selected energy storage management (ESM) is the series switching type.

The functional requirements, interfaces, power/energy requirements and issues are detailed on the chart.

Ranking highest is the charge discharge philosophy. The ESM must insure achievement of the compatibility between the energy storage elements, power source and utilization. Thus, the ESM must be designed after the batteries are characterized, mission criteria defined, array specified and the load demand stipulated.

To insure a small array and maximum energy transfer, peak power tracking which will also command array position, is envisaged.

EPS SUBASSEMBLY REQUIREMENTS AND FUNCTIONS
ENERGY STORAGE MANAGEMENT

FUNCTION:	MANAGE AND CONTROL THE PROCESS, INTERFACES AND ELEMENTS OF THE ENERGY STORAGE SUBSYSTEM
INTERFACES:	ENERGY STORAGE ELEMENTS POWER SOURCE/ENERGY CONVERSION POWER PROCESSING POWER DISTRIBUTION AND MANAGEMENT
REQUIREMENTS:	FUNCTIONALLY SIMILAR FOR THE TYPES OF SATELLITES UNDER CONSIDERATION. HOWEVER, DUTY CYCLE AND RATING WILL BE HIGHEST FOR THE MATERIAL PROCESSING IN SPACE SATELLITE.
ISSUES:	CHARGE/DISCHARGE PHILOSOPHY CHARGE/DISCHARGE STATUS AND METERING COMPATIBILITY WITH INTERFACES HIGH EFFICIENCY HIGH POWER & VOLUMETRIC DENSITY EASE OF MANUFACTURING, INTEGRATION & TEST LOW LCC

The selected energy storage is the NiH_2 CPV battery.

The function, interfaces, requirements, and issues are discussed on the chart.

One of the critical issues of great concern is cycle life which, of course, is analogous to the total WHr that a secondary energy storage is capable of delivering at EOL. High volumetric and weight density are paramount relevant technology project goals.

EPS SUBASSEMBLY REQUIREMENTS AND FUNCTIONS

ENERGY STORAGE

FUNCTION: ACCEPT AND STORE ELECTRIC POWER DURING LIGHT PERIOD FOR USE AND DISCHARGE DURING ECLIPSE BY THE SPACECRAFT (SC) AND ITS LOADS.

INTERFACES: ENERGY STORAGE MANAGEMENT SYSTEM

- CHARGE DISCHARGE SYSTEM
- INSTRUMENTATION

REQUIREMENTS: FOR COMMERCIAL COMMUNICATION SATELLITE--72 MIN. EVERY 24 HRS. 5KW TOTAL LOAD (GEOSYNCHRONOUS)

FOR ADVANCED GPS--1 HR. EVERY 11-HR. PERIOD

FOR MATERIAL PROCESSING IN SPACE--35 MIN. EVERY 103-MIN. PERIOD

ISSUES: VOLTAGE LEVEL, LONG LIFE, HIGH CHARGE DISCHARGE CYCLE (~ 60,000)

HIGH ENERGY DENSITY

HIGH VOLUMETRIC DENSITY

HIGH TURN-AROUND EFFICIENCY AT EXPECTED DISCHARGE RATES

LONG SHELF LIFE

LOW COST, ACTIVE DEVELOPMENT IN PROCESS

The selected type of preferred power processor is the DC to AC inverter of the harmonic cancellation type, redundantly centralized.

The function, interfaces, requirements, and issues are shown in great detail on the facing chart. The requirements are identical to the three spacecraft. A power level between 1 kWe to 10 kWe should require a distribution voltage of 120/208 Vac and an array input to the processor of 120 to 240 Vdc.

Thus, the main issues evaluated were voltage level, centralized vs. decentralized processing and as further shown in the distribution assembly analysis and technology project plan.

EPS SUBASSEMBLY REQUIREMENTS AND FUNCTIONS
POWER PROCESSOR

FUNCTION:	TO ACCEPT RAW POWER FROM THE POWER/ENERGY SOURCE AND THE STORAGE SYSTEM FOR PROCESSING INTO QUALITY POWER SUITABLE FOR DISTRIBUTION AND UTILIZATION
INTERFACES:	POWER SOURCE/ENERGY CONVERSION ENERGY STORAGE AND ENERGY MANAGEMENT POWER DISTRIBUTION AND MANAGEMENT
REQUIREMENTS:	THE REQUIREMENTS OF THE THREE SATELLITES MAY BE SATISFIED BY AN IDENTICAL PROCESSOR MODULARIZED TO SUIT THE POWER LEVEL
ISSUES:	CENTRALIZED OR DECENTRALIZED PROCESSORS, EFFICIENCY, INPUT VOLTAGE LEVEL, OUTPUT VOLTAGE LEVEL, AC VS. DC, FREQUENCY, NUMBER OF PHASES, POWER FACTOR, TRANSIENT RESPONSE, EMI, STANDARDIZATION, ETC.

The selected EPS power distribution and management system consists of a single and 3-phase 120/208 Vac sinusoidal transmission which is rigorously specified and protected at each branch location to create a "user friendly" utility environment.

The functions, interfaces, requirements, and issues are documented on the chart.

Power quality was among the important issues treated. The 'space environment' was taken into account for proper evaluation of voltage level. None of the power carrying elements, except of course, the solar array, are directly exposed. However, the technology plan should be implemented to resolve those issues rigorously.

The subject of operating frequency is also recommended for further special analysis although the practicality of 400 Hz is technically most tempting.

SUBASSEMBLY REQUIREMENTS AND FUNCTIONS

EPS POWER DISTRIBUTION & MANAGEMENT

FUNCTION:	TO ACCEPT QUALITY POWER FROM THE POWER PROCESSORS. PROTECT THE SWITCHING AND FAULT ISOLATION EQUIPMENT. DISTRIBUTE THE POWER WITHOUT LOSING THE QUALITY AND VIOLATING INTEGRITY. CONTROL THE LOADS. PROVIDE MEANS FOR ASSESSING PERFORMANCE AT ANY DISTRIBUTION BUS LOCATION.
INTERFACES:	POWER PROCESSING POWER DISTRIBUTION LOAD MANAGEMENT
REQUIREMENTS:	THE REQUIREMENTS ARE BASICALLY IDENTICAL FOR THE THREE SATELLITES.
ISSUES:	VOLTAGE LEVEL, POWER QUALITY, SWITCHING METERING AND PROTECTION, EFFICIENCY, WEIGHT, SIZE AND BASIC CONCEPT OF BUSING.

The technology project plan for the power source/energy conversion is shown on the chart.

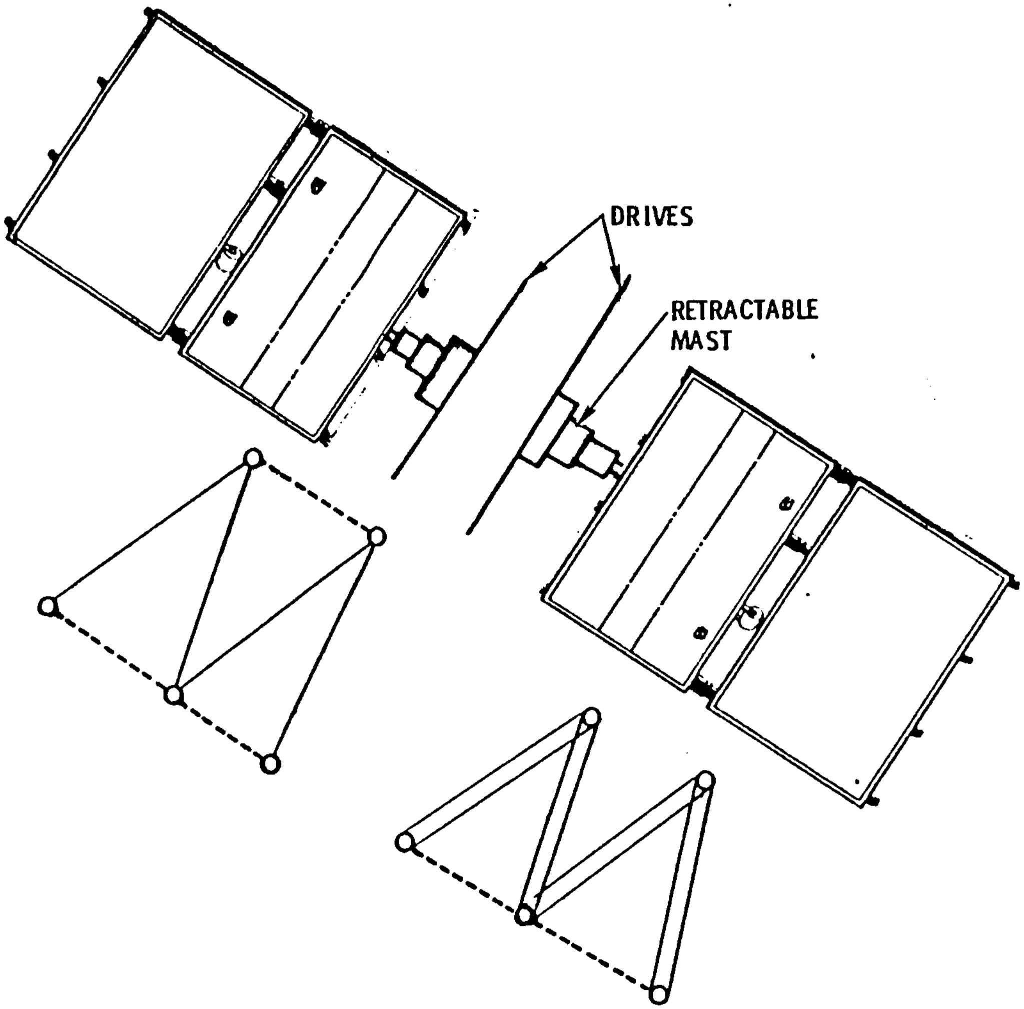
The problems needing solution, the objective, the method of approach with specific program tasks and the expected results for achieving an advanced power source are shown in detail.

A conceptual sketch of the array highlights the need for array retraction mechanisms to allow servicing, retrievability, modifications, controllability and possible threat situations.

TECHNOLOGY PROJECT PLAN

SUBSYSTEM: EPS

ASSEMBLY: POWER SOURCE/ENERGY CONVERSION



PROBLEM

HIGH EFFICIENCY, LONG LIFE, LOW DEGRADATION, HIGH POWER DENSITY, LOW LCC RETRACTABLE ARRAYS NEEDED FOR 1990

OBJECTIVE

DEVELOP A TWO DEGREES OF FREEDOM GaAs PLANAR ARRAY SYSTEM AND A FOLLOW-ON CONCENTRATION SYSTEM

APPROACH

- ESTABLISH AN INTEGRATED AUTONOMOUS CONCEPT FOR ARRAY LAYOUT, RETRACTABLE MASTING POWER TRANSFER AND DRIVES
- DESIGN, FABRICATE AND TEST THE ELEMENTS AND THE SYSTEM ENGINEERING MODELS
- FLIGHT QUALIFY WITH GROUND SIMULATOR A COMPLETE SYSTEM
- VERIFY BY SPACE FLIGHT COMPATIBILITY WITH INTENDED MISSIONS

EXPECTED RESULTS

ACQUIRE THE ENGINEERING AND HARDWARE BASE FOR DESIGN AND FABRICATION OF 1990's SPACECRAFTS

The technology project plan for the energy storage management (ESM) is shown on the chart.

The problems, objectives, approach to solutions, plan tasks and expected results are outlined.

A conceptual schematic highlights a typical energy storage management arrangement.

The need for compatibility between the ESM and the rest of the EPS, especially the energy storage system, (ESM), cannot be overstressed. The ESM, batteries, fuel cells or other elements must be carefully characterized in the same manner as any other circuit component (capacitors, transistors, etc.).

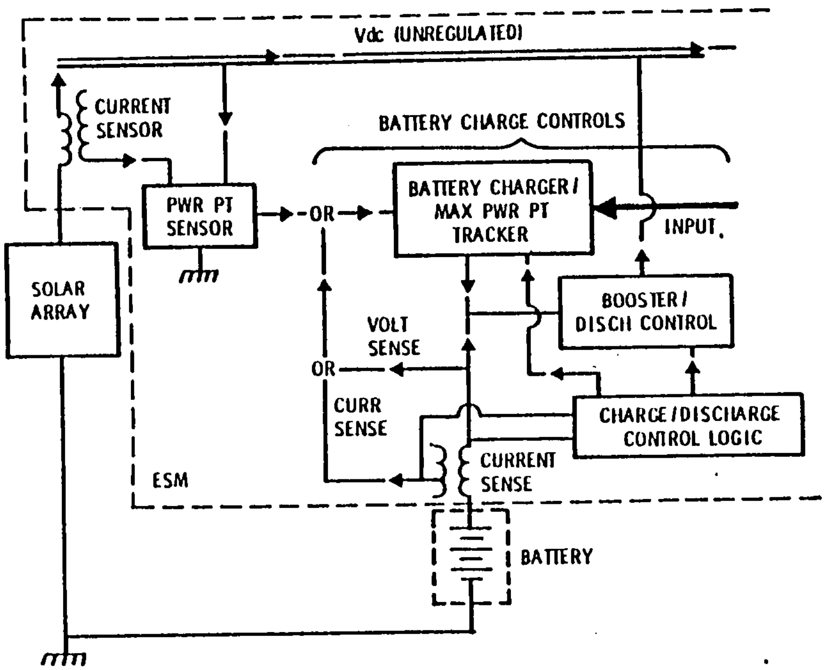
The manufacturing process and quality control must be consistent to allow the establishment of replicable data bank. Without such data, it is impossible to design acceptable ESM systems or expect consistent targetted performance from these designs. Once the ESM data is formally documented, a final design of the interfacing systems may be completed.

It may be desirable to insure that final steps of ES technology transfer should be performed by engineering personnel. Present practice is entrusted to electro-chemists or scientific personnel. The final result would be an adaptive programmable smart charger, energy storage and system 'friendly.'

TECHNOLOGY PROJECT PLAN

SUBSYSTEM: EPS

ASSEMBLY: ENERGY STORAGE MANAGEMENT (ESM)



PROBLEM

CHARGE AND DISCHARGE REGIME MUST BE COMPATIBLE WITH THE BATTERY, TO MAXIMIZE ENERGY AVAILABILITY OVER THE MISSION DURATION. IT MUST ALSO BE COMPATIBLE WITH THE EPS TO OPTIMIZE POWER DENSITY, RELIABILITY, LCC AND PRODUCIBILITY

OBJECTIVE

DEVELOP AN ENERGY STORAGE MANAGEMENT SYSTEM CONSISTING OF A CHARGER/DISCHARGER, CHARGE DISCHARGE CONTROLLER/PROCESSOR, LOCAL AND INTERFACE SENSORS

APPROACH

- ESTABLISH A DATA BANK CHARACTERIZING BATTERY PERFORMANCE PARAMETERS
- ESTABLISH AN INTEGRATED OPERATIONAL CONCEPT FOR THE BATTERY CHARGE/DISCHARGE MANAGEMENT, SOLAR ARRAY, POWER PROCESSOR AND LOADS
- EVOLVE REQUIREMENT SPECIFICATIONS, INCLUDING SERVICING AND REDUNDANCY
- DESIGN, FABRICATE, TEST AND OPTIMIZE THE ESM
- FLIGHT QUALIFY WITH GROUND SIMULATOR
- VERIFY BY SPACE FLIGHT AND CERTIFY FINAL CONFIGURATION

EXPECTED RESULTS

HAVE A FLIGHT QUALIFIED AND PROVEN EMS AND SUPPORTING DATA BANK

The technology project plan for the energy storage (ES) is shown on the chart.

The problems, objectives, approach, tasks and expected results are delienated. A conceptual mounting arrangement of NiH_2 batteries is shown.

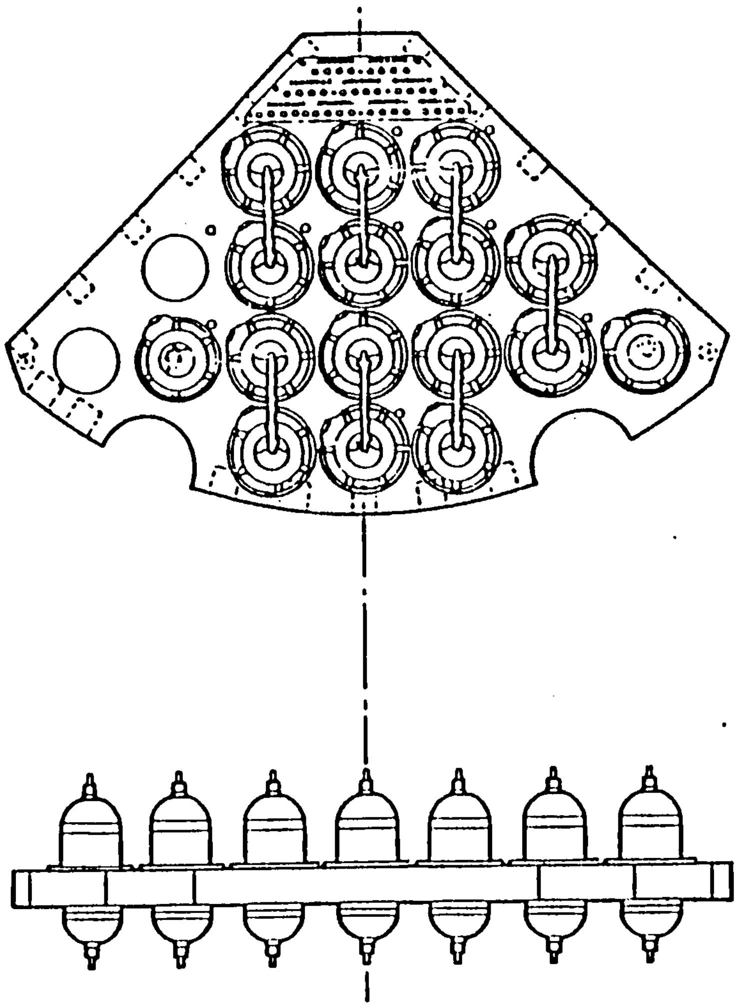
The development of a CPV NiH_2 battery that is consistently reliable as an engineering component is stressed. The technology plan is oriented toward that goal.

The results will yield a space qualified, reliable high grade component which may be designed into advanced spacecraft and yield predictable results without individual testing and customized, one of a kind EMS.

With known predictable characteristics, instrumentation of temperature, charge level, optimum voltage, charge regime and autonomous sequencing for array segmenting will be possible.

TECHNOLOGY PROJECT PLAN
SUBSYSTEM: EPS
ASSEMBLY: ENERGY STORAGE (ES)

CONCEPTUAL LAYOUT FOR NiH_2 BATTERIES



PROBLEM

HIGH ENERGY AND VOLUMETRIC DENSITY, HIGH CYCLE NUMBER AND HIGH EFFICIENCY LONG SHELF LIFE BATTERIES ARE NEEDED FOR THE 1990 SPACECRAFT

OBJECTIVE

TO CONTINUE AND DEVELOP A CPV NiH_2 BATTERY PACKS WITH BUILT IN MONITORING

APPROACH

- ESTABLISH A DEVELOPMENT AND TEST PLAN FOR BATTERIES
- BUILD UP A DATA BANK THROUGH TESTING AND ANALYSIS AND EVOLVE BATTERY REQUIREMENT SPECIFICATIONS FOR ESM DESIGN
- FABRICATE AND ASSEMBLE CELLS, BATTERIES, AND BANKS ENGINEERING MODELS
- VERIFY PERFORMANCE COMPATIBILITY VIA FLIGHT TEST ON A HOST SATELLITE

EXPECTED RESULTS

SPACE QUALIFIED INTEGRATED BATTERY/ ESM INSTRUMENTED

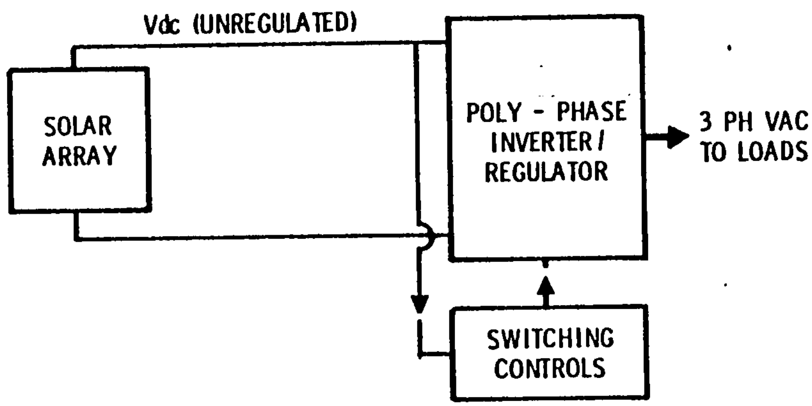
The technology project plan for the power processor is shown on the chart.

The problems, objective approaches, tasks and expected results are delineated. The simplified block diagram shows the conceptual interconnection between the array bus (d.c.) and the PP with the a.c. output leading into the distribution bus. Ring counters and pulse width modulators insure synchronization and harmonic cancellation.

The a.c. 3 ph, distribution system offers versatibility, flexibility, reliability and standardization, among other advantages. Transformer rectifiers may be used locally if required. Rotating field is available for machinery. The sinusoidal waveform insures fidelity of specification, minimization of EMI and compatibility with existing avionic equipment.

Centralized redundant processor offers the benefits of scale and attributes of efficienty analogous to a utility.

TECHNOLOGY PROJECT PLAN
SUBSYSTEM: EPS
ASSEMBLY: POWER PROCESSOR (PP)



PROBLEM

HIGH VOLTAGE (120/ 208 VDC) HIGH POWER (5 TO 8 KWE) HIGH RELIABILITY, HIGH EFFICIENCY, HIGH POWER AND VOLUMETRIC DENSITY INVERTER IS NEEDED FOR ADVANCED SPACECRAFT

OBJECTIVE

DEVELOP A SPACECRAFT SYSTEM COMPATIBLE MULTI-PHASE INVERTER

APPROACH

- CONDUCT A PROGRAMMABLE POWER PROCESSOR (P^3), REDUNDANCY, AUTONOMY, AND POWER QUALITY STUDY
- ESTABLISH INVERTER CONCEPT AND SPECIFICATIONS
- UPGRADE INTEGRATED POWER ELECTRONIC CHIP TECHNOLOGY
- DESIGN, FABRICATE AND TEST THE ELEMENTS AND ENGINEERING MODELS
- FLIGHT QUALIFY WITH GROUND SIMULATOR OF REPRESENTATIVE MISSIONS
- VERIFY VIA SPACE TESTS IN A FULLY INSTRUMENTED P.M.S.

EXPECTED RESULTS

ACQUIRE THE ENGINEERING CAPABILITY, FLIGHT EXPERIENCE PERFORMANCE DATA AND FLIGHT READY HARDWARE

The facing chart shows the technology project plan for power distribution and management.

The problems, objectives, approaches, and expected results are outlined. The concept for a generalized distribution network is shown on the sketch.

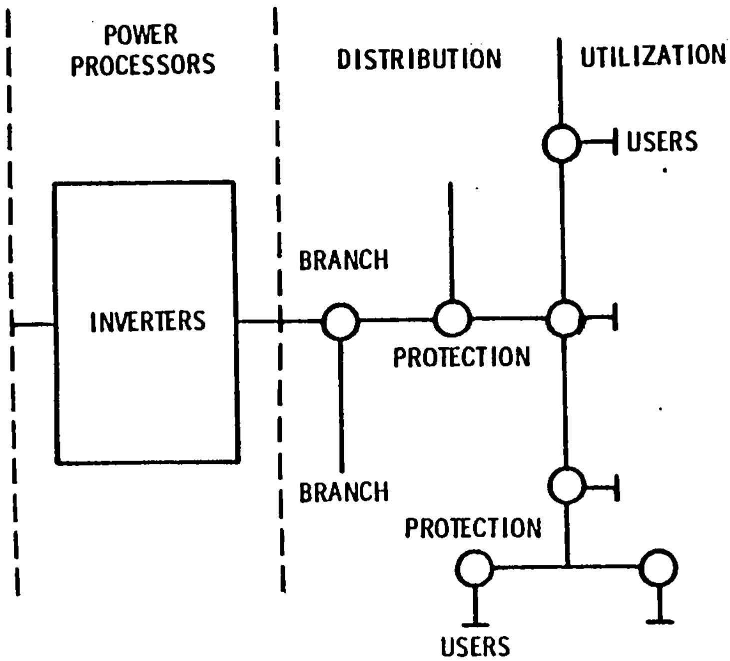
The analogy to a utility is observed. The user is protected from grid perturbation. The source is isolated from user anomalies by a series string of switches, fault isolators, and branch protection.

The grid is characterized and specified at each point; i.e., regulation, power quality, impedance, EMI, grounding, etc. Each user can design his black box confidently while the SC is being built. User may be "on" or "off" and addition of payloads may be made up to the full power rating, by "plugging in."

TECHNOLOGY PROJECT PLAN

SUBSYSTEM: EPS

ASSEMBLY: POWER DISTRIBUTION AND MANAGEMENT (PMS)



PROBLEM

THE NEED EXISTS TO DEFINE AND DEVELOP CONCEPTS AND HARDWARE FOR HIGH VOLTAGE, HIGH POWER DISTRIBUTION AND MANAGEMENT

OBJECTIVE

DEVELOP A STANDARDIZED LINE OF DISTRIBUTION AND PROTECTION EQUIPMENT

APPROACH

- CONDUCT A STUDY TO FIRM UP THE REQUIREMENT SPECIFICATIONS
- DEVELOP STANDARDIZED SWITCHING METERING AND LOAD CONTROL UNITS (LCU's) (INTERRUPTERS, LOAD BALLASTS, TELEMETRY)
- INCORPORATE IN GROUND TEST FLIGHT HARDWARE
- FLIGHT TEST SELECTIVELY THOSE COMPONENTS REPRESENTATING NEW TECHNOLOGY

EXPECTED RESULTS

PROVEN FLIGHT QUALIFIED DISTRIBUTION EQUIPMENT: TRANSFORMERS, SWITCHING GEAR, SHUNTS AND SINKS, CONTROL PROCESSORS, AND TRANSDUCERS

Technology plan recommended schedule and estimated budget are shown for power source/ energy conversion and energy storage management.

It is recommended that the ESM be carefully coordinated with the characterization of the energy storage. The broken line in the schedule spread sheet indicates a tracking period, with preliminary ESM design only.

TECHNOLOGY PLAN
SUBSYSTEM: EPS

TECHNOLOGY PROJECTS	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
POWER SOURCE/ENERGY CONVERSION	0.1 M	0.5 M	0.7 M	1.5 M	1.0 M
• ARRAY SYSTEMS CONCEPTS/DESIGNS					
• ARRAY SYSTEMS DEVELOPMENT					
• ARRAY SYSTEMS FAB & TEST EM's					
• ARRAY SYSTEMS FLIGHT TESTS					
• ARRAY SYSTEMS MULTIPLE SOURCE TRANSFER					
ENERGY STORAGE MANAGEMENT	0.1 M	0.2 M	0.2 M	0.6 M	1.0 M
• ESTABLISH TEST PLANS TO OBTAIN DATA BANK & COORDINATE WITH BATTERY TEST ACTIVITIES					
• ANALYZE TRADE & SELECT PREFERRED ESM CONCEPT					
• WRITE REQUIREMENTS SPECS					
• DESIGN, FAB & GROUND TEST CHARGE/DISCHARGE SYSTEM					
• PERFORM "IN SPACE" QUALIFICATIONS					

The schedule and estimated cost for the technology project plan for energy storage (ES) and power processing is shown.

TECHNOLOGY PLAN (CONTINUED)
SUBSYSTEM: EPS

TECHNOLOGY PROJECTS	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
ENERGY STORAGE	0.1 M	1.2 M	1.2 M	1.5 M	1.5 M
• VERIFY REQUIREMENTS AND COORDINATE SPECIFICATIONS					
• DESIGN & DEVELOP PROTOTYPE BATTERIES					
• FAB & TEST PROTOTYPES AND APPLICATIONS					
• ESTABLISH BATTERY DATA BANK, SPECIFICATIONS AND ESM INTERFACE					
• GROUND TEST QUALIFY					
• FLIGHT TEST QUALIFY					
POWER PROCESSING	0.2 M	0.5 M	0.7 M	0.7 M	1.0 M
• CONDUCT A (P^3) STUDY TO FINALIZE CONCEPT & SPECS					
• DESIGN, SELECT COMPONENTS, FAB & TEST ENGINEERING MODELS					
• FLIGHT QUALIFY WITH GROUND SIMULATOR					
• VERIFY WITH SPACE FLIGHT					

The schedule and projected budget for the power distribution and management is shown on the facing spread sheet.

TECHNOLOGY PLAN (CONTINUED)
SUBSYSTEM: EPS

TECHNOLOGY PROJECTS	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
POWER DISTRIBUTION AND MANAGEMENT	0.1 M	0.7 M	1.0 M	1.0 M	1.5 M
• REQUIREMENT SPECIFICATIONS					
• DEVELOP STANDARDIZED SWITCHING, MONITORING & FAULT PROTECTION					
• PERFORM GROUND FLIGHT TEST AND ANALYSIS					
• PERFORM INTEGRATED S/C (THERMAL, ELECTRICAL, STRUCTURAL) ENGINEERING MODEL TESTS					
• PERFORM SELECTIVE FLIGHT QUALIFICATION ON HARDWARE					
• INTEGRATE WITH TEST SPACECRAFT					

4.5 COMMUNICATION SUBSYSTEM

The elements of a communications subsystem consist largely of antennas, receivers, transmitters, and inter-connection devices. The antenna system requires the highest level of concentration because it is orbit sensitive as well as mission sensitive (designed to fit a specific orbit or mission). Further, the antenna is normally connected to both the receiver and transmitter establishing the figure of merit (G/T for receivers and EIRP for transmitters) for each.

A phased array antenna is versatile with respect to gain adjustment, beam steering, and for developing multiple beams. Its relative complexity compared to a prime focus fed parabola or cassegrain antenna is compensated for by these valuable systems features.

Advanced solid state and time switching devices are under study on many other programs such as Milstar, Acts, and others. The modest system gain in efficiency for these techniques does not warrant a dedicated effort for this program which could dilute the antenna improvement wherein large system gains are achievable.

COMMUNICATION SUBSYSTEM

SUBSYSTEM ELEMENTS	SELECTED ALTERNATES
HIGH GAIN ANTENNAS	PHASED ARRAY
RECEIVERS	TIME SWITCHING
TRANSMITTER	ADVANCED SOLID STATE

COMMUNICATIONS TECHNOLOGY PROJECT

FLEXIBLE ANTENNA SYSTEM

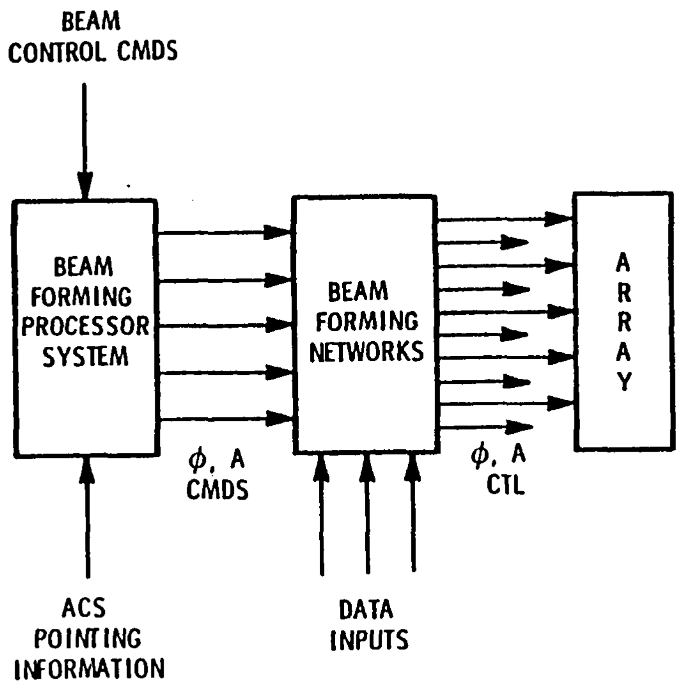
The flexible antenna system permits communications operating with several terminals simultaneously with adjustable gain commensurate with the data rates associated with the functions served by these terminals. The antenna could operate in a broad beam mode for emergency purposes simultaneously with narrow beam operations during mission orbital phases.

The antenna must receive attitude information from the Attitude Control System (ACS) for beam pointing and steering. The beam pointing processor adjusts the phase and amplitude of the signals to develop beams of proper signal direction to satisfy the mission needs. The beam forming networks permit the energy to be directed in the array to develop these beams.

The phased array is small in size in the EHF portion of the spectrum and its gain potential will result in orders of magnitude of improvement in information data rate with small impairment to the field-of-view of most mission sensors and/or blockage to the solar array. A further physical benefit is that electronic scanning does not impart unwanted forces on the spacecraft.

The project shown opposite, then, is directed at the development of an antenna that will not compound the problem of satellite "real estate" demands, but rather, helps to alleviate the problem by itself being of a small, phased array concept, not competing for surface area of the spacecraft.

TECHNOLOGY PROJECT PLAN - COMMUNICATIONS
FLEXIBLE ANTENNA SYSTEM



FLEXIBLE, MULTIBEAM ANTENNA SYSTEM

PROBLEM

- ANTENNA POINTING, GAIN AND BEAM QUANTITIES REQUIRED DURING SPACECRAFT LIFE VARY WITH THE ORBIT AND OPERATIONS PHASES. A FLEXIBLE, SMALL SIZED UNIT IS REQUIRED FOR 1990 SPACECRAFT

OBJECTIVE

- DEVELOP A VARIABLE GAIN ANTENNA SYSTEM WHICH CAN SCAN ± 60°, DEVELOP MULTIPLE BEAMS (AT LEAST TWO), CAN VARY BEAMWIDTH OVER A RANGE OF FROM 2 TO 120 DEGREES IN AN APERTURE OF LESS THAN 3 FT IN DIAMETER

APPROACH

- PERFORM DESIGN STUDY
- DEVELOP BREADBOARD AND TEST FEED NETWORKS AND ARRAYS
- PRODUCE AND VERIFY FINAL DESIGN
- PERFORM ON ORBIT PROOF-OF-CONCEPT

EXPECTED RESULTS

- QUALIFIED HARDWARE FOR SPACECRAFT APPLICATIONS

SPECIAL FACILITIES/EQUIPMENT

- COMPUTER/GRAPHICS SYSTEM; MICROPROCESSOR CONTROL SYSTEM DEVELOPMENT EQUIPMENT
- ANTENNA RANGE
- MICROWAVE (EHF) SYSTEMS DEVELOPMENT CONTROL EQUIPMENT

FIELD OR SHUTTLE TEST FLIGHT

- NONE

RELATED TECHNOLOGY AREAS

- ATTITUDE CONTROL
- STRUCTURES
- ELECTRONIC PACKAGING
- POWER
- THERMAL CONTROL

4.6 GN&C ASSEMBLIES

The GN&C subsystem is composed of the three assemblies described in the upper half of the chart: inertial reference, navigation, and attitude control. The chart is arranged to show these assemblies and their interfacing spacecraft subsystems through a digital data bus. Control of GN&C functions is maintained by software in Data Management Subsystem processors, and through ground RF links. The payload, solar array drive, antenna drive and propulsion receive data processed from GN&C sensor measurements.

GN&C ASSEMBLIES

INERTIAL REFERENCE SYSTEM

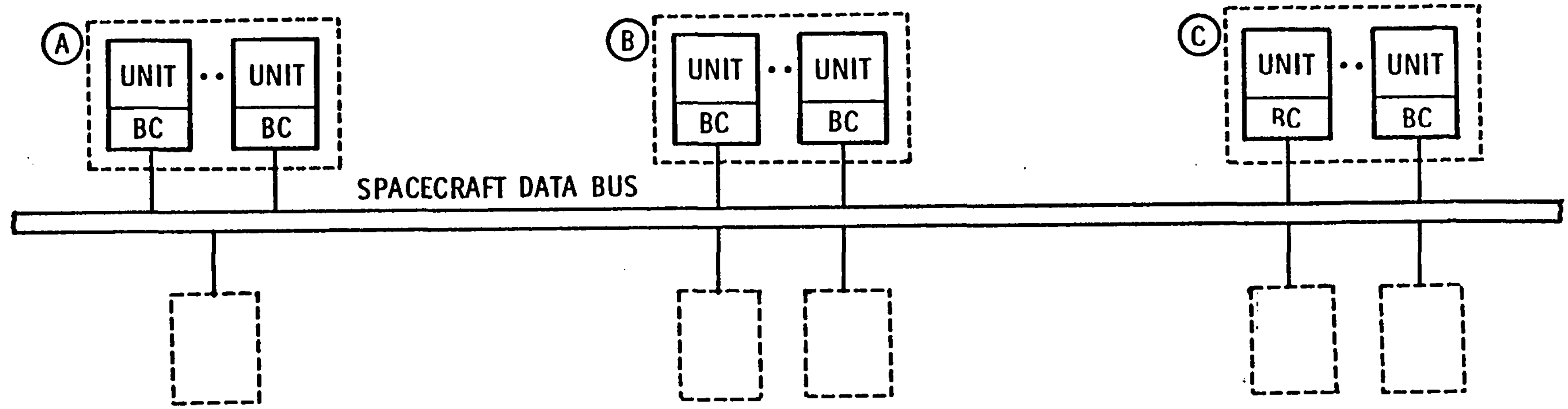
- STAR SENSORS AND GYROS
- EARTH DISK AND SUN
- GYRO COMPASSING
- EARTH MAGNETIC FIELD AND SUN

NAVIGATION MEASUREMENTS

- GROUND TRACKING
- GLOBAL POSITIONING SYSTEM
- EARTH LIMB STAR CROSSING
- STAR AND MOON POSITIONS

ATTITUDE CONTROL (3-AXIS STABILIZED)

- MOMENTUM WHEELS OR CMG'S
- MAGNETS
- TRIM TABS OR GRAVITY GRADIENT BIAS



TT&C

- UPLINK GND CMDS AND DATA
- DOWNLINK HEALTH AND STATUS DATA
- REMOTE CONTROL FOR LAUNCH AND DOCKING

GN&C DATA PROCESSING

- ATTITUDE AND NAV FILTERS
- ATTITUDE CONTROL LAWS
- PROPULSION, SOLAR ARRAY, AND ANTENNA STEERING
- MODE CHANGES AND COMPONENT SWITCHING
- INITIALIZATION, ACQUISITION, AND RE-ACQ
- HEALTH AND STATUS PROCESSING

CMD/DATA INTERFACES

- DELTA-V PROPULSION
  - ON-OFF AND SELECTION
  - STAGE SEPARATION
- SOLAR ARRAY AND ANTENNA DRIVES
  - MOTOR/ELECTRONICS CMDS
  - POSITION MEASUREMENTS
- PAYLOAD DATA
  - MEASUREMENT DATA
  - MODE COMMANDS

NOTES

- BC = BUS CONNECTOR ELECTRONICS
- UNITS CONTAIN ACCEPTANCE TEST POINTS

GUIDANCE, NAVIGATION AND CONTROL

The spacecraft guidance, navigation and control (GN&C) subsystem provides attitude orientation for the spacecraft during the periods of ascent to final orbit, coasting on-orbit operations, and orbit correction thrusting. It accomplishes this by use of both onboard and ground functions which establish inertial and Earth-local frames of reference. All GN&C functions fall into one of three assembly sub-classifications: inertial reference, navigation, or attitude control. The inertial reference system for future Earth orbiting civilian spacecraft will utilize sun and Earth sensors, with a radiation-hardened Earth sensor deemed the most needed improvement. Autonomous navigation -- complete spacecraft self-sufficiency from the ground or other satellites -- will greatly reduce navigational costs. Methods to relax the now-critical balance and symmetry required of spacecraft for optimum coasting attitude and thrust vector control will reduce future spacecraft design costs.

GUIDANCE, NAVIGATION AND CONTROL

SUBSYSTEM ELEMENT	SELECTED ALTERNATE
INERTIAL REFERENCE SYSTEM	HARDENED EARTH SENSOR
NAVIGATION SYSTEM	AUTONOMOUS NAVIGATION
ATTITUDE CONTROL SYSTEM	MASS PROPERTIES BALANCE

GN&C TECHNOLOGY PROJECTS

- INERTIAL REFERENCE SYSTEM - HARDENED EARTH SENSOR
- NAVIGATION SYSTEM - AUTONOMOUS OPERATIONS
- ATTITUDE CONTROL - RELAXATION OF MASS PROPERTIES REQUIREMENTS

ASSEMBLY SELECTION

The chart opposite lists the alternates to each of the GN&C's assemblies in their selection rank order, and the current level of the state of the art of each alternative (1 = most advanced technology; 2 = known technology but requiring major development; 3 = requires engineering development only).

GUIDANCE, NAVIGATION & CONTROL

- ASSEMBLY SELECTION -

RANKING	S.O.A.
• INERTIAL REFERENCE S/SYST (LOCAL ANGULAR ORIENTATION)	
1. HARDENED EARTH SENSOR	1
2. CONVENTIONAL EARTH SENSOR	3
3. MAGNETOMETER	3
4. GROUND BEACON	2
5. CROSSLINK	2
6. ION SENSOR	1
• INERTIAL REFERENCE S/SYST (INERTIAL ANGULAR POSITION AND RATE)	
1. SUN DETECTOR	3
2. GYRO ASSEMBLY	3
3. STAR SENSOR	3
• NAVIGATION SYSTEM	
1. AUTONOMOUS	2
2. GROUND TRACKING	3
3. SATELLITE TRACKING	2
• ATTITUDE CONTROL	
1. MASS PROPERTIES BALANCE	2
2. MOMENTUM WHEELS, MAGNETS, & RCS	3
3. CMGs, MAGNETS, & RCS	3
4. GRAVITY GRADIENT	2

The functions of the inertial reference assembly are to measure spacecraft angular position and rate, and to control the thrust vector direction in orbit correction operations. The inertial reference assembly utilizes environmental radiation sources and interfaces strongly with the spacecraft computer, electrical power, thermal control, and structural subsystems. Software needs dominate the onboard computer capacity and speed requirements, but performance requirements are dictated primarily by other spacecraft subsystems and the payload. Sensor costs increase dramatically with accuracy requirements, thus a major issue is to reduce these requirements while at the same time improving component life, reducing complexity, and increasing autonomy.

GN&C REQUIREMENTS/FUNCTIONS
INERTIAL, REFERENCE ASSEMBLY

- FUNCTIONS: MEASURES SPACECRAFT ANGULAR VECTOR POSITION & RATE
  MEASURES SPACECRAFT TRANSLATIONAL VECTOR ACCELERATION

- INTERFACES: EXTERNAL ENVIRONMENT (STARS, SUN, EARTH GRAV, EARTH MAG, PROPULSIVE ACCEL)
  HARDWARE
  - COMPUTER I/O
  - STRUCTURE
  - THERMAL CONTROL
  - ELECTRICAL POWER

  SOFTWARE
  - COMPUTER COMMANDS
  - SEPARATION INITIALIZATION & RETRIEVAL MECHANISMS

- REQUIREMENTS: MEASURE SPACECRAFT ATTITUDE TO ACCURACY DICTATED BY
  - PAYLOAD
  - THERMAL CONTROL
  - ELECTRICAL POWER
  - SEPARATION & RETRIEVAL MECHANISMS

  MEASURE SPACECRAFT TRANSLATIONAL ACCELERATION IN THRUSTING PERIOD

- ISSUES: VERY HIGH COST VS ACCURACY CURVE--
  LONG LIFE, LOW COMPLEXITY, PROVEN COMPONENTS & SOFTWARE
  EXTERNALLY MOUNTED COMPONENTS WITH PLUME & SHADOW-FREE FIELDS OF VIEW
  HARDENED, AUTONOMOUS FROM GROUND OR RECOVERABLE AFTER FAILURE

GN&C REQUIREMENTS/FUNCTIONS -- NAVIGATION ASSEMBLY

Spacecraft navigation has the function of measuring the orbital position and rate to the accuracy needed by the payload and other subsystems. Factors that effect navigation accuracy are highly approach-dependent, but include environmental disturbances (atmospheric drag, magnetic field, solar pressure, and gravitational anomalies) and celestial object measurement accuracies. Currently, most navigation is preformed using data from frequent tracking by ground stations. The next step in technology is to use Global Positioning System (GPS) or TDRS satellites for navigational data. Ultimately, Earth-star measurement techniques will lower navigation costs and provide independence from other sources.

GN&C REQUIREMENTS/FUNCTIONS
NAVIGATION ASSEMBLY

- FUNCTIONS -
  - MEASURES SPACECRAFT ORBITAL VECTOR POSITION AND RATE DURING
    - COAST & PAYLOAD OPERATIONAL PERIODS
    - THRUST PERIODS
    - SEPARATION AND RETRIEVAL
- INTERFACES-
  - EXTERNAL ENVIRONMENT (AIR DRAG, SOLAR PRESSURE)
  - HARDWARE (GPS RECVRS OR ADV TECH STAR/EARTH LIMB SENSORS)
    - COMPUTER I/O
    - STRUCTURE
    - THERMAL CONTROL
  - SOFTWARE
    - GROUND TRACKING UPLINK, GPS DATA PROCESSING, OR AUTONOMOUS PROCESSING
    - SEPARATION INITIALIZATION
    - PREDICTION INPUT DATA FROM PROPULSION & UPLINK
- REQUIREMENTS -
  - MEASURE SPACECRAFT POSITION AND VELOCITY TO ACCURACY DICTATED BY
    - PAYLOAD
    - ELECTRICAL POWER
    - RETRIEVAL SYSTEMS
- ISSUES -
  - LONG LIFE, LOW COMPLEXITY, PROVEN COMPONENTS & SOFTWARE
  - HARDENED, AUTONOMOUS FROM GROUND OR RECOVERABLE AFTER FAILURE

GN&C REQUIREMENTS/FUNCTIONS -- ATTITUDE CONTROL ASSEMBLY

The spacecraft attitude control assembly controls attitude during payload operations, orbit correction thrusting, and in many cases during the launch by a separate stage. Both external and internal environments produce torque disturbances which the attitude control system must be designed to overcome. In recent years the technology advances in attitude control design have resulted in more efficient and reliable operation, but have neglected potential design philosophy improvements which would benefit other subsystems; thus the major issue is that the interfaces with these other subsystems need attention.

GN&C REQUIREMENTS/FUNCTIONS
ATTITUDE CONTROL ASSEMBLY

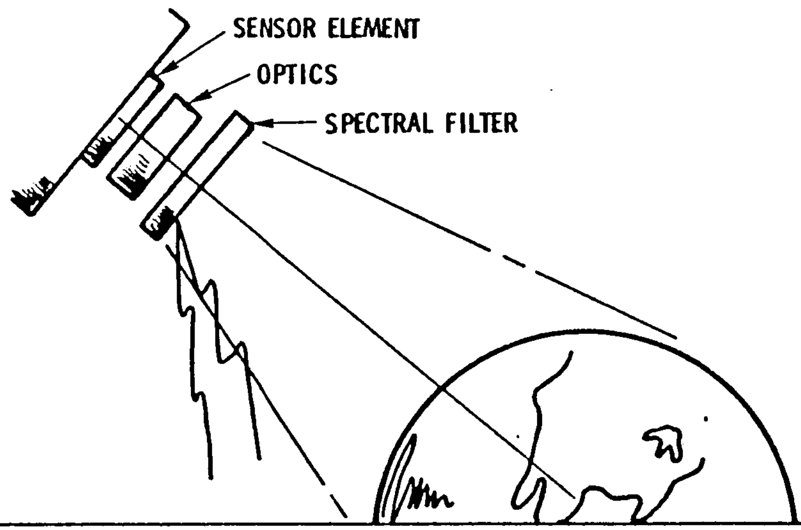
- FUNCTIONS -
  - MAINTAIN SPACECRAFT COASTING ATTITUDE
  - STEER THRUST VECTOR FOR ORBIT CORRECTIONS
  - MANEUVER SPACECRAFT IN ATTITUDE
- INTERFACES -
  - EXTERNAL ENVIRONMENT (AIR DRAG, EARTH MAG, EARTH GRAV, SOLAR PRESS)
  - INTERNAL ENVIRONMENT (S/C DIPOLE, MOMENT OF INERTIA, STATIC TRIM, DYNAMIC DISTURBANCES)
  - HARDWARE
    - COMPUTER I/O
    - STRUCTURE
    - THERMAL CONTROL
    - ELECTRICAL POWER
  - SOFTWARE
    - COMPUTER COMMANDS
    - MODE & STATUS MEASUREMENTS
    - FEEDBACK SENSOR MEASUREMENTS
- REQUIREMENTS -
  - PROVIDE TORQUES TO CONTROL DISTURBANCES & MAINTAIN ATTITUDE
- ISSUES -
  - LARGE NUMBER OF APPROACHES AVAILABLE
  - USUALLY INFLUENCES OVERALL SPACECRAFT DESIGN
  - ELECTROMECHANIC DEVICES REQUIRE REDUNDANT & BACKUP DESIGNS

TECHNOLOGY PROJECT PLAN -- GN&C SUBSYSTEM -- HARDENED EARTH SENSOR

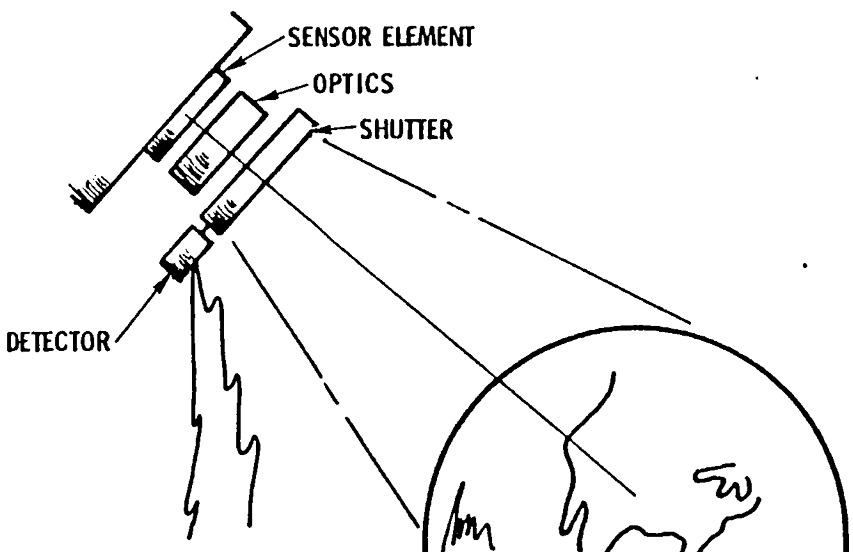
Techniques to measure two axes of the spacecraft attitude from the relative position of the Earth disk have been used for many years; however, precision and operating life of these sensors should be improved by increased protection against natural radiation. Military spacecraft could also benefit from Earth sensor hardening since it would be less susceptible to man-made radiation. Two approaches should be investigated: spectral filtering and mechanical screening using a shutter. A trade of the two approaches would allow one approach to be selected for development and ground testing, followed by standard flight qualification.

TECHNOLOGY PROJECT PLAN
GN&C SUBSYSTEM
HARDENED EARTH SENSOR

• SPECTRAL EXCLUSION APPROACH



• ELECTROMECHANICAL SHUTTER APPROACH



PROBLEM

- EARTH SENSORS ARE MATURE TECHNOLOGY, BUT ARE PRONE TO RADIATION DEGRADATION

OBJECTIVE

- TO DEVELOP A PROTECTIVE OR RECOVERABLE SENSOR, ABLE TO WITHSTAND LASERS AND A-BOMBS

APPROACH

- STUDY FILTER AND SHUTTER CAPABILITIES
- TEST PROTOTYPES IN LABORATORY
- SELECT ONE METHOD FOR DEVELOPMENT
- GROUND TEST FOR PROTECTIVE LEVEL MEASUREMENTS
- FLIGHT QUALIFY

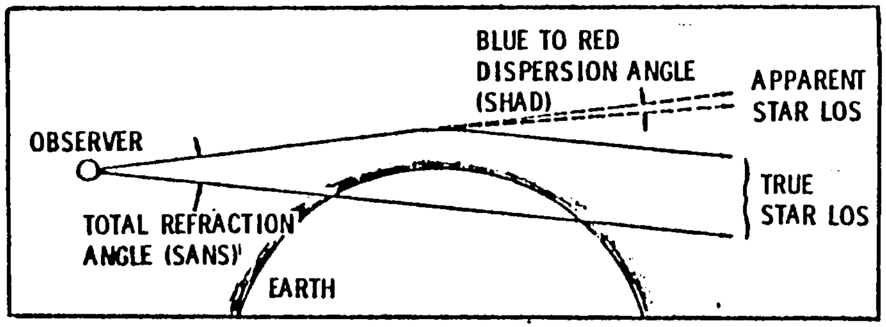
EXPECTED RESULTS

- ACQUIRE NEW HARDENED EARTH-REFERENCED ATTITUDE MEASUREMENT CAPABILITY

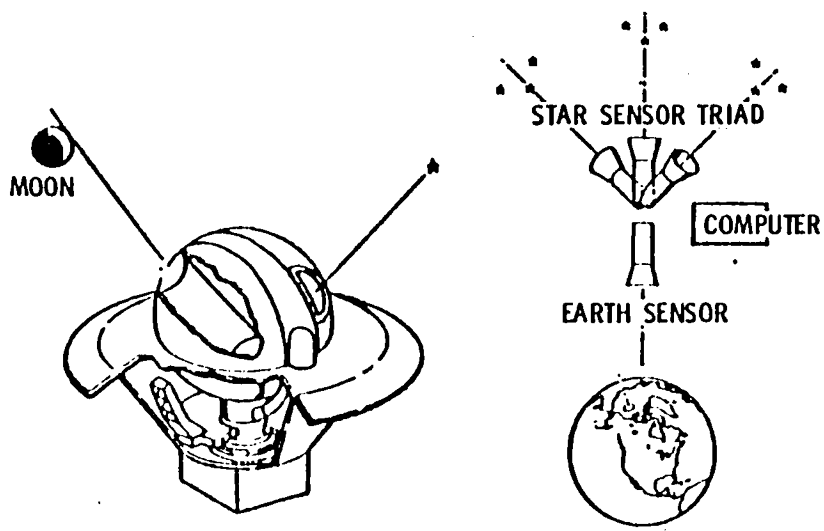
Theoretical and design studies of autonomous navigation systems have been keeping pace with computer processing and electro-optical technology advancements, but have not received comparable interest and funding. An early version of space sextant has flown as a Shuttle payload, and the Stellar Horizon Atmospheric Dispersion (SHAD) system will be a payload on the P80-1 spacecraft. Two others in earlier development stages are the Stellar Autonomous Navigation System (SANS) and the Multi-Mission Attitude Determination and Autonomous Navigation (MADAN) system. All four systems are capable of equalling or exceeding present day system accuracies, and each should be studied to select one for accelerated development and use in the 1990's. The selected one should be ground tested, extensively flight tested, and utilized for navigation of the test spacecraft.

TECHNOLOGY PROJECT PLAN
GN&C SUBSYSTEM
AUTONOMOUS NAVIGATION SYSTEM

- SANS AND SHAD



- MANDAN AND SPACE SEXTANT



PROBLEM

- AUTONOMOUS NAVIGATION SYSTEMS ARE SLOWLY BEING DEVELOPED, BUT ARE NEEDED IMMEDIATELY

OBJECTIVE

- TO SPEED DEVELOPMENT OF MOST PROMISING METHODS

APPROACH

- COMPARE COST AND VERSATILITY OF EACH METHOD
- SELECT ONE METHOD FOR ACCELERATED DEVELOPMENT
- DEVELOP LOW COST APPROACH FOR SELECTED METHOD
- GROUND TEST AND FLIGHT QUALIFY

EXPECTED RESULTS

- ACQUIRE NEW AUTONOMOUS NAVIGATION SYSTEM FOR 1990's SPACECRAFT

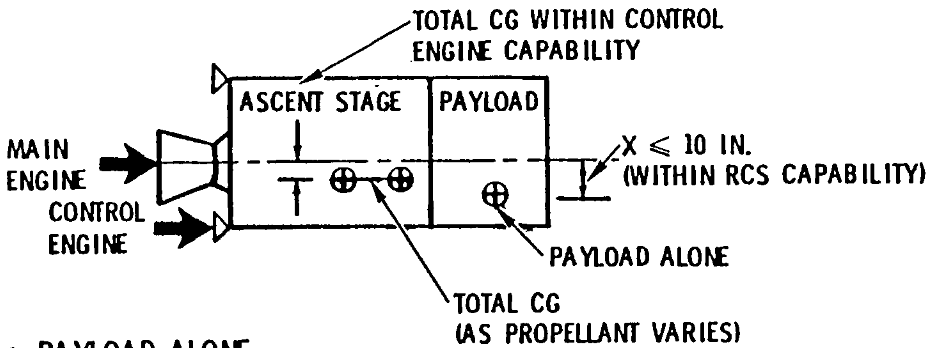
TECHNOLOGY PROJECT PLAN -- GN&C SUBSYSTEM -- RELAXATION OF S/C MASS PROPERTIES REQUIREMENTS

Currently, each spacecraft is designed with careful attention to mass properties balance. This is crucial to the stabilization of spinning spacecraft, but is also needed for current three-axis stabilized spacecraft in order to minimize RCS and main propulsion propellant, and the size of momentum wheels, control moment gyros, and magnets. The approach causes literally thousands of man-hours to be spent in the spacecraft design effort on locating each component to maintain balance and symmetry. Shuttle-launched spacecraft need no longer be as severely weight limited as those that are launched by expendable boosters, however, and thus may trade additional weight for design simplicity. More propellant and larger control components may be needed, to control center of gravity offsets. Interaxis coupling caused by significant products of inertia (mass dissymmetry) may be overcome through modern control law concepts and nonorthogonal magnets that react with the Earth magnetic field. A study of these approaches, including computer simulations, should be undertaken to define spacecraft mass properties bounds imposed by controllability, and should be flight tested using the test spacecraft.

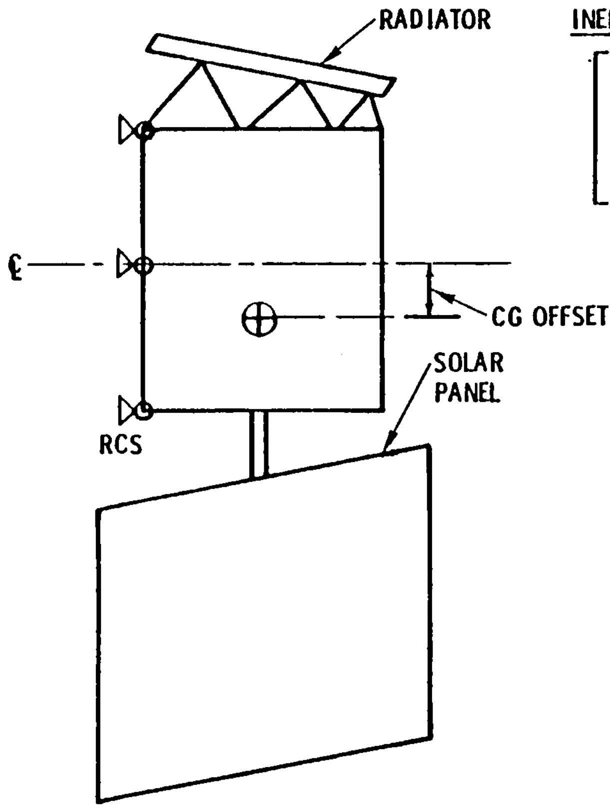
TECHNOLOGY PROJECT PLAN

RELAXATION OF S/C MASS PROPERTIES REQUIREMENTS

- PAYLOAD + ASCENT STAGE (AFTER SHUTTLE SEPARATION)



- PAYLOAD ALONE



INERTIA TENSOR:

$$\begin{bmatrix} I_{xx} & P_{xy} & P_{xz} \\ P_{yx} & I_{xy} & P_{yz} \\ P_{zx} & P_{zy} & I_{zz} \end{bmatrix}$$

WHERE $P_{ij} >> 0$

PROBLEM

- SATELLITES ARE CURRENTLY BALANCED TO FORCE CG TO ℄ WITHIN 1/8-INCH
- BALANCE COMPROMISES ALL OTHER SUBSYSTEMS, LENGTHENS CABLES, AND INCREASES STRUCTURE ... (INCREASES COST)

OBJECTIVE

- TO RELAX CG AND PRODUCTS OF INERTIA (P_{ij}) REQUIREMENTS

APPROACH

- DEFINE CG AND P_{ij} REQUIREMENTS FROM
  - SHUTTLE SEPARATION AND RETRIEVAL CAPABILITY
  - ASCENT STAGE TOTAL CG BOUNDS
- DEVISE CONTROLLABLE MAGNET ASSEMBLY TO PROVIDE TORQUE BIAS PROFILE
- DERIVE DETAILED FUEL SLOSH MODEL USING MODERN COMPUTER TECHNOLOGY
- SIZE RCS PROPELLANT QUANTITY AND MOMENTUM WHEEL CAPACITY
- PERFORM COMPUTER TIME SIMULATION
- INTEGRATE SYSTEM INTO SPACECRAFT DESIGN

EXPECTED RESULTS

- SHORTER, LESS COSTLY SPACECRAFT DEVELOPMENT CYCLE

TECHNOLOGY PLAN - GN&C SUBSYSTEM

Schedule and cost estimates for the three GN&C subsystem technology advancement program recommendations are shown in the chart. Estimates for the hardened Earth sensor, autonomous navigation system, and relaxation of mass properties requirements developments are $1.7M, $1.9M and $1.6M, respectively, and represent 4 to 5 year programs.

TECHNOLOGY PLAN
GN&C SUBSYSTEM

TECHNOLOGY PROJECTS	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
HARDENED EARTH SENSOR	0.5 M	0.5 M	0.5 M	0.2 M	
• FEASIBILITY STUDIES AND TEST					
• GROUND TESTS					
• FLIGHT QUALIFICATION					
AUTONOMOUS NAVIGATION SYSTEM	0.2 M	0.6 M	0.5 M	1 M	0.5 M
• APPROACH COMPARISON AND SELECTION					
• DEVELOP STANDARD VERSION					
• GROUND TESTS					
• FLIGHT QUALIFICATION					
RELAXATION OF S/C MASS PROPERTIES REQMTS	0.2 M	0.3 M	0.4 M	0.6 M	0.1 M
• ANALYSIS AND SIMULATION					
• SPACECRAFT INTEGRATION					
• FLT VERSION DEV AND GROUND TEST					
• FLIGHT QUALIFICATION					

4.7 DATA MANAGEMENT SUBSYSTEMS

The Data Management Subsystem consists of eight basic elements; the first four are hardware related, the second four software related. Overall vehicle requirements bound not only the range of options possible for each subsystem element, but also influence the selection criteria when performing the trades necessary to determine the selected alternatives for each subsystem element.

The Data Management Technology Projects address the methodology of satisfying vehicle requirements based on history, manufacturing, testing, and mission specifications. Although three distinct plans are outlined, they are interrelated and directly influence each plan's result.

DATA MANAGEMENT SUBSYSTEMS

SUBSYSTEM ELEMENTS	SELECTED ALTERNATIVES
PROCESSORS	GENERAL PURPOSE
STORAGE	OPTICAL
CABLES/CONNECTORS	FIBRE-OPTIC
INTERFACES	BIU-VHSIC
ORGANIZATION	DISTRIBUTED RESOURCES CONTROL
LANGUAGES	HIGH ORDER (ADA)
PROCESSING	PLESIOSYNCHRONOUS
ARCHITECTURE	STANDARD/FUNCTIONAL

DATA MANAGEMENT TECHNOLOGY PROJECTS

- DISTRIBUTED PROCESSING ARCHITECTURE - MODULAR, FAULT TOLERANT, AUTONOMOUS
- HIGH SPEED INTERNODAL CONNECTIONS & CABLES - FIBRE OPTIC
- STANDARD SUBSYSTEM/DMS ACCESS, LOGIC, POWER SWITCHING

The facing page depicts the software components of the data management system. They are listed in order of selection, followed by a numerical indication of technology maturity - (1) not mature, (2) needing additional development, (3) mature, needing application techniques.

DATA MANAGEMENT SYSTEM
SELECTION/RANKING
SOFTWARE COMPONENTS

	ORGANIZATION	LANGUAGES	PROCESSING	ARCHITECTURE
1.	DISTRIBUTED RESOURCES/CONTROL (2)	[3]HIGH ORDER (2)	PLESIOSYNCHRONOUS (2)	[4]STANDARDIZED/ FUNCTIONAL (2)
2.	LOCAL PROCESSOR CENTRAL CONTROL (2)	ASSEMBLY (3)	ASYNCHRONOUS (3)	STANDARDIZED/ PHYSICAL (2)
3.	DEDICATED SUBSYSTEM PROCESSORS CENTRAL CONTROL (3)	MACHINE (3)	SYNCHRONOUS (3)	CUSTOM/ PHYSICAL (2)
4.	LOCAL PROCESSING HEIRARCHICAL CONTROL (3)			
5.	CENTRALIZED PROCESSOR/CONTROL (3)			

3 - ADA: IMMATURE LANGUAGE

4 - BASED AROUND 1750A INSTRUCTION SET ARCHITECTURE AND INCLUDES TOPOLOGY, NETWORKS, AND PROTOCOLS

STATE OF ART = ( )

DATA MANAGEMENT SYSTEM
SELECTION/RANKING
HARDWARE COMPONENTS

The facing page depicts the hardware components of the data management system. They are listed in order of selection followed by a numerical indication of technology maturity - (1) not mature, (2) mature, but needing additional development, (3) mature needing application techniques.

DATA MANAGEMENT SYSTEM
SELECTION/RANKING
HARDWARE COMPONENTS

	PROCESSORS[1]	STORAGE	CABLES/CONNECTORS	INTERFACE
1.	GENERAL PURPOSE (3)	OPTICAL (1)	FIBER OPTIC[2] (1) (INTEGRATED OPTOELECTRONICS)	BIU + VHSIC (1)
2.	PARALLEL (3)	BUBBLE (2)	COAX (3)	MUX/DEMUX (3)
3.	ARRAY (3)	PLATED WIRE (3)	TWISTED SHIELDED PAIR (3)	CONVERTERS (3)
4.	SIGNAL (3)	TAPE (3)	WIRE (3)	
5.		DISK (3)		

1 - EACH TYPE HAS MULTIPLE SUBSETS BASED ON CONFIGURATION OF I/O, MEMORY, RM METHODOLOGY

2 - SPECIFIC TYPE DEPENDENT UPON ENVIRONMENT & REQUIREMENTS

( ) = STATE OF ART

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

PROCESSORS (VHSIC TYPE)

The Data Management Subsystem processor hardware consists of multiple sets operating under dynamic reconfiguration criteria--as opposed to replication of elements. Maximum processing capability, standardized architecture, and designed-in fault tolerance, while simultaneously minimizing size, power, and weight, are properties common to processors utilizing VHSIC technology and advanced spacecraft design concepts.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

PROCESSORS (VHSIC TYPE)

FUNCTION:

PROVIDE DATA PROCESSING CAPABILITY IN MULTIMEGA BIT RANGE
SIZE, POWER, WEIGHT, FAILURE RATE, LIFE CYCLE COST REDUCED BY 1/10
STANDARDIZED ARCHITECTURE
FAULT TOLERANT

INTERFACES:

BETWEEN INPUT/OUTPUT DEVICES - ACCEPTS SENSOR DATA, PROCESSES AND OUTPUTS TO SUBSYSTEM OR STORAGE ASSEMBLIES VIA BIU
PROVIDES GATEWAY BETWEEN SPACECRAFT DATA PROCESSING AND PAYLOADS (PROVIDES SERVICE TO PAYLOADS)

REQUIREMENTS:

LONG LIFE WITHOUT MAINTENANCE, HIGH DEPENDABILITY, RADIATION HARDNESS, WEIGHT, POWER, VOLUME MINIMIZATION, EXCESS PROCESSING CAPABILITY

ISSUES:

UNDER DEVELOPMENT - HARDWARE DRIVEN, PROPRIETARY DESIGN DATA
FRAGMENTED APPROACH TO DESIGN - DOES NOT INCLUDE RANGE OF ATTRIBUTES

FIBER OPTIC CABLES/COUPLERS

Fiber optic data transmission media possess those qualities most conducive to advanced spacecraft design; i.e., accommodation of extremely high data rates, minimal weight and volume, low susceptibility to EMI, and the capability to accept media access technology advancements as they mature. With regard to the latter attribute, the extremely high transmission rates permit incorporation of integrated opto-electronic transmitters and receivers with logic devices.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

FIBRE OPTIC CABLES/COUPLERS

<u>FUNCTION</u>: PROVIDE A WIDE BANDWIDTH CAPABILITY (500 MBPS DATA RATES)

- o BUILT-IN GROWTH PROVISION
- o MINIMIZE NUMBER OF CABLES
- o MINIMIZE POWER/WEIGHT/VOLUME

PROVIDE EMI DATA TRANSMISSION ENVIRONMENT

PROVIDE THE CAPABILITY TO INTEGRATE DATA & VIDEO (MINIMIZE CONNECTIONS)

<u>INTERFACES</u>: BETWEEN THE TRANSMITTING AND RECEIVING DPS NODES

<u>REQUIREMENTS</u>: PERMIT A TAXONOMY OF COST/EFFECTIVE MULTIPOINT DPS ARCHITECTURES

- o TOPOLOGIES - TRANSMISSION SYSTEM
- o ACCESS TECHNIQUES - ALLOCATION OF SYSTEM BANDWIDTH

<u>ISSUES</u>: RELIABILITY OF OPTICAL COMPONENTS

COMPATIBILITY OF F.O. & WIRE

COUPLINGS (ACTIVE/PASSIVE)

OPTICAL ELECTRONIC INTERFERENCE

RADIATION TOLERANCE

Standardization of interfaces between data processing elements, as well as between DMS and satellite subsystems such as guidance, navigation and control, electrical power, thermal control, etc., can be accomplished by two differing methodologies. The first forces input and output data and command characteristics into a single, non-flexible format. The second approach, utilizing the attributes of the OSI reference model, provides for the functional separation of data processing tasks. This allows information flow control, monitoring and fault isolation to occur independent of satellite vehicle processing tasks. In summary, an intelligent bus interface unit, when used in conjunction with appropriate host software, becomes an integral part of a seven-layer protocol based on the ISO Open System Interconnect Reference Model.

This separation of functions allows for a more flexible, heterogeneous mix of satellite subsystems.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

BUS INTERFACE UNIT

FUNCTION: PROVIDE A CONNECTION TO THE COMPUTER SET NETWORK WHILE POSSESSING THE FOLLOWING CAPABILITIES:

- o SEPARATION OF SUBASSEMBLIES FROM VEHICLE PROCESSING (INDEPENDENT DEVELOPMENT)
- o RELIABLE TRANSMISSION OF DATA TO PROCESSING NODES
- o ERROR DETECTION AND ISOLATION
- o INDIVIDUAL AND GROUP ADDRESS RECOGNITION
- o MEDIA ACCESS MECHANISM
- o AUTOMATIC REROUTING UPON ERROR DETECTION

INTERFACES: SUBSYSTEMS - THERMAL, EPS, COMM., ETC.
PROCESSORS - ALGORITHM, MODING & DATA PROCESSING

REQUIREMENTS: ABILITY TO MAINTAIN S/C DATA PROCESSING PERFORMANCE IN THE PRESENCE OF SYSTEM ANOMOLIES

ISSUES: STANDARDIZATION OF INTERFACES

- o SOFTWARE
- o HARDWARE

POWER/WEIGHT/VOLUME/COST
PROTOCOLS
MEDIA ACCESS METHODOLOGY
TRANSPORT LAG

INTEGRATED OPTO-ELECTRONICS

The integration of data processing functions, optical transmitters, and receivers on the same LSI integrated circuit die provides for a size and weight reduction as well as a technology approach that would provide for a standard, digital satellite data processing system. Data could be encoded and processed at the point of origin, eliminating the need to buffer and clock out data at centralized points, as in a multiplex/demultiplex architecture. Fault isolation, high connectivity, uniform delay time, high reliability, short signal transfer time, broadcast capability, and efficient transmission of bursty data are attributes of an integrated opto-electronic DMS.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

INTEGRATED OPTOELECTRONICS

FUNCTION: INTEGRATION OF HIGH SPEED DIGITAL ELECTRONICS AND OPTO-ELECTRONIC DEVICES ON THE SAME LSI INTEGRATED CIRCUIT DIE

INTERFACES:

SUBSYSTEM-TO-SYBSYSTEM INTERCONNECTIONS

- o GALLIUM ARSENIDE LASER TYPE TRANSMITTER TO FIBER OPTIC CABLE
- o GALLIUM ARSENIDE RECEIVER

BOARD-TO-BOARD INTERCONNECTIONS

CHIP-TO-CHIP INTERCONNECTION

REQUIREMENT: INTERCONNECT CHIPS, BOARDS, OR SYSTEMS WITH SERIAL OPTICAL (FIBER OR FREE SPACE) CHANNELS

ISSUES:

DEVELOP RISK - 5-YEAR DEVELOPMENT

SYSTEM DESIGN IMPACT

NETWORKS

In developing a strawman network for an on-board satellite DMS, it is necessary to consider overall network communication requirements. This includes input characterization and definition, performance criteria, access protocol alternatives, assessment of gateways, impact of data rate differentials (housekeeping and payload), reliability, and guidelines for distributed operating systems. The majority of these efforts must be performed more or less simultaneously during network development.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

NETWORKS

FUNCTION: PROVIDE THE SUPPORT INTERCONNECTS IN TERMS OF TOPOLOGY/CONNECTIVITY, MEDIA, PROTOCOLS, ACCESS TECHNIQUES AND NETWORK OPERATING SYSTEM

INTERFACES: THE NETWORK IS THE PRIMARY DATA TRANSMISSION MECHANISM USED FOR DPS NODAL INTERCONNECTS; THIS INTERCONNECT EXISTS BETWEEN SUBSYSTEMS, ASSEMBLIES, AND USER EQUIPMENTS

REQUIREMENTS: DATA TRANSFER IS IN ESSENCE BI-MODAL, SUBSYSTEM SIGNAL REQUIREMENTS ARE IN THE KBPS RANGE WHILE PAYLOAD SUPPORT SERVICES COULD EXCEED 50 MBPS

ISSUES:

- o A MEASURE OF HOW CLOSELY THE NODES IN THE SYSTEM ARE LINKED
- o THE NUMBER OF PERMISSIBLE LEVELS & GATEWAYS PERMISSIBLE
- o RELIABILITY, AUTONOMY, MODULARITY, TEST, AND COST INTERRELATIONSHIPS FOR SELECTED TOPOLOGIES

HIGHER ORDER LANGUAGE (HOL) - ADA

The most appropriate software language for satellite DMS should be an industry standard language that is strong is reliability and maintainability and also supports distributed processing. Although ADA is not mature, it has exceptionally heavy government and industry backing. It has been designed specifically for general D.O.D. use--supporting structured programming, multi-tasking, real-time programs, and available for 1750 Instruction Set Architecture (ISA).

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

HIGHER ORDER LANGUAGE (HOL) - ADA

FUNCTION: PROVIDE THE CAPABILITY TO SPECIFY MISSION OBJECTIVES IN FORM AND FORMAT CLOSE TO NATURAL LANGUAGE

INTERFACES: PRIMARILY WITH DATA PROCESSING EQUIPMENT

REQUIREMENTS:
- MACHINE INDEPENDENCE
- HIGHLY STRUCTURED
- INFORMATION HIDING (PROGRAM TO PROGRAM)
  - o INTERFACE DEPENDENT ONLY
- LOWER COSTS
  - o DESIGN, DEVELOPMENT, INTEGRATION & CHECKOUT, OPERATIONS, MAINTENANCE

ISSUES:
- (RELATIVE TO ADA)
- IMMATURE COMPILER
- APPLICATION EXPERIENCE IN SPACE OR COMPLEX ENVIRONMENT
- PORTABILITY (MACHINE TO MACHINE)
- VERIFICATION DUE TO LANGUAGE COMPLEXITY
- COMPATIBILITY OF ADA TO EXPERT SYSTEMS AND AI

EXPERT SYSTEMS/ARTIFICIAL INTELLIGENCE (AI)

Demands on future spacecraft include autonomy from ground and/or space-based control centers. This autonomy creates the need to replace the decision-making process generated by external support centers, with an on-board capability. Software, flown on satellites currently, is designed for standard repetitive problems. Future spacecraft software will need to deal with adaptive problem solving. The interactive handling of functions, together with the need to possess problem-solving capability, is tied somewhat to an organized base of knowledge.

Expert systems exploit this knowledge base in such a way as to constrain the search for solutions. In this sense, expert system complexity is related to the existing knowledge base. For future spacecraft this knowledge base will increase proportionally to the degree of autonomy desired.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

EXPERT SYSTEMS/ARTIFICIAL INTELLIGENCE (AI)

FUNCTION:

- PROVIDE THE MEANS TO CORRELATE A KNOWLEDGE BASE DEVELOPED BY "EXPERTS" IN ORDER TO PRODUCE A SOLUTION, PARTICULARLY IN REGARDS TO ROUTINE OPERATIONS & MAINTENANCE
- PROVIDE THE MEANS TO PERFORM INFERENCES BASED UPON A KNOWLEDGE BASE AND EXPERIENCE

INTERFACES: PRIMARILY STRUCTURED IN LANGUAGE AND PROCESSOR ARCHITECTURE
DATA FROM AND COMMANDS TO VEHICLE SYSTEMS ARE RESULTANT FROM THIS TECHNOLOGY

REQUIREMENTS: SUPPORT AUTONOMOUS & SURVIVABLE GOALS OF FUTURE SPACECRAFT

ISSUES: NEAR-TERM RISK FOR PRACTICAL APPLICATION IS HIGH. HOWEVER DESIGN MUST PLAN FOR INCORPORATION OF EXPERT SYSTEMS AND AI AS THEY MATURE

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

DATA STORAGE/DATA COMPRESSION - 10^{12} BITS/DAY (1900s)

The need to increase the information return from space-borne processing and imaging system has grown dramatically during the past decade. Data rates that exceed the telecommunications channel capacity for the 1990 timeframe are quite possible, requiring that on-board signal/data processing play a pivotal role in utilizing available communication channels at higher efficiency. The approach to higher efficiency is generally recognized to be through data compression techniques. Although telecommunication channels are of primary concern, on-board mass storage for periods of extended autonomy also demands a differentiation between data and information storage.

DMS ASSEMBLY REQUIREMENTS/FUNCTIONS

DATA STORAGE/DATA COMPRESSION - 10^{12} BITS/DAY (1990's)

FUNCTION: PROVIDE STORAGE CAPABILITY FOR SPACECRAFT & PAYLOAD DATA

- o STORAGE CLASSES INCLUDE PRIVATE AND GLOBAL DATA FOR SHORT-TERM & ARCHIVAL FUNCTIONS

INTERFACES: PRIMARILY SPACECRAFT AND PAYLOAD PROCESSORS

REQUIREMENTS: RADIATION HARD, INCREMENTAL, SHARED & DEDICATED, FAST ACCESS & RECALL (RANDOM ACCESS)

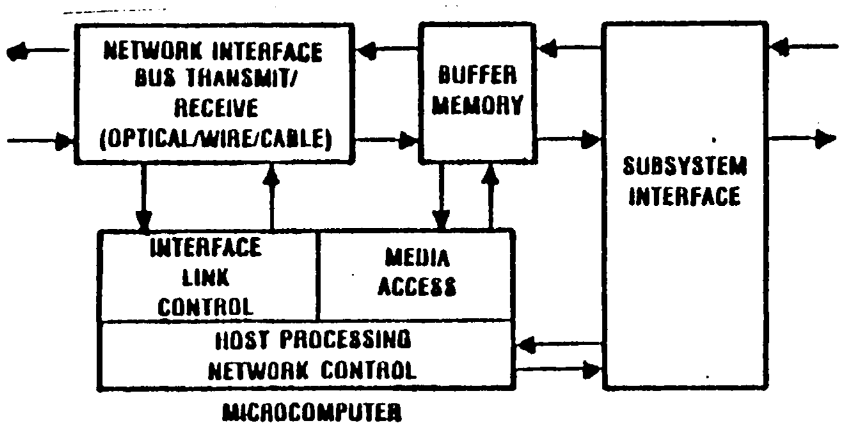
ISSUES: POWER, WEIGHT, RELIABILITY, RADIATION HARDNESS
VERIFICATION OF DATA COMPRESSION ALGORITHMS

- o IMAGE & PATTERN RECOGNITION
- o AUTOMATED FEATURE EXTRACTION
- o AUTOMATED CROPPING, SIGNAL PROCESSING
- o EFFICIENT DATA BASE MANAGEMENT
- o 3-D SIGNAL DATA COMPRESSION
  - ENTROPHY/NON-ENTROPHY PRESERVING TECHNIQUES

In designing tomorrow's real-time spacecraft DMS, the challenge is to accommodate current requirements, and simultaneously build in future growth potential. The intelligent bus interface unit provides for this growth on the basis of incorporating diverse subsystem components into a digital network. In real-time systems, traffic characteristics are often uneven. With the assumption that the overall throughput of the system can be handled by the application processes, small changes in the traffic characteristics must be handled through use of flow control techniques within protocol. For example, a computer may turn off its interrupts for a short time while involved in a critical process. This may cause the refusal of one BIU's acceptance of messages from another BIU. This rippling effect and overall system control, while providing flexibility, can only be accommodated by an intelligent BIU as outlined in this plan.

TECHNOLOGY PROJECT PLAN

SUBSYSTEM: INTERFACE



PROBLEM: SPACECRAFT HARDWARE IS CURRENTLY INTERCONNECTED BY THE USE OF COSTLY CUSTOM INTERFACE DEVICES WITH INFLEXIBLE ORGANIZATION ATTRIBUTES.

OBJECTIVE: DEVELOP A STANDARDIZED INTERFACE THAT SUPPORTS TECHNOLOGY INSERTION, MAXIMIZES UTILIZATION OF AVAILABLE ASSETS & SURVIVABILITY, & PROVIDES FOR MFG. & MAINTENANCE COST EFFECTIVE PROCEDURES.

APPROACH:

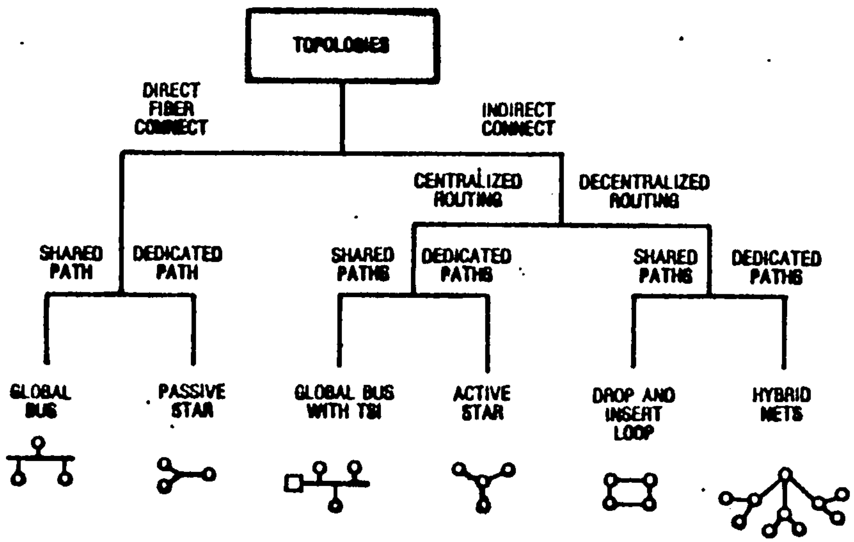
- DESIGN, DEVELOP & VALIDATE A MODEL OF SPACECRAFT LAN
- DEFINE ALTERNATIVE PROTOCOL SCHEMES, PROCESSING NODES (NO. & TYPE), TOPOLOGY & TRAFFIC MODELS
- SIMULATE SELECTED SCHEMA VIA S/W TECHNIQUES
- DESIGN, FABRICATE & TEST INTERFACE UNIT IN S/C-90 DMS TEST BED

EXPECTED RESULTS: DESIGN OF A BIU THAT SATISFIES S/C-90 GOALS OF MODULARITY, FAULT TOLERANCE, & AUTONOMY WHILE MAKING USE OF VHSIC/GAAs DEVICES THAT MAXIMIZES PERFORMANCE & MINIMIZES SIZE, POWER, & WEIGHT

Although almost no data exists on use of fiber optic buses in space, ground tests and projections indicate that present-day optical emitters, detectors, and connectors should operate successfully in space. Interconnection topologies are classified according to the notion of connectivity--a measure of how closely nodes in the system are linked. Structures range from fully connected ones, such as the mesh, to a single point-to-point linked bus. It is important to examine each topology in terms of autonomy, reliability, modularity, ease of test, verification and validation, and finally in terms of cost.

This approach includes modelling the vehicle data traffic, isolation requirements between payloads and vehicle and expected mission requirements. Simulations and definition of system characteristics for each of the topologies selected should produce copious data for analysis.

SUBSYSTEM: CABLES/CONNECTORS



TAXONOMY OF FIBER OPTIC TOPOLOGIES

PROBLEM: CURRENT SPACECRAFT CABLING IS NOT COST/EFFECTIVE WRT MFG. AND MODIFICATION.

OBJECTIVE: DEVELOP A TOPOLOGY UTILIZING FIBER OPTIC INTERCONNECTS THAT PROVIDES SIMPLIFICATION OF CABLING, AND PROVIDES FLEXIBILITY IN SYSTEM DESIGN.

APPROACH:

- SELECTION OF APPROPRIATE TOPOLOGIES BASED UPON SECURITY/PRIVACY, DECENTRALIZATION AND RELIABILITY
- EXAMINE ACCESS METHODOLOGIES.
- DEFINE SYSTEM CHARACTERISTICS
- DEVELOP FUNCTIONAL SPECIFICATIONS FOR EACH NETWORK ALTERNATIVE
- DESIGN, DEVELOP AND FABRICATE SELECTED FIBER OPTIC TOPOLOGIES

EXPECTED RESULTS

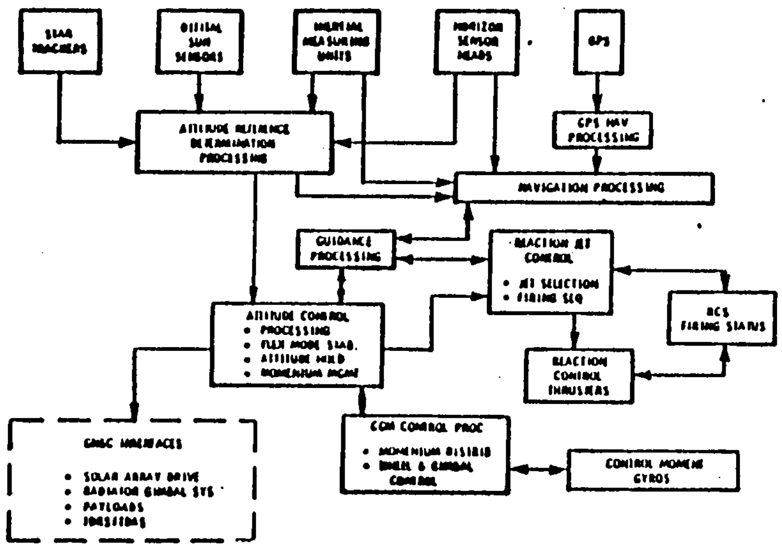
SPECIFICATION OF A FIBER OPTIC TAXONOMY CONSISTING OF TOPOLOGIES AND ACCESS TECHNIQUES (I.E., THE TRANSMISSION SYSTEM AND ALLOCATION OF THE SYSTEM BANDWIDTH.

ARCHITECTURE

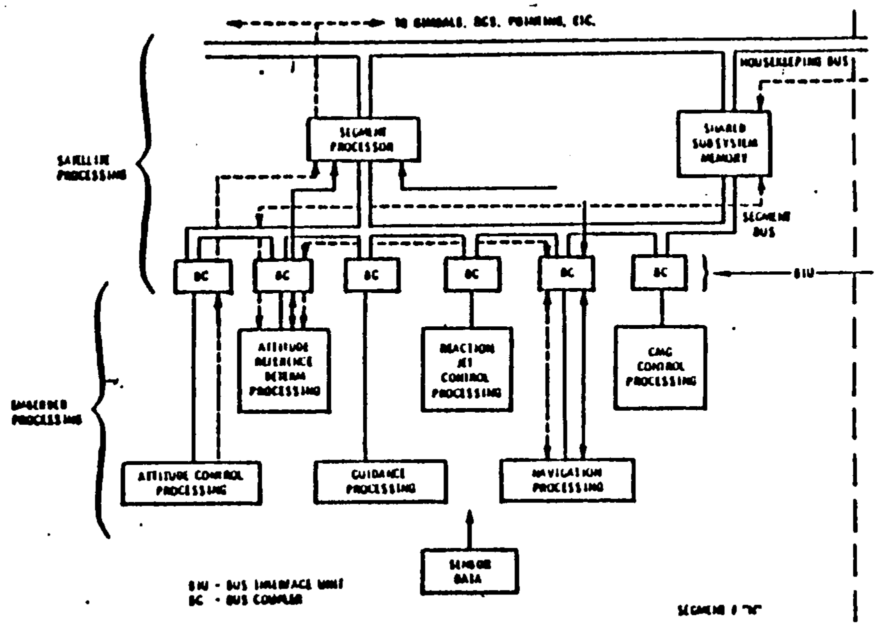
The design goals of advanced spacecraft in terms of fault tolerance, modularity, and autonomy demand solutions not satisfied by current architectures. The autonomous nature of advanced satellite systems and the evolutionary style of growth demand a DMS that is modular and expandable. This, of course, lends itself to the use of distributed computing approaches--interacting computers, each containing processors to support the implementation of the overall spacecraft application. The architecture chosen must implement an extremely fault tolerant, ultra-reliable mechanism for communicating data at varying data rates between the individual components/subsystems of the advanced spacecraft. The most likely implementation is a loosely coupled system where independent computers act as access points into the communications system for dedicated subsystems such as guidance and control, thermal control, power, etc. These computers serving as interfaces would be connected by a communications network, using a ring, star, or bus.

Requirements, modelling and simulation of subsystem, payload, and vehicle activities need to be done in order to produce a strawman architecture. This architecture would then be tested against mission requirements and the cost impact of modifying (relaxing or constraining) the requirements.

SUBSYSTEM: ARCHITECTURE



FUNCTIONALLY DEDICATED, CENTRAL CONTROL



LOCAL PROCESSING, DISTRIBUTED CONTROL

PROBLEM: FUTURE SATELLITE SYSTEM DEMANDS FOR LONG-LIFE, MODULARITY, FLEXIBILITY AND BETTER UTILIZATION OF INFORMATION, FACILITIES, AND RESOURCES CANNOT BE SATISFIED WITH CURRENT DATA MANAGEMENT ARCHITECTURES.

OBJECTIVES: DESIGN AND DEVELOP A STRAWMAN ARCHITECTURE THAT SATISFIES THE GOALS OF FAULT TOLERANCE, MODULARITY AND AUTONOMY APPLICABLE TO THE 1990'S SPACECRAFT MISSIONS.

APPROACH:

- DETERMINE MISSION REQUIREMENTS
- SURVEY SOA AND TECHNOLOGY TRENDS
- DEVELOP A COMPOSITE OF DMS OPTIONS; HARDWARE & SOFTWARE
- PERFORM TRADE ANALYSIS ON OPTIONS
- DETERMINE SELECTED STRAWMEN (~3)
- DEVELOP SIMULATION MODELS & DETERMINE STRENGTHS & WEAKNESSES
- DEVELOP SIMULATION MODELS OF SPACECRAFT DATA BUS TRAFFIC FLOW (DATA & COMMAND)
- DEVELOP FAULT TOLERANCE METHODOLOGY & DYNAMIC RECONFIGURATION SCHEMA
- DESIGN & DEVELOP PROTOTYPE HARDWARE & SOFTWARE
- FABRICATE FLIGHT HARDWARE & SOFTWARE FOR VEHICLE FUNCTIONS
- PROVIDE PAYLOAD SERVICES VIA SIMULATION

TECHNOLOGY PROJECT PLAN

SCHEDULES TECHNOLOGY PROJECTS	FY 86	FY 87	FY 88	FY 89	FY 90
INTERFACE	0.7M	1.0M	1.0M	0.5M	
DESIGN & DEVELOP LAN					
DEFINE PROTOCOL SCHEMA					
DEVELOP TRAFFIC MODELS					
DESIGN, DEVELOP BIU					
FAB & TEST BIU					
SYSTEM TEST-SIM					
SYSTEM TEST-HW/SW					
CABLES/CONNECTORS	0.1M	0.1M	0.7M	0.7M	
TOPOLOGY SELECTION					
ACCESS METHODOLOGY STUDY					
DEFINE REQUIREMENTS					
DEVELOP SPECS					
DESIGN & DEVELOP TOPOLOGY					
FAB & TEST TOPOLOGY					
ARCHITECTURE	0.2M	0.8M	0.8M	0.2M	1.0M
MISSION REQUIREMENTS					
DEVELOP OPTIONS					
PERFORM TRADES					
DETERMINE STRAWMAN					
DEVELOP SIM, MODELS					
DEVELOP FT TECHNIQUES					
DESIGN & DEVELOP HW/SW					
INCOROPORATE PL SERVICES					

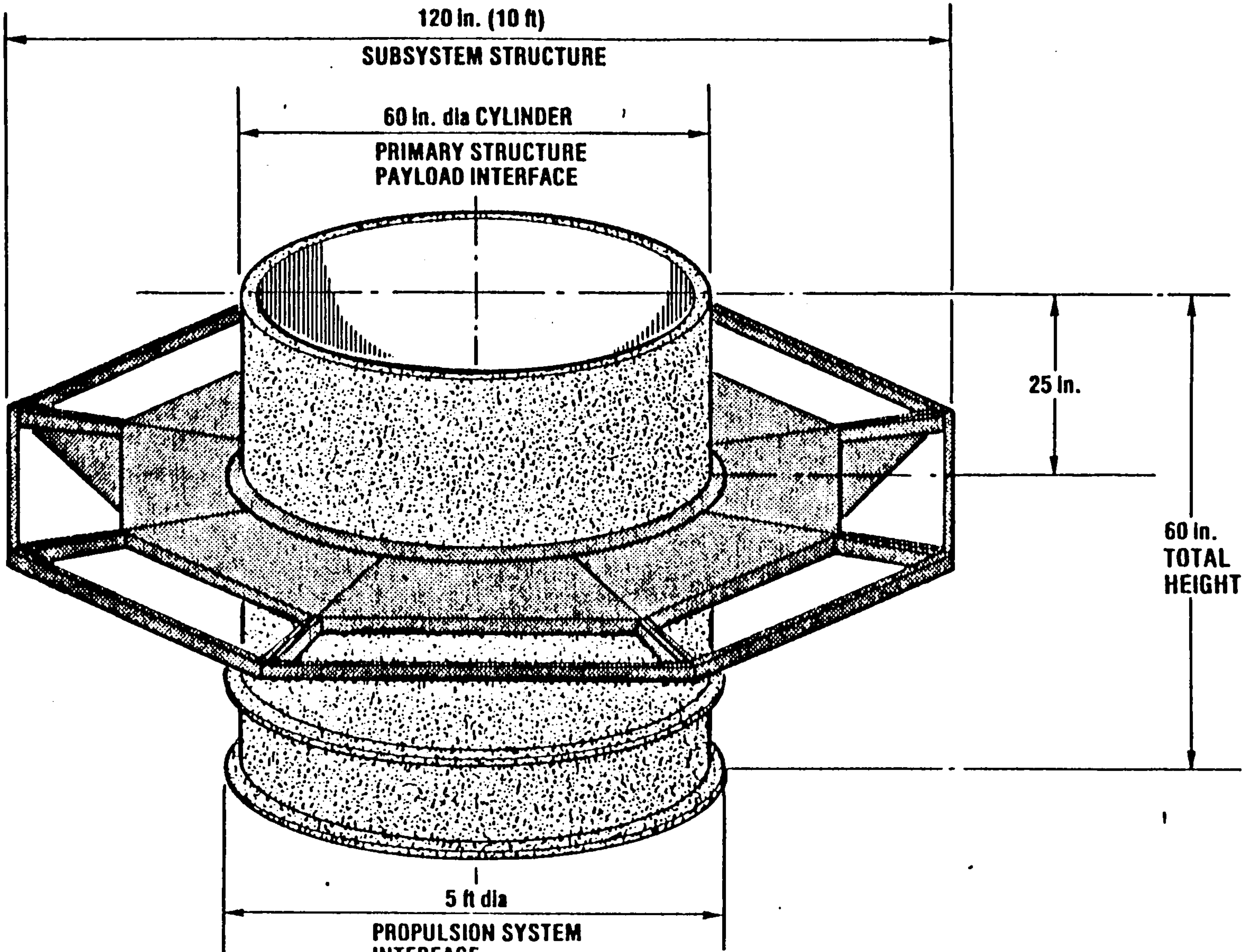
SPACECRAFT INITIATIVE ISSUES

The following section presents a series of observations and initial recommendations on the future of the advanced spacecraft initiatives program.

SPACECRAFT INITIATIVE ISSUES

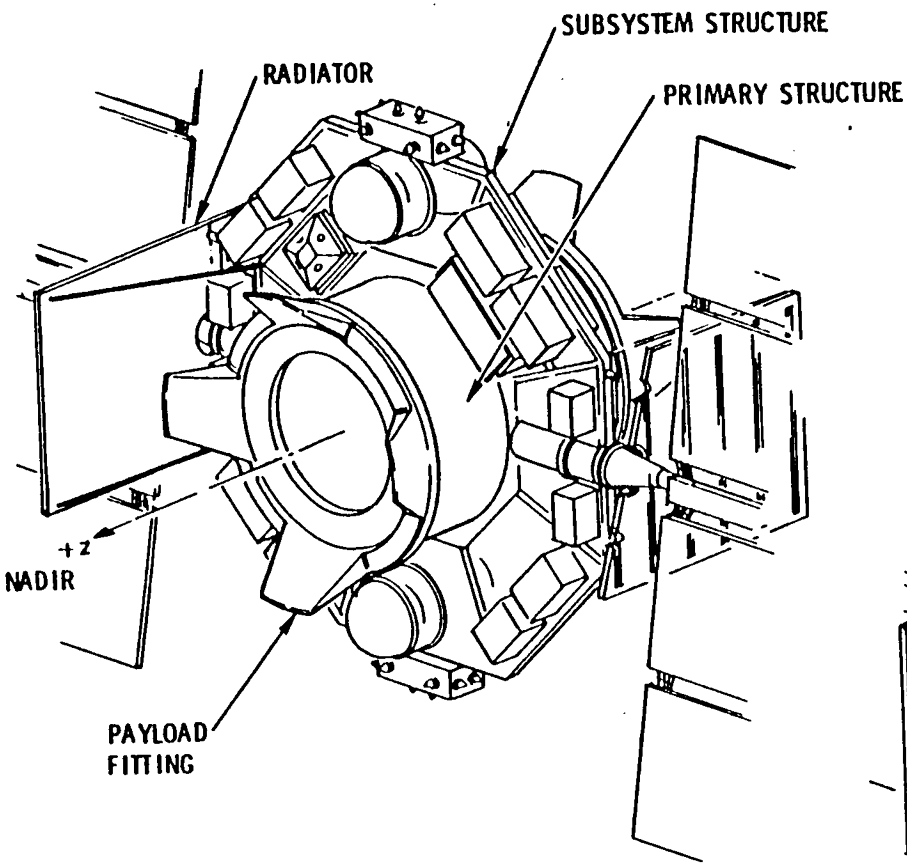
We conclude that the form and format of the initiatives spacecraft configuration and program be based on that which was evolved over the course of this study - starting with the basic spacecraft structure shown opposite. The logic is that the test spacecraft indeed be designed along the lines of the technology problems and issues that want to be demonstrated, proved, and space qualified.

TEST SPACECRAFT BASIC STRUCTURE

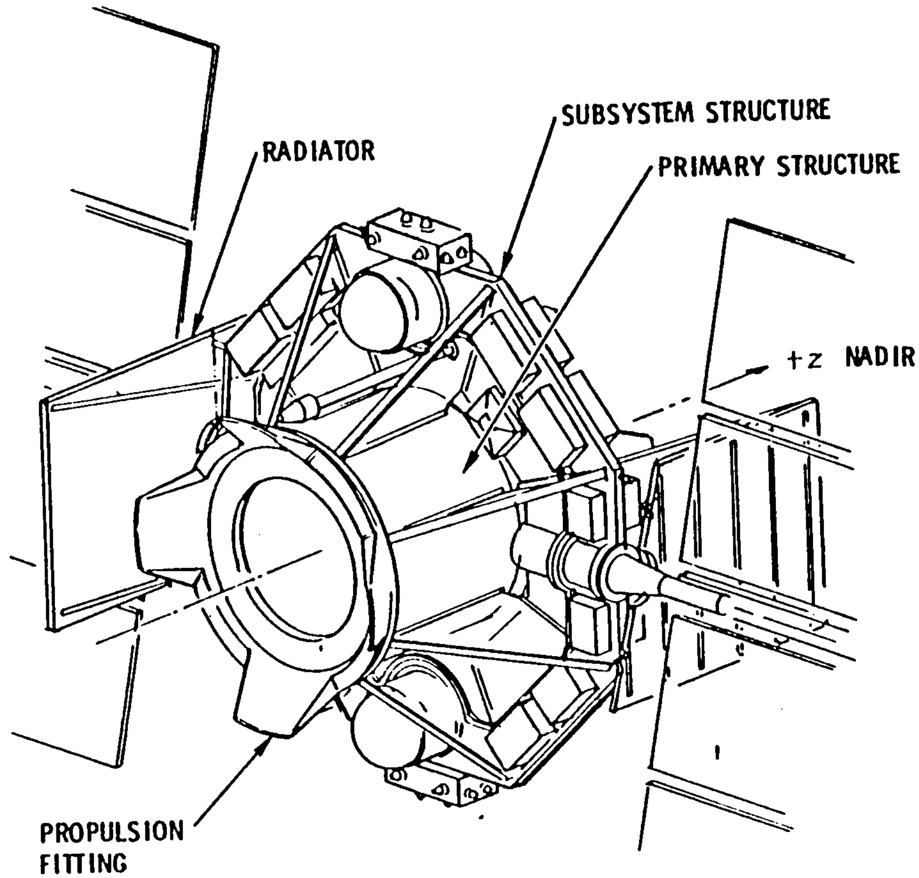


The total design concept of the initiatives vehicle then tends to take the form of the spacecraft built around the technologies covered by the study.

TEST SPACECRAFT



VIEW OF FORWARD FACE OF SUBSYSTEM STRUCTURE



VIEW OF AFT FACE OF SUBSYSTEM STRUCTURE

The listing opposite is representative of the advanced technology experiments that will want to be built into the design of this test spacecraft. These constitute the more critical issues defined during the study that require resolution, research, and space qualification. The configuration of vehicle then must accommodate the need to test and qualify such diverse new technology material as an open structure; a structure/thermal system that encompasses the use of a capillary pump loop; an operational concept thar reflects a major relaxation in mass properties characteristics, etc. It is required that the impact of those technology issues be well understood before the actual initiative spacecraft design can be carried out.

INITIATIVE (TEST) SPACECRAFT

MISSION EXPERIMENTS

DEVELOP/TEST SELECTED STRUCTURAL CONCEPT

STATIC/DYNAMIC ANALYSIS/TEST PROGRAM FOR THE OPEN STRUCTURE

CPL CONDENSER/RADIATOR INTEGRATED INTO FLIGHT STRUCTURE

CPL - EVAPORATOR/COLD PLATE INTEGRATED INTO FLIGHT STRUCTURE

CPL SYSTEM SPACE QUALIFIED

AUTONOMOUS OPERATION OF NAVIGATION SYSTEM

EFFECT OF RELAXATION OF MASS PROPERTIES REQUIREMENTS

OM ORBIT PROPELLANT REFUELING

ON ORBIT MAINTENANCE AND REPAIR

PLUME IMPINGEMENT/CONTAMINATION STUDIES

The subject matter of this study contract was addressed principally to missions and spacecraft that constitute the routine, work a day activity of our space programs. Our requirements were to be found in responding to the needs of our manufacturing and test departments, spacecraft operations, and the like, as well as in the needs for somewhat more sophisticated thermal management, power generation and data processing. Our needs did not force the issue of highly advanced, high technology subsystems, such as those opposite, required by the planetary and space exploration, astronomy and space weapons program.

Technologies, such as those listed opposite, can and will enhance the performance of spacecraft in our "routine" mission model, and in their time will be major contributors to improved performance of those missions.

ENHANCING TECHNOLOGY PROJECTS

- SOLAR PHOTOVOCTAIC, HIGH CONCENTRATION, RETRACTABLE GaAs ARRAY
- FULLY "SOLID STATE" FUEL CELLS
- $LiTiS_2$ ENERGY STORAGE BATTERY
- HIGH FREQUENCY (> 400Hz, i.e. 6KHz, 20KHz) ELECTRIC POWER DISTRIBUTION
- AUTONOMOUS OPERATION OF SPACECRAFT FUNCTIONS
- VERY HIGH SPECIFIC IMPULSE AND LARGE THRUST ENGINES (NUCLEAR; ELECTRIC)
- CONTINUING DISTRIBUTED DATA PROCESSING, AUTONOMOUS OPERATIONS SPACECRAFT ARCHITECTURE
- LASER COMMUNICATIONS/LASER RANGING

NEXT PHASE - FOLLOW ON

This study has:

- Identified the requirements that drive the development of a new, advanced approach to unmanned spacecraft design.
- Selected subsystem and technology concepts to best satisfy those requirements.
- Prepared initial technology project plans to bring the technologies to an adequate level of advancement.

Recognizing that individual mission project offices cannot accept the risk of using unproven techniques and methods in the design of their spacecraft, this study cannot be successfully concluded until the recommended technology concepts and subsystems have been tested and space qualified. That, then, is the mission of the High Technology Unmanned Spacecraft Initiatives program, i.e. to test, verify and space qualify those high technology functions that will make the advanced mission spacecraft possible.

It is suggested that the immediate follow on to the study described in this report be a series of technology project starts, a preliminary project definition, and a preliminary design of the spacecraft itself (only conceptual designs and initial configurations have been developed to date). The objective would be to get a jump on some of the more critical technologies, and to be ready for a formal definition program in FY 1987 and a development start in FY 1988.

SPACECRAFT INITIATIVES PROGRAM

NEXT PHASE - FOLLOW ON FOR FY 1986

- INITIAL TECHNOLOGY ADVANCEMENT PROJECTS:
  - STRUCTURES/THERMAL MANAGEMENT CONCEPT, CAPILLARY PUMP LOOP DEVELOPMENT
  - NiH_2 COMMON PRESSURE VESSEL BATTERY DEVELOPMENT
  - DATA MANAGEMENT ARCHITECTURE DEVELOPMENT
  - HIGH SPEED DATA BUS DEVELOPMENT
- PRELIMINARY PROJECT DEFINITION
  - INITIATIVES SPACECRAFT PRELIMINARY DESIGN
  - SPACECRAFT MISSIONS/TESTS/QUALIFICATION PROGRAM PLANS
  - SPACECRAFT OPERATIONS CONCEPTS
    - EXPERIMENTS DATA MANAGEMENT
    - EXPERIMENTS CHANGEOUT
    - MISSION INFORMATION CONTROL
  - PROGRAM MANAGEMENT CONCEPTS - CENTERS PARTICIPATION
- SYSTEM/SPACECRAFT DEFINITION - FY 1987
- SYSTEM/SPACECRAFT DEVELOPMENT - FY 1988 START