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**BRAYTON ISOTOPE POWER SYSTEM
(BIPS)
PHASE I
FIRST ANNUAL TECHNICAL REPORT**

**PREPARED BY
ADVANCED CLOSED CYCLE ENGINES PROJECT
AIRESEARCH MANUFACTURING COMPANY
PHOENIX, ARIZONA 85034**

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MASTER

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ABBREVIATIONS AND ACRONYMS

ACS	Auxiliary Cooling System
AFWL	Air Force Weapons Laboratory
AIRLA	AiResearch, Los Angeles
AIRPHX	AiResearch, Phoenix
ALO	Albuquerque Operations
BCL	Battelle Columbus Laboratory
BIPS	Brayton Isotope Power System
BRU	Brayton Rotating Unit
CCD	Configuration Control Document
DOD	Department of Defense
ECS	Emergency Cooling System
EHS	Electrical Heat Source
FMECA	Failure Modes, Effects and Criticality Analysis
FS	Flight System
GDS	Ground Demonstration System
GE	General Electric
GMS	Gas Management System
HRHX	Heat Rejection Heat Exchanger
HSA	Heat Source Assembly
HSX	Heat Source Heat Exchanger
IHS	Isotope Heat Source
IPP	Integrated Program Plan
LES 8/9	Lincoln Experimental Satellite (No. 8 and 9)
MARSCOM	Materials Review and Selection Committee
MBR	Mini-Brayton Recuperator
MHW	Multi-Hundred Watt
MJS	Mariner Jupiter Saturn
ORNL	Oak Ridge National Laboratory
PDR	Preliminary Design Review
PSC	Power Supply Console
RTG	Radioisotope Thermoelectric Generator
SAMSO	Space and Missile System Organization
SLA	Sandia Laboratories, Albuquerque
SNS	Space Nuclear Systems

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ABBREVIATIONS AND ACRONYMS (Cont'd)

TECO Thermo Electron Corporation

W Watt Electrical
W_e
W_t Watt Thermal

PREFACE

The ERDA BIPS program culminates over 15 years of government and industry sponsored study and R&D efforts. From the early 1960s to early 1970s, 15 million dollars were spent by the NASA with AIRPHX to develop "technology readiness" for the closed Brayton cycle in anticipation of future dynamic space power conversion system requirements. Of significance was the NASA-Brayton Rotating Unit program in which a 10 kW_e closed gas turbine was developed and successfully tested for 32,500 hours of operation with a cycle efficiency of 36 percent at the NASA Lewis Research Center.

In 1972, the NASA sponsored a study in which many candidate space power conversion systems were evaluated for mission requirements from 500 to 2500 W_e. As a result, the closed Brayton cycle was identified as a favored system due to its high cycle efficiency, compatibility with nuclear heat sources, high reliability, design flexibility (modularization and/or scalability potential) and advanced development status. A study contract was subsequently awarded by the NASA to define in more detail a "Mini-BRU" (for Miniature Brayton Rotating Unit) closed cycle gas turbine in the 500- to 2500-W_e range. Later, a system study was conducted to define a complete space power conversion system in the same power range. The results of these studies led to the award, in 1974, of the current NASA sponsored Mini-BRU, Recuperator and Heat Source Assembly hardware programs. In June 1975, the BIPS Phase I program for the development of a system integrating the components was awarded by the ERDA.

The Brayton Isotope Power System (BIPS) is a 500- to 2000-W_e sealed closed loop space power system with a design life of seven years. The power conversion system includes a closed cycle gas turbine engine, isotope heat source, recuperator, and a space radiator.

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Thermal-to-electric energy conversion is effected by the Mini-BRU, shown in Figure 1. The Mini-BRU contains a radial inflow turbine, radial outflow compressor, and a brushless 4-pole Rice alternator/motor. These components are mounted on a common shaft which rotates at 52,000 rpm and is supported on gas lubricated and cooled foil-type journal and thrust bearings. The complete Mini-BRU assembly consists of a flight-type housing including a columbium turbine plenum, a compressor-discharge-gas-cooled alternator heat exchanger, and the alternator output terminals. Mini-BRU related development tasks are shown in Figure 2.

The heat source assembly (HSA), shown in Figure 3, is being developed by GE, the major subcontractor to AIRPHX. The HSA serves to transfer the thermal energy ($2400 W_t$) provided by the isotope heat source (IHS) to the working fluid (an inert gas mixture of xenon and helium) which drives the Mini-BRU. The assembly consists of a heat source heat exchanger, a Multi-Foil insulation blanket, an outer housing with mounting points and instrumentation leads, an auxiliary cooling system, and an emergency cooling system.

The heat source heat exchanger is constructed of a columbium alloy and is heated by radiation from the isotope and transfers the heat energy to the working fluid by forced convection. Multi-Foil insulation consisting of multiple layers of zirconia-coated nickel foil surrounds the heat exchanger. These layers of insulation form a series of radiation shields which both insulate the heat exchanger and provide auxiliary and emergency cooling functions.

The HSA for the Ground Demonstration System (GDS) will utilize an electric heater to simulate the flight system multi-hundred watt plutonium fueled heat source.

The Mini-Brayton Recuperator (MBR) transfers turbine discharge waste heat to the compressor discharge working fluid prior to the fluid entering the heat source assembly. This recovery of thermal energy

NASA/BIPS MINI BRU

TECHNOLOGY AREAS

MS 4035-2

MINI-BRU DEVELOPMENT TASKS

MS 4059-5

FIGURE 2

MINI-BRAYTON HEAT SOURCE ASSEMBLY

FIGURE 3

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serves to increase cycle efficiency by reducing the required heat source output for a given power level. The recuperator is a counterflow offset plate fin heat exchanger fabricated entirely from Hastelloy X (design shown on Figure 4.) The core assembly is brazed using a gold-base alloy applied in foil form. The cold side and hot side effectivenesses are predicted to be 0.975 and 0.955, respectively.

The radiator rejects the waste heat of the Brayton cycle and thereby maintains the compressor inlet temperature at a low level. One part of the GDS program is the evaluation of alternative flight system radiator concepts and configurations. The present concept is a cylindrical tube fin design which surrounds the remainder of the BIPS components, thereby contributing to their protection from micro-meteoroid impact. Aluminum and beryllium are the candidate materials being considered for construction of the radiator.

For the GDS, the space radiator is simulated by a gas-to-liquid heat exchanger. This heat exchanger is designed to simulate the gas-side pressure drop of the flight system space radiator.

The Mini-BRU, recuperator, heat source assemblies, and cooler are connected by a system of ducts and bellows. Materials of the various GDS components (principally 6061 Al, 347 SS, Hastelloy X, and refractory columbium alloy C-103) require that various bimetallic joints or transition sections be developed. The development of GDS component material characteristics and fabrication and joining techniques, especially with regard to the refractory alloy components, represents a major technical challenge in the BIPS program and is being vigorously pursued as a combined government/industry effort. A systematic, programmed approach has been implemented to obtain the test data required to achieve confidence in the BIPS design.

The system operating temperatures, the relatively low output power, and the high cost and weight of the radioisotope require the

MINI-BRAYTON RECUPERATOR

FIGURE 4

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use of a low loss insulation system in order to increase cycle efficiency and keep overall weight and cost within limits. A Multi-Foil insulation system consisting of layers of thin metallic foil (zirconia coated nickel and zirconia coated molybdenum) has been selected to shroud the turbine plenum, recuperator, heat source heat exchanger, the hot ducts, and bellows of the GDS. Total GDS losses, because of extensive instrumentation, may be as high as $960 W_t$. The flight system insulation is expected to limit thermal losses to between 575 and $625 W_t$.

The overall control of the BIPS will be provided by a solid state control system. All controls-speed control (parasitic electric load), voltage regulation (alternator field control), and electric power conditioning (filtering) are electrical. Redundant circuitry will be utilized to assure that system reliability, performance, and operational requirements are met.

The BIPS GDS is intended to simulate the flight system (FS) as closely as possible. The GDS configuration is defined in the Configuration Control Document (CCD), AIRPHX Report No. 75-311274B.

The CCD includes reference material, a related documents listing, and pertinent system and components design data. Also included is a preliminary BIPS FS design description and certain appropriate background information that may be useful to potential users.

As a working document, the CCD will be revised as necessary to maintain current descriptions of the components and system. After Phase I has been completed, the CCD will provide a GDS "as built" description and record. When sufficient information is available, either new or changed, the CCD will be revised and updated to reflect these changes. Between these major revisions, Addenda and Errata will be issued to provide the most current activities and information to all CCD holders.

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BRAYTON ISOTOPE POWER SYSTEM
(BIPS)
PHASE I
FIRST ANNUAL
TECHNICAL REPORT

1. INTRODUCTION

This annual technical report, prepared by AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, summarizes the achievements on the ERDA Brayton Isotope Power System (BIPS) Program under ERDA Contract E(04-3)-1123, from June 1975 through July 1976. The contractor is being supported by three major subcontractors: General Electric Company for heat rejection heat exchanger, heat source, and system support; AiResearch Manufacturing Company of California for bellows; and Thermo-Electron Corporation for insulation. Figure 5 represents the relationship of the subcontractors and other government/industry supporting efforts with AiResearch for the ERDA-BIPS Program.

The following sections present BIPS program background, program overview, technical achievement summary, and BIPS document abstracts. Summary sections are purposely brief and are included to familiarize the reader with program objectives, current status, and major accomplishments. Details of the work performed during the past year have been carefully documented in the technical reports referenced herein. In addition, abstracts of these documents are included in the annual report, grouped by area of technical effort, to enable the reader to obtain detailed information on any aspect of the BIPS program through the document retrieval system.

BIPS TEAM

FIGURE 5

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2. BACKGROUND

The objective of the BIPS program is to develop a closed gas turbine dynamic conversion system for space application. The baseline system, Figures 6 and 7, is a 7-year life, 450 lb, 1300 W_e unit using Brayton cycle hardware developed for the NASA LeRC and two 2400 W_t Multi-Hundred Watt isotope heat sources developed for the ERDA.

Phase I of the three-phase BIPS program is the conceptual design of the flight system, the design, development, and testing of a prototype Ground Demonstration System (GDS). The Mini-Brayton Rotating Unit (Mini-BRU), Mini-BRU Recuperator (MBR), and Heat Source Assembly (HSA) will be integrated into the ground demonstrator loop, and the system will be tested under simulated space conditions at the AiResearch Space Power Laboratory.

Successful completion of the Phase I effort in mid 1978 is expected to lead to the Phase II and Phase III follow-on efforts. Phase II is a 24-month effort for the development and qualification of a flight system. Qualification will include testing with an isotope heat source. Phase III is a 12-month effort to fabricate flight-qualified hardware for delivery in April 1981.

The Phase I tasks are summarized on Table I, and their time phasing is shown on the Phase I schedule, Figure 8. The interrelationship and timing of Phases I, II, and III, and other related BIPS programs are presented on Figure 8.

The Phase I program objectives are listed on Table II.

The GDS (Phase I) program constitutes the initial development of the Flight System and will demonstrate features and techniques as follows:

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FLOW SCHEMATIC

HEAT SOURCE ASSEMBLY

MINI-BRU

FLIGHT SYSTEM

RECUPERATOR

BIPS DESIGN SPECIFICATION

Design Life	7 years
Electrical Power Output	EOM 1300 W ₀ EOM { 5 years - 1235 W ₀ 7 years - 1200 W ₀
Output Voltage	120 V dc Optional: 67 V ac, L-N, 3 phase, 1733 Hz Optional: 28 V dc
Specific Power	6.4 W ₀ /kg (2.9 W ₀ /lb)
Physical Characteristics	
Length	244 cm (96 in.)
Diameter	152 cm (60 in.)
Weight	204 kg (450 lb)
Power Conversion Efficiency (Net)	25 percent minimum
Design Heat Sink Temperature	216°K (-70°F)
<u>General Specifications</u>	
o Mechanical, Electrical, and Thermal Interface Compatible with Space Shuttle	
o Reliability = 0.95 for 5 years	
o Meteoroid Protection in Accordance with NASA SP8013	
o Shock Design Criteria for Component Mounts = 50g; Support Structure = 25g	
o Resonant Frequency > 60 Hz	
o Vibration Design Criteria Compatible with Shuttle/ IUS Launch

- COMPLETED
- ⊙ IN PROGRESS
- NOT STARTED

TABLE I

TASK OBJECTIVES SUMMARY

TASK 1 - PROGRAM MANAGEMENT

- Define technical objectives
- ⊙ Control costs
- ⊙ Meet schedule
- ⊙ Manage resources to achieve all technical goals
- ⊙ Prepare advanced program plans
- ⊙ Timely reporting
- ⊙ Maintain CCD and IPP
- Establish documentation procedures
- ⊙ Manage subcontracts

TASK 2 - IBFS PRELIMINARY DESIGN

- Define system meeting ERDA objectives
- Provide design flexibility
- Show tradeoffs and compromise of:
 - ⊙ Checkout on launch pad
 - ⊙ Operate before or through launch
 - Spin stabilized platform
- ⊙ Define long lead development (Task 9)
- ⊙ Design report
- Design review meeting

TASK 3 - GDS PRELIMINARY DESIGN AND TEST PLAN

- Prepare design, material and handling specifications
- Prepare GDS test plan
- Prepare P&I diagram
- Prepare test facility specs
- Prepare assembly, test and operating plans
- Prepare GDS layout drawings
- Prepare test facility layout drawings
- Prepare control circuit schematic diagrams
- Conduct design review meeting
- Prepare design report

TASK 4 - GDS DETAIL ANALYSIS AND DESIGN

- ⊙ Prepare manufacturing drawings for all GDS components
- ⊙ Prepare manufacturing drawings for all test facility components
- ⊙ Prepare Method of Test for all components
- ⊙ Prepare inspection procedure (IP)-components
- ⊙ Complete transient analysis
- ⊙ Prepare circuit diagrams and wiring diagrams
- Build a mock-up (full scale)
- Conduct detail design review
- Submit detail design review report

TASK 5 - FABRICATION AND ASSEMBLY

- ⊙ Fabricate all GDS components
- ⊙ Fabricate all test facility components
- ⊙ Generate equipment logs
- Assemble GDS
- Install GDS in test facility

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TABLE I (Contd)

TASK 6 - TEST AND EVALUATION

- o Operate at full design speed
- o Operate at full design power
- o Confirm component performance
- o Confirm system performance
- o Make fully automatic startup
- o Complete 1000-hr continuous run
- o Prepare test report

TASK 7 - QUALITY, RELIABILITY AND SAFETY

- o Implement QA plan and enforce compliance with procedures
- o Implement safety plan
- o Implement reliability plan
- o Complete PHA (Preliminary Hazard Analysis)
- o Complete FTA (Fault Tree Analysis)
- o Conduct PSSR (Preliminary System Safety Review)
- Prepare GDS FMECA
- Prepare IBFS FMECA

TASK 8 - REPORTS AND DATA

- o Prepare contractually required reports
 - o Monthly
 - o Annual
 - o Financial top summary
 - o QA, R&S
 - o Final
- o Prepare, issue and maintain program control documents
 - Configuration control document (CCD)
 - Integrated program plan (IPP)
 - Subcontractor work statements
 - o Procurement control documents
- o Prepare test procedures
 - Test flow plan
 - o Test, receiving, handling, cleaning, assembly instructions
 - o Test reports

TASK 9 - ADVANCED DEVELOPMENTS

- o Develop advanced controls
- o Develop Be radiator mfg. techniques
- o Develop advanced insulation system

TASK 10 - FLIGHT DESIGN AND ENGINEERING PROGRAM PLAN

- o Prepare Phase II plan

BRAYTON ISOTOPE POWER SYSTEM INTEGRATED PROGRAM SCHEDULE

FIGURE 8

BIPS PHASE I - PROGRAM OBJECTIVES

GENERAL

- DEFINE CONCEPTUAL FLIGHT SYSTEM (SERVES AS A BASIS FOR GDS DESIGN)
- DESIGN, FABRICATE AND ASSEMBLE THE GDS
- DESIGN, PROCURE AND CONSTRUCT TEST FACILITY MODS AND EQUIPMENT
- CONDUCT PERFORMANCE AND 1000 HOUR ENDURANCE TESTS
- CONDUCT LONG LEAD DEVELOPMENT NECESSARY TO DELIVER THE FIRST FLIGHT UNIT BY 1981 (CONTROLS, INSULATION, SPACE RADIATOR)
- AS PRIME-CONTRACTOR, ESTABLISH DESIGN SPECIFICATIONS, PERFORMANCE OBJECTIVES AND DOCUMENTATION REQUIREMENTS

SPECIFIC

- 500 TO 2000 W_e DC (EOM)
- 1300 W_e DESIGN POINT
- 0 TO 100% USER LOAD
- COST \$5K/WATT_e W/\$1.0K/WATT_t FUEL
- 3.5 WATT_e/POUND
- USE TITAN IIIC OR SHUTTLE AS LAUNCH VEHICLE
- 7 YEAR LIFE

TABLE II

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- o Flight system hardware
- o Design flexibility
- o High cycle efficiency
- o Low specific weight and volume
- o Quality of output power
- o Safety and reliability
- o General system integration techniques

Further, using the knowledge gained from GDS performance and endurance testing and from the long lead development effort, the Phase II and III program plans for the BIPS flight system development and qualification will be generated.

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3. PROGRAM OVERVIEW

The ERDA-BIPS contract began June 13, 1975, with Tasks 1, 2, 7, and 8 commencing on that date (see Table I for task summaries). Task 3 was initiated at the beginning of August 1975; Task 4 was started in July 1975; and Task 11 was added in April 1976. The technical accomplishments for the year, which are summarized in following paragraphs, are:

3.1 Flight System Preliminary Design

The Flight System preliminary conceptual design was developed to provide the following definition for the GDS preliminary design:

- o Performance requirements
- o Basic packaging
- o Structural requirements

BIPS integration with the launch and spacecraft vehicles and compatibility with operational situations were considered; however, refinement and selection of baseline concept were deferred until the last quarter of 1976 when additional launch vehicle and spacecraft contractor studies will be available.

3.2 GDS Preliminary Design

The GDS Preliminary Design was completed and approved at the Preliminary Design Review (PDR) meeting in July 1976 (AIRPHX Report No. 76-312035). Notable accomplishments on this task are:

- o System layouts prepared
- o Flight prototypical structure designed
- o A full size system mockup was built (Figure 9)

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BRAYTON ISOTOPE POWER SYSTEM MOCKUP

FIGURE 9

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- o Component design requirements defined
- o NASA controls tested
- o Control system philosophy developed
- o Synchronous and induction motor starts demonstrated
- o GDS assembly procedure defined (AIRPHX Report No. 76-311748)
- o GDS test plan prepared (AIRPHX Report No. 76-311752)
- o Test facility requirements defined and environmental simulation system ordered (AIRPHX Report No. 76-311736)

3.3 GDS Detail Design

GDS Detailed Analysis and Design are continuing. The accomplishments for the task to date are:

- (a) A Materials Review and Selection Committee (MARSCOM) was formed in November 1975 to supervise the materials effort defined by the Integrated Program Plan (IPP) (AIRPHX Report No. 75-311574A).
- (b) Extensive research and tests such as welding, rate of contamination, and determination of creep properties on the refractory columbium alloy (C-103) are progressing. Evaluation of the data and preparation of reports, including results and recommendations, are in process.

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- (c) Ducting, bellows, and bimetallic joint analyses and testing are either underway or being planned.
- (d) Research and testing of the multi-foil insulation are underway. Meltdown tests have been completed, and investigation of the interaction between the C-103 and Ni foils is in progress.

3.4 Quality, Reliability and Safety

The Quality, Reliability, and Safety (Q, R, and S) task accomplishments for the first year are:

- (a) Reliability Program Plan, System Safety Program Plan, and QA Program Supplement for ERDA BIPS were approved (AIRPHX Report Nos. 75-311360, 75-311221, QCGI-137).
- (b) Numerous documents were published defining and analyzing systems Q, R, and S.
- (c) Liaison on the reliability program was established with Space and Missile System Organization (SAMSO), Sandia Laboratories, Albuquerque (SLA), and Air Force Weapons Laboratory (AFWL); Liaison with ERDA-Albuquerque Operations (ALO) was established for the safety program.

3.5 Reports and Data

The reports and data task accomplishments included over 75 publications documenting efforts on all tasks.

3.6 Workhorse Loop Add-On

A workhorse loop add-on task, which allows system checking without jeopardizing the refractory components, was initiated in April 1976. The accomplishments to date are:

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- o Workhorse loop layouts were completed.
- o Superalloy turbine plenum constructed of Waspaloy (A) was designed.

Details of Paragraphs 3.1 through 3.6, above, are discussed in the following section.

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4. TECHNICAL ACHIEVEMENT SUMMARY

4.1 Task 2 - FS Preliminary Design

The purpose of the FS conceptual design is to define the BIPS FS configuration and performance requirements. Because the various missions, launch vehicles, and spacecraft for which the BIPS is intended as a power source are also in the planning stage, it was necessary to divide Task 2 into two parts. Task 2, Part 1, established the baseline configuration and performance requirements sufficiently to design a prototypical GDS. Task 2, Part 2, will include studies, in conjunction with the user contractors, to develop interface and integration requirements and procedures.

Preliminary study results are provided in AIRPHX Report No. 76-3112000. This report includes information related to the following:

- o System description
- o Performance
- o Orientation (momentum consideration)
- o Shock and vibration design criteria
- o Leakage rates (see also AIRPHX Report No. 76-311791)
- o Sensitivity characteristics

The effort expended on the FS Preliminary Design was primarily the conceptual design and layout of the BIPS components (Mini-BRU, HSAs, MBR, radiator, support structure, and ducting). The layout of the components is shown in Figures 7 and 10. Figure 7 also shows the design specifications for the FS.

The orientation of the Mini-BRU (either vertical or horizontal) was a prime consideration in the system layout. A study was performed [AIRPHX Report No. 75-311457(05), Appendix 1], and the conclusions reached were:

BIPS-FS

58.50
DIA.

FIGURE 10

- (a) The weight and performance penalties of a vertically oriented Mini-BRU are minimal.
- (b) The vertical orientation of the Mini-BRU is the most versatile. The vertical configuration is compatible with a spin stabilized vehicle as well as with a 3-axis stabilized vehicle. Also, the Mini-BRU thrust bearings are able to withstand the axial thrust of the booster rocket on takeoff (up to 10 g's) without redesign. A horizontal orientation, if required for a particular application, is available with minimal ducting and structural changes.
- (c) Regardless of the Mini-BRU orientation, the angular momentum of the Mini-BRU is typically less than 0.1 percent of a spin-stabilized vehicle and only 2 to 5 percent of a 3-axis stabilized vehicle. Precessional torque due to the Mini-BRU can be easily compensated for as a result.

The BIPS sensitivity factors, working fluid analysis, and FS performance optimization are summarized in Tables III, IV, and V, respectively. The ground support equipment/spacecraft/mission integration is shown in Figure 11.

An all-superalloy FS is being investigated as an alternative to a refractory alloy system. In this investigation, the cycle performance study has been completed, a materials study is underway, and the structural analysis has been initiated.

A start-up and load transient analysis study was conducted on the BIPS FS performance (AIRPHX Report No. 75-311279), and an example of the system simulation is shown on Figure 12. The study considered system response to start-up, transient loading, and shutdown operating modes.

BIPS SENSITIVITY FACTORS

	PARAMETER VARIATION	RESULTING CHANGE $\Delta\eta_{CY}$, %
COMPRESSOR η	1%	0.55
TURBINE η	1%	0.55
ALTERNATOR η	1%	0.32
E_R * 0.97 to 0.96	1%	1.2
β where $\beta = 1 - \frac{\Delta P}{P}$	1%	0.8
THERMAL LOSS	-160 watts	1.0
BEARING LOSS	-44.3 watts	1.0
COMPRESSOR INLET TEMP**	-16°F	1.0
TURBINE INLET TEMP	60°F	1.0
EMISSION	6.5%	0.5
SINK TEMP	-26°F	1.0

* E_R IS THE RECUPERATOR HIGH PRESSURE SIDE EFFECTIVENESS.
 **ACHIEVED BY ADDING (12%) 14 FT² RAD. AREA. REFER TO FIGURE 1-7, CCD.

TABLE III

WORKING FLUID ANALYSIS

(COMPARISON OF MAXIMUM EXPECTED NEW SYSTEM LEAKAGE RATE WITH ACCEPTABLE LEAKAGE RATE)

MAXIMUM EXPECTED
NEW SYSTEM LEAKAGE
RATE, STD CC/SEC(HELIUM)

$$1.4 \times 10^{-7}$$

ACCEPTABLE LEAKAGE RATE
COMPATIBLE WITH 3.87%
ISOTOPE DEGRADATION
AT 5 YEARS

$$3.7 \times 10^{-5}$$

$$\text{ACCEPTABLE/MAX. EXP.} = 265$$

NOTE: THE MAXIMUM EXPECTED LEAKAGE RATE(AFTER PROOF TEST OF ALL JOINTS FOLLOWING MANUFACTURING)
IS 265 TIMES LOWER THAN WHAT IS ACCEPTED BEFORE SYSTEM PERFORMANCE IS DEGRADED.

TABLE IV

FLIGHT SYSTEM PERFORMANCE OPTIMIZATION

W_e BOM	W_e EOM (7 Years)	Weight lb	Area ft ²
1300	1200	450	134

TABLE V

GSE/SPACECRAFT/MISSION INTEGRATION

MECHANICAL
PAYLOAD/
BIPS INTERFACE
SHOCK, VIBRATION
SYSTEM ANALYSIS

COOLING (4800 W_T)
GROUND SUPPORT
LAUNCH
IN-ORBIT SHUTTLE
MISSION ABORT

ELECTRICAL POWER
START POWER
ON-PAD CHECKOUT
LAUNCH
PRE-INSERTION C/O
POWER QUALITY
OUTPUT VOLTAGE

CONTROL/MONITORING
CHANNELS
SIGNAL INTERFACE
NUCLEAR
HARDENING

SPACE RADIATOR
PERFORMANCE
TRANSIENT PERFORMANCE
HARDENABILITY
METEOROID PROTECTION
COATING PERFORMANCE
MANUFACTURING TECHNIQUES

FLOW PLAN
SEQUENCING
HANDLING
MONITORING

INTEGRATION FAMILIARIZATION
REVIEW NUMEROUS INTEGRATION
DOCUMENTS

FIGURE 11

SYSTEM DYNAMIC SIMULATION

COMPONENT PERFORMANCE DATA

TURBINE
COMPRESSOR
ALTERNATOR
HEAT EXCHANGERS
BEARINGS

APPLICATION- CONFIGURATION

PACKAGING
DUCTING
PERFORMANCE
REQUIREMENTS
LOAD PROFILE
WINDAGE
START TORQUE
CONTROL SYSTEM
CHARACTERISTICS

NONLINEAR SYSTEM MODEL

DIGITAL
ANALOG

SYSTEM TRANSIENT PERFORMANCE

STARTUP/SHUTDOWN
LOAD RESPONSE

OBSERVE PERFORMANCE:

FLows
TEMPERATURES
TORQUES
VOLTAGES
SPEED
AVAILABLE POWER

REFERENCE REPORT 75-311279

FIGURE 12

Fifteen operating modes, covering hot and cold starts, load transients, and shutdown for both the three capsule and two capsule systems, were conducted. The information obtained from this study was used in a preliminary evaluation of the performance of the various components being subjected to the predicted transients. An example of the BIPS transient startup is shown in Figures 13 through 16.

A comparison of the system performance objectives and requirements versus the system design specifications is presented on Table VI and a preliminary reliability allocation and estimation summary for the subsystems are presented on Table VII.

The FS requirements will be incorporated in the GDS design, where practical, to provide a data base for FS definition.

4.2 Task 3 - GDS Preliminary Design and Test Plan

The work performed on this task resulted in the completion and approval of the GDS Preliminary Design in July 1976 (Report No. 76-312035). Notable accomplishments during this eleven-month effort are discussed below.

4.2.1 BIPS Frequency and Stress Analysis

A frequency and stress analysis was performed on the BIPS in accordance with the design criteria of Table VIII. The design criteria were based on the model of the dynamic system shown in Figure 17 and the rationale presented on Table IX. The frequency analysis summary is shown on Tables X and XI; the stress analysis summary is shown on Table XII. For further information, refer to AIRPHX Report Nos. 76-311998 and 76-311773.

FIGURE 13

BIPS TRANSIENT STARTUP

FIGURE 14

BIPS TRANSIENT STARTUP

FIGURE 15

BIPS TRANSIENT STARTUP

FIGURE 16

COMPARISON OF OBJECTIVES AND SPECIFICATIONS

SYSTEM PERFORMANCE OBJECTIVES AND REQUIREMENTS

- (1) THE FS WILL BE CAPABLE OF POWER OUTPUT FROM 500 TO 2000 W_0 , EOM, WITH MINIMUM REDESIGN AND REQUALIFICATION.

- (2) 28 ± 2 PERCENT VDC IS THE REFERENCE OUTPUT VOLTAGE.

NOTE

A CAPABILITY FOR HIGHER AC VOLTAGE OUTPUT MAY BE ADVANTAGEOUS IF THE OUTPUT CAN BE ACHIEVED DIRECTLY FROM THE GENERATOR.

- (3) THE CONTROL SYSTEM WILL BE CAPABLE OF MODULATING POWER TO THE SPACECRAFT FROM 0 TO 100-PERCENT IN 20 MILLISECONDS RESPONSE TIMES. THIS WILL BE ACCOMPLISHED BY A PARASITIC LOAD.

- (4) PARTIAL POWER DURING LAUNCH IS DESIRABLE.

- (5) ABILITY TO OPERATE WITH EITHER NON-SPINNING OR SPIN STABILIZED SPACECRAFT FOR ORBITAL TRANSFER AND/OR THROUGHOUT THE MISSION WOULD BE ADVANTAGEOUS; HOWEVER MOST POTENTIAL MISSIONS WILL BE ON NON-SPINNING SPACECRAFT.

- (6) FS LIFE TIME REQUIREMENTS IS $L = 7$ YEARS AND MEAN MISSION DURATION (MMD) = 5 YEARS.

$$\text{WHERE MMD} = \int_0^L \text{RDT (TRANSLATES TO R} = 0.60 \text{ FOR 5 YEARS)}$$

AND R = PROBABILITY OF PRODUCING DESIGN POWER AT TIME T

SYSTEM DESIGN SPECIFICATIONS

- (1) RATED MINI-BRU ALTERNATOR POWER OUTPUT RANGE: 350-2146 W_0

- (2) 120 VDC (AS DEFINED BY AIRPHX SPEC SC-76-312008)
OPTION A: 67 VAC L-N, 3 ϕ , 1733 HZ
OPTION B: 28 VDC (MIL-STD-1539)
OPTION C: 270 VDC (MIL-STD-704B)

- (3) SAME AS OBJECTIVE

- (4) GDS TEST PLAN INCLUDES OPERATION OF GDS IN AN INERT GAS

- (5) COMPATIBLE WITH SPINNING OR SPIN STABILIZED OPERATION

- (6)
 - ALL HARDWARE DESIGNED FOR 10 YEARS OPERATION
 - COLUMBIUM ALLOY C-103 COMPONENTS DESIGNED FOR 1 PERCENT CREEP IN 7 YEARS,
 - OVERALL SYSTEM RELIABILITY AT 5 YEARS IS GREATER THAN 0.95
 - PRELAUNCH, LAUNCH, AND OPERATIONAL PHASE FAILURE MODES WILL BE IDENTIFIED

TABLE VI

COMPARISON OF OBJECTIVES AND SPECIFICATIONS (CONTD)

SYSTEM PERFORMANCE OBJECTIVES AND REQUIREMENTS

- (7) BASED ON A GFE HEAT SOURCE COST OF \$1000 PER W_t , THE RECURRING COST GOAL FOR THE FS AT 1300 W_g WILL BE LESS THAN \$5000 PER W_g .
- (8) FS WEIGHT GOAL, AT 1300 W_g , IS 450 POUNDS.
- (9) THE FS WILL BE CAPABLE OF LAUNCH ON THE SPACE SHUTTLE.
- (10) DUE TO A POTENTIAL EXPLOSIVE VAPOR ENVIRONMENT, THE ON-PAD TEMPERATURE OF EXPOSED SURFACES WILL BE MAINTAINED BELOW 380°F.
- (11) THE SYSTEM WILL BE DESIGNED WITH AN ASSUMED SINK TEMPERATURE EQUAL TO, OR GREATER THAN, THAT OF A GEO-SYNCHRONOUS ORBIT (19,323 NM). THE SYSTEM WILL BE CAPABLE OF STABLE OPERATION WITH UNBALANCED SOLAR INPUT.
- (12) THERMAL INPUT TO THE SPACECRAFT MUST BE OF AN AMOUNT THAT WILL NOT CAUSE THE SPACECRAFT TO RISE ABOVE 100°F.
- (13) THE MAGNETIC FIELD AT ONE METER IS NOT YET DEFINED.
- (14) THE ON-PAD BIOLOGICAL DOSE AT ONE METER WILL BE ≤ 0.20 REM PER HOUR.
- (15) THE FS WILL BE RESISTANT TO NATURAL AND MAN-MADE RADIATIONS.
- (16) FS COMPONENTS WILL BE INHERENTLY FLEXIBLE IN MOUNTING TO FACILITATE INTEGRATION WITH THE REQUIRED SPACECRAFT CONFIGURATION.
- (17) ON PAD AND IN-ORBIT FUELING CAPABILITIES SHOULD BE PROVIDED.

SYSTEM DESIGN SPECIFICATIONS

- (7) SAME AS OBJECTIVE
- (8) SAME AS OBJECTIVE
- (9) SAME AS OBJECTIVE (ALSO COMPATIBLE WITH TITAN IIIC AND ATLAS CENTAUR*)
- (10) SAME AS OBJECTIVE
- (11) SAME AS OBJECTIVE
- (12) SAME AS OBJECTIVE
- (13) ELECTROMAGNETIC FIELD AS DEFINED BY MIL-STD-1541 AND MIL-STD-461A
- (14) SAME AS OBJECTIVE
- (15) SAME AS OBJECTIVE - - MAN-MADE RADIATION TBD; OTHERS: SC-76-311742
- (16) SAME AS OBJECTIVE
- (17) SAME AS OBJECTIVE

*ATLAS CENTAUR AND TITAN IIIC DELETED FROM THE CONTRACT AS POTENTIAL LAUNCH VEHICLES; HOWEVER, INITIAL DESIGN EFFORT INDICATED COMPATIBILITY

PRELIMINARY RELIABILITY ALLOCATION AND ESTIMATION

SUMMARY

SUBSYSTEM	FAILURE RATE X 10 ⁻⁹ ALLOCATED/ ESTIMATED	R AT 5 YEARS ALLOCATED/ ESTIMATED
MINI-BRU	229/173	0.990/0.992
RECUPERATOR (MBR)	125/125	0.995/0.995
HEAT SOURCE ASSEMBLY (HSA) - (2)	125/125	0.995/0.995
SPACE RADIATOR	229/229	0.990/0.990
CONTROLS	229/192*	0.990/0.992*
LOOP CONTAINMENT (JOINT INTEGRITY)	100/110	0.996/0.995
DUCTING AND BELLOWS	134/134	0.994/0.994
SYSTEM	1171/1088*	0.950/0.953*

*CHANGE SINCE PUBLICATION OF 76-311851

TABLE VII

BIPS DESIGN CRITERIA FOR PRELIMINARY RIGIDITY AND STRENGTH REQUIREMENTS

1. LOWER LIMIT OF FUNDAMENTAL FREQUENCIES OF THE BIPS MOUNTED COMPONENTS TO BE APPROXIMATELY 60 CPS.
2. LIMIT LOADING OF THE BIPS COMPONENTS TO BE 50 G's.
3. LIMIT LOADING OF THE BIPS INTERFACE STRUCTURE TO BE 25 G's.

TABLE VIII

SCHEMATIC OF DYNAMIC SYSTEM

FIGURE 17

BASIS FOR BIPS DESIGN CRITERIA FOR PRELIMINARY RIGIDITY AND STRENGTH REQUIREMENTS

REFERENCE 76-311998

UPON THE ASSUMPTION THAT THE PAYLOAD CONSISTING OF THE BIPS-SPACECRAFT-IUS ASSEMBLY IS CANTILEVERED MOUNTED TO THE SPACE SHUTTLE.

- A. AVOID COUPLING OF THE FUNDAMENTAL FREQUENCIES OF THE CANTILEVERED PAYLOAD WITH THE FUNDAMENTAL FREQUENCIES OF THE SPACE SHUTTLECRAFT (3-13 CPS).
- B. AVOID COUPLING OF THE FUNDAMENTAL FREQUENCIES OF THE DISCRETE MASSES OF THE BIPS WITH THE FUNDAMENTAL FREQUENCIES OF THE CANTILEVERED PAYLOAD. RESULTS IN A LOWER LIMIT OF THE NATURAL FREQUENCIES OF THE BIPS COMPONENT OF ABOUT 60 CPS.
- C. AVOID HIGHER FUNDAMENTAL FREQUENCIES OF BIPS COMPONENTS THAN NECESSARY TO SATISFY A. AND B. ABOVE IN ORDER TO MINIMIZE THE DYNAMIC RESPONSE TO SHOCK AND VIBRATION.
- D. SHOCK AND VIBRATION RESPONSE OF THE MHW-RTG FOR THE LES 8 AND 9 DURING QUALIFICATION TESTING.
- E. PROVIDE HIGHER STRUCTURAL CAPABILITY FOR THE BIPS COMPONENTS AND MOUNT PADS THAN THE COMPONENT INTERFACE STRUCTURE TO COMPENSATE FOR STATICALLY DETERMINATE MOUNTING SYSTEMS AS COMPARED TO THE REDUNDANCY OF THE INTERFACE STRUCTURES.

TABLE IX

FREQUENCY ANALYSIS SUMMARY

REFERENCE 76-311998

APPROACH

1. FIRST APPROXIMATION OF THE FLEXURAL BENDING NATURAL FREQUENCIES OF THE CRITICALLY LOADED INTERFACE BEAMS AND STRUTS.
2. THE FUNDAMENTAL FREQUENCIES OF THE RADIATOR WERE DETERMINED BY KALNIUS SHELL PROGRAM LUMPING THE TOTAL MASS TOGETHER.
3. A DYNAMIC MODEL WAS SET UP TO DETERMINE THE FUNDAMENTAL FREQUENCIES OF THE INTERFACE STRUCTURES AS A SYSTEM.

HSA	180 LB
RECUP	100
MINI-BRU	38
INTERFACE STRUCTURES	42
MISC	20

TOTAL MASS 380 LBS

RESULTS

	LATERAL VIB (CPS)	LONG. VIB (CPS)	RADIAL VIB (CPS)
ALUMINUM	70	210	82
LOCKALLOY	139	417	163
BERYLLIUM	190	170	223

FUNDAMENTAL FREQUENCY OF THE RADIATOR

TABLE X

FREQUENCY ANALYSIS SUMMARY

U = UPPER BEAM
L = LOWER BEAM

LOWEST NATURAL FREQUENCY OF THE BIPS (CPS)

UPPER LOWER	1-1/2x1/16	1-1/2x1/8	1-3/4x1/16	2x1/16	2-1/4x1/8	3x1/8
1x1/16	A 38 L 74 B 101					
1x1/8	A 42 L 82 B 112	A 56 L 110 B 153				A 70 L 138 B 190
1-1/2x1/16				A 54 L 108 B 149		
1-3/4x1/16			A 55 L 106 B 146			
2x1/16				A 63 L 125 B 171		
2-1/4x1/8					A 84 L 165 B 227	

NOTE: (1) A = ALUMINUM
L = LOCKALLOY
B = BERYLLIUM

TABLE XI

STRESS ANALYSIS SUMMARY

REFERENCE 76-311998

1. UPPER STRUCTURE, 1 1/2 X 1/16 LOCKALLOY TUBE, SUPPORTS THE HSA.
2. LOWER STRUCTURE, 1 X 1/16 LOCKALLOY TUBE, SUPPORTS THE MINI-BRU AND RECUPERATOR.
3. ALL LOADS TRANSMITTED TO THE RADIATOR.
4. ALL MOUNT PADS ARE DESIGNED FOR 50 G's. ALL INTERFACE STRUCTURES ARE DESIGNED FOR 25 G's.

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TABLE XII

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4.2.2 GDS Layout and Support Structure

The GDS component, ducting, and support structure layout and interface requirements are included in AIRPHX Report No. 76-311972. The support structure for the GDS, shown in Figure 18, is a flight prototypical configuration which serves to position and support the BIPS components within the GDS vacuum chamber (or FS radiator). The GDS interfaces and mount systems are shown in Figure 19.

In order to minimize weight and maintain a high degree of stiffness and strength, tubular construction is used. The FS is predicated on use of Lockalloy (a Be/Al composite); the GDS will duplicate the FS structure using aluminum. The BIPS system is considered to have adequate stiffness and strength to avoid user integration problems. The BIPS GDS is shown in Figure 20.

4.2.3 BIPS Control System

The function of the BIPS Control System is threefold:

- (a) Provide conditioned power, using a 28-vdc supply, to accelerate the rotating unit from zero to self-sustaining speed, as discussed in Section 4.2.4
- (b) Condition and regulate the output power to maintain specified voltage and quality
- (c) Maintain speed as required to maintain turbine inlet temperature at optimum design conditions

A simplified block diagram of the control system is shown in Figure 21. The sequence in which this control system performs is discussed below.

FLIGHT PROTOTYPICAL SUPPORT STRUCTURE

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FIGURE 18

GDS INTERFACES - MOUNT SYSTEMS

FIGURE 19

BIPS-GDS

FIGURE 20

SIMPLIFIED BLOCK DIAGRAM

FIGURE 21

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PHOENIX, ARIZONA

After the Mini-BRU has reached self-sustaining speed of 26,000 rpm, it will accelerate, on its own, to design operating speed of 52,000 rpm. Prior to the Mini-BRU reaching design speed, the alternator field is excited by the voltage regulator/exciter, and the alternator begins producing a three-phase ac voltage. The ac voltage is full wave rectified to provide 120 volts dc to the user load.

Design speed is held within ± 0.1 percent of the desired operating point by the speed control. Speed control is effected by a parasitic load in parallel with the user load. If the speed sensor senses an overspeed condition, the parasitic load will increase, and rotating speed will be restored to design point. Conversely, reduction in speed below the programmed setpoint results in a reduction in parasitic load.

Once steady-state system operation (52,000 rpm, 1600°F turbine inlet temperature, and 1.3 kW_e output power) has been reached, then the full user load can be applied. The load sensor maintains the total of user load plus parasitic load at a constant level. A change in user load will result in an offsetting change in parasitic load so that total load on the system remains at a value which will result in constant speed.

The controls are completely solid state; no dynamic control elements are required. Speed control (parasitic electric load) and electric power conditioning and regulation are implemented with circuits designed for future flight packaging and qualification. Redundancy and use of "hi-rel" components provide the required reliability.

Three control systems were analyzed; (1) NASA Control, (2) NASA/AiResearch Control, and (3) Digital Control. The analyses trade-off for the three systems is shown in Figure 22. The NASA/AiResearch

ANALYSES TRADE OFF

	NASA CONTROL	NASA/AIRESEARCH CONTROL	DIGITAL CONTROL
PERFORMANCE			
BOM	1.095 KW	1.250 KW	1.300 KW
EOM	0.915 KW	1.060 KW	1.200 KW
POWER QUALITY	SC-76-312008	SC-76-312008	SC-76-312008
RELIABILITY	0.9916	>0.9916	0.9971

FIGURE 22

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PHOENIX, ARIZONA

Control will be used for initial testing; however, the digital control has higher reliability and exhibits better performance than the other two systems, therefore, it will be further developed. A plot of performance versus time for the NASA control, digital control, and a turbine exhaust temperature sensing control is shown on Figure 23.

For additional information on the control systems, refer to the Controls Design Report, AIRPHX Report No. 76-311937.

4.2.4 Alternator Motor Start

Two approaches using the alternator for motoring the Mini-BRU rotating group to self-sustaining speed (approximately 26,000 rpm) have been successfully demonstrated. These are induction and synchronous motoring. Either mode can be used to motor start the Mini-BRU with adequate torque margin. The induction start scheme has the advantage of simplicity in circuit function but has the disadvantages with the handling of high currents and voltages. The synchronous start offers the advantages of low voltage and current but somewhat more complex logic circuitry.

4.2.5 GDS Assembly and Test Facility

The GDS assembly procedure was defined, evaluated, and will be documented as AIRPHX Report No. 76-311748. The assembly consists of 21 major steps and is presented in the PDR document and supplement (AIRPHX Report Nos. 76-312035 and 76-312035A, respectively). An outline of the BIPS GDS assembly and test sequence is shown in Figure 24, and Figure 25 represents the completed GDS assembly.

The high vacuum test chamber and pumping system (shown in Figure 26) and the GDS test facility (shown in Figure 27) requirements were defined. The specifications on these designs are documented as AIRPHX Report Nos. 76-311736, 76-311738, 76-311740.

PERFORMANCE VS TIME

FIGURE 23

BIPS/GDS ASSEMBLY AND TEST SEQUENCE

HARDWARE FABRICATION

GFE HARDWARE

MINI BRU (2)
RECUPERATOR (1)
HSA (3)
EHS (3)

BIPS HARDWARE

SUPPORT STRUCTURE
HRHX (1)
DUCTING, BELLOWS,
BI-MET JOINTS
WORKHORSE PLENUM
AND HEATERS (2)
MULTI-FOIL INSULATION

PRE-CONDITIONING

VACUUM
BAKEOUT

STORAGE

STORE IN
DRY N₂

ASSEMBLY AND TEST

ASSEMBLE
WORKHORSE
LOOP

CONDITION
LOOP

TEST
WORKHORSE
LOOP

REMOVE
SUPERALLOY
PLENUM & HEATER

INSTALL
EHS's &
Cb PLENUM

CONDITION
LOOP

GDS
PERF. TEST

GDS
ENDURANCE
TEST

FIGURE 24

21. COMPLETED GDS ASSEMBLY

FIGURE 25

CONCEPTUAL GDS AND VACUUM CHAMBER

REFERENCE 76-311736

FIGURE 26

BIPS-GDS FACILITY

REFERENCE 76-311740

ACTIVITIES:

CLEANING OF COMPONENTS
STORAGE OF COMPONENTS
ASSEMBLY OF GDS
INSULATION APPLICATION
WELDING
GDS PERFORMANCE TESTING
GDS ENDURANCE TESTING

PROVISIONS:

CLASS 10,000 BUILDING
CLASS 100 ASSEMBLY AREAS
CLEANING EQUIPMENT
STORAGE DESICCATORS
WELD CHAMBER
VACUUM TEST SYSTEM
CONTROL AND DATA
ACQUISITION CENTER
FACILITY AND TEST
ARTICLE PROTECTION

1. DIGITAL DATA ACQUISITION SYSTEM / 150K BCD RECORDING
2. GDS VISUAL EMERGENCY SHUTDOWN
3. GDS COMPONENT PANEL
4. GAS CONTROLS
5. FACILITY STATUS PANEL

FIGURE 27

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4.2.6 Comparison of the BIPS FS and BIPS GDS

As stated previously, the BIPS GDS is intended to simulate the BIPS FS as closely as possible to ensure FS design integrity. By referring to Table XIII and Figures 28 and 29, it can be seen that the GDS and FS are functionally identical; their performance is essentially identical; and there are few differences, physically, between the two systems. For further information, refer to AIRPHX Report Nos. 76-311965 and SC-76-311742A.

4.3 Task 4 - GDS Detailed Analysis and Design

4.3.1 Materials Review and Selection Committee

Under this task, a Materials Review and Selection Committee (MARSCOM) was formed in November 1975 at the request of the ERDA. The primary purpose of the committee is to oversee, integrate, and direct the materials test effort so that the test results, when incorporated with the GDS endurance test results, will guide the design of the FS and establish the theoretical reliability of the system for its seven year life. The committee consists of:

J. Hadley - AIRPHX (Chairman)
C. Alexander - Battelle Columbus Laboratory
J. Griffo - ERDA-SNS Washington
R. Titran - NASA Lewis Research Center
A. Schaffhauser - ERDA - Oak Ridge

Through the aid of MARSCOM, the materials development effort is progressing satisfactorily. A comprehensive program plan for test work has been initiated to aid in confirming the system reliability [Integrated Program Plan (IPP), AIRPHX Report No. 75-311574A].

TABLE XIII
SIMILARITIES AND DIFFERENCES

BETWEEN THE BIPS GDS AND THE BIPS FS

SUB-SYSTEM	CONFIGURATION	MATERIALS	PERFORMANCE	WEIGHT
MINI BRU	Identical except for instrumentation (Added for GDS tests)	Identical	Identical	Identical (38 pounds)
MBR	Similar except for instrumentation (Added for GDS tests) and size (MBR used in GDS tests is oversize since it has been optimized for three HSAs rather than two). The same basic design can be incorporated into a smaller version optimized for the 2 HSA flight system.	Identical	FS optimized for 2 capsule operation; GDS optimized for 3 capsules	Less for flight system (134/106 pounds)
HSA	Identical except for: 1) Instrumentation (added for GDS tests), 2) EHS power leads (for GDS), 3) Gas management valve (used only in HSA for FS for venting helium generated by isotope decay), and 4) Auxiliary cooling valve (used for venting cover gas from insulation - the GDS will utilize system which will permit reinjection of cover gas, FS ACV will be one-shot mechanism, probably actuated by radio command).	Identical except for external support housing and end domes (stainless steel for GDS; Beryllium for FS) and as noted under "configuration"	Identical	Similar; FS predicted to be somewhat lighter, primarily because Beryllium will replace stainless steel for housing.
RADIATOR	GDS will utilize a liquid to gas HRHX to simulate the space radiator of the FS	GDS HRHX - copper; FS - radiator - aluminum or Beryllium or Lockalloy	HRHX will simulate space radiator	(FS ~ 80 pounds) in Beryllium
CONTROLS	GDS: All circuits breadboarded; circuit boards to be plug-in type, no hybridizing, ease of accessibility and reliability prime considerations. Parasitic load and load drivers convection cooled. FS: All circuits hybridized, packaged for minimum volume, weight. All cooling by radiation	TBD	Identical	Flight System lighter due to hybridizing electronic components (FS ~ 10 pounds)
BELLOWS AND DUCTS	Identical except HRHX ducting for GDS different from radiator ducting of FS. FS has two more low temperature bimetallic joints. (HRHX inlet/outlet ducting). GDS has 15 more weld joints than FS.	Identical	Identical	Basic system without cooler and radiator identical. (FS ~ 27 pounds)
STRUCTURE	Identical except GDS uses vac tank support in place of radiator for FS. Radiator/ component support structure interface ring is identical to FS interface ring.	GDS uses all aluminum. FS uses Lockalloy and Beryllium	Identical	FS lighter structure (FS ~ 32 pounds)
INSULATION	Identical except for additional instrumentation penetrations	Identical	6 to 8% higher thermal loss in GDS (300 to 400 watts) due to instrumentation penetrations.	Identical (18 pounds)

- NOTES: (1) Although intended to be "identical" in many instances, lessons learned from GDS, performance and endurance tests may lead to changes in flight system components and/or configuration.
- (2) For test purposes, GDS will incorporate a number of additional valves, gas supply systems, and protective devices.
- (3) GDS loop will contain two turbine bypass shutoff valves and a pressure relief valve for development testing protection, FS will not.
- (4) GDS loop will contain a one-way check valve in compressor inlet to eliminate the possibility of reverse flow during startup. Possibility of removing check valve from FS will be investigated during GDS testing.
- (5) GDS loop will not be as well sealed as the FS because of extensive instrumentation and greater number of potential leak paths. For this reason, an He-Xe tank will be connected to GDS loop. A pressure regulator will control inlet pressure into closed loop and provide replenishment of working fluid to compensate for leakage. The FS will be sealed after initial charging.
- (6) Flight monitoring system will be included in GDS to a limited degree. Transducers selected for flight, and some associated electronics, will be included in GDS test.

FLIGHT SYSTEM CYCLE SCHEMATIC

380°R SINK TEMPERATURE
EMISSIVITY = 0.80
AREA = 134 SQ FT.

NET CYCLE EFFICIENCY
27%

FIGURE 28

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
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GDS AT 4800 W_t

NET CYCLE EFFICIENCY
27%

FIGURE 29

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The status of the test work is detailed in the following paragraphs. Topical reports documenting these tests will be prepared.

4.3.2 Contamination Sources

The primary sources of contamination are the alternator stator organic compounds, the MBR outgassing, the graphite in the heat source, and gas entrapment in the foil insulation.

4.3.3 Alternator Stator

BCL has implemented a test to devise a bakeout cycle of the stator and to establish an estimation of the total contaminant expected. After 100 hours of bake out, the emission of material is in the range of 1/2 to 1/3 grams per year. Tests are continuing to study the contamination rate and its effects on alternator performance.

4.3.4 MBR Outgassing

The MBR is expected to evolve carbon and oxygen from the surface and the interior of the alloy. Test work has been defined and the emission rate of contaminant will be evaluated at BCL.

4.3.5 HSA Outgassing

A test program has been conducted at BCL to determine methods of minimizing the offgassing from the graphite in the heat source. Experience with the MHW system is being utilized to determine what additional sources of contamination may exist in the IHS.

4.3.6 Foil Insulation

Entrapped gasses in the foil insulation could be a source of contamination. An experiment has been defined and is underway at TECO and BCL to establish the magnitude of the anticipated problem and its effect on the operation of the system.

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4.3.7 Contamination Effects on C-103

Tests on the uptake rate of CO and the effect of contamination level on the C-103 properties are underway. The results of the tests can be used to establish a projection of the effects on the C-103 properties. Recent data indicate that contamination of the parts per thousand range is required before a serious effect is noted.

4.3.8 MBR Tests

Work is being conducted to assess the stability of the brazed MBR. Samples of brazed recuperator sections are being aged at NASA up to 5000 hours and will be examined for braze diffusion and alloy stability. A prototype recuperator is being thermally cycled at AIRLA, using GDS system parameters to confirm the design expectations.

4.3.9 Bimetallic Joint

NASA has completed development of the bimetallic joints. Evaluation of cycled and aged specimens has been completed. A joint design, torque in groove, has been accepted and further confirmation is being conducted at ORNL.

4.3.10 System Tests

In order to confirm the anticipated effects in the system, a post test analysis will be conducted to evaluate the results from operating the GDS. C-103 specimens will be located in critical areas to determine the actual contamination effects in the system. In addition, samples will be taken from the MBR and turbine wheel tips to establish the stability of the superalloys in the high purity environment.

The development of a mathematical model of the system contamination effects is also in progress. As the various effluent rates are

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established, they will be programmed into the model. The mathematical model will be confirmed by performing a test on a fairly simple C-103 shape and then checked through chemical analysis.

4.4 Task 7 - Quality, Reliability and Safety

Under this task, the following program plans were approved:

- (a) Reliability Program Plan - BIPS GDS, Phase I, AIRPHX Report No. 75-311360, dated September 30, 1975
- (b) Reliability Program Plan - GDS, Phase I, GE Report No. GE-BIPS-72-002, dated December 4, 1975
- (c) System Safety Program Plan - Phase I, AIRPHX Report No. 75-311221, dated September 30, 1975
- (d) QA Program Supplement for ERDA-BIPS, AIRPHX QCGI No. 137, dated September 30, 1975, Rev. November 19, 1975
- (e) QA Plan - GDS Program, GE-BIPS-71-001, dated September 15, 1976

Q, R, and S efforts resulting from these plans were documented as follows:

- o AIRPHX - Endurance Test Rationale, July 1, 1975
- o AIRPHX/NASA - Recommended Acceptance/Reliability tests for GFE Components, July 29, 1975
- o Preliminary Failure Modes, Effects and Criticality Analysis (FMECA) - BIPS FS, AIRPHX Report No. 76-311709, dated January 12, 1976

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- o BIPS Design Integrity Checklist, COORD A0106, dated January 23, 1976, AIRPHX Report No. 76-311971, dated June 10, 1976
- o Preliminary FMECA - BIPS GDS, AIRPHX Report No. 76-311965, dated June 1, 1976
- o Loop Containment Assessment - BIPS FS, AIRPHX Report No. 76-311791, dated June 1, 1976
- o Preliminary Reliability Allocation and Estimation - BIPS AIRPHX Report No. 76-311851, dated June 1, 1976
- o Liaison established with SLA, AFWL, SAMSO
- o Preliminary Hazard Analysis - BIPS FS, AIRPHX Report No. 75-311629, dated October 31, 1975
- o Preliminary Hazard Analysis - GDS, AIRPHX Report No. 75-311665, dated November 30, 1975
- o BIPS - transient probability study GE-BIPS - 73-001, dated November 13, 1975
- o Liaison established with ERDA - ALO
- o QA requirements in procurement specifications, source control drawings, reliability analyses

4.5 Task 11 - Workhorse Loop Add On

A "Workhorse Loop" add-on task to the BIPS was awarded by the ERDA and initiated in April 1976. This effort consists of the design and

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fabrication of a superalloy plenum and heater for loop checkout and the technical assessment of an optimized superalloy flight system (see AIRPHX Report No. 76-311790). The objectives, limitations, configuration, and status of the workhorse loop are summarized in Table XIV.

The workhorse loop layouts have been completed and one view is shown on Figure 30. The superalloy turbine plenum constructed of Waspaloy (A) has been analyzed for a turbine inlet temperature of 1400°F and a turbine inlet pressure of 105 psia operating condition. The recommended configuration is satisfactory, from a stress standpoint, for a seven-year continuous life (see AIRPHX Report No. 76-311903).

4.6 Task 8 - Reports and Data

The results of effort on all tasks (Tasks 1, 2, 3, 4, 7, 8, and 11) were documented; abstracts of these documents are included in Section 6.

WORKHORSE LOOP

- **OBJECTIVES**
 - CHECK OUT VACUUM SYSTEM
 - CHECK OUT GDS SUPERALLOY COMPONENTS
 - CHECK OUT CONTROLS
 - MBR AND MINI-BRU PERFORMANCE
- **LIMITATIONS**
 - 100 HR LIFE AT 1600°F TIT AND 60 PSIA
 - 200 HR LIFE AT 1600°F TIT AND 40 PSIA
 - 1000 HR LIFE AT 1400°F TIT AND 40 PSIA
 - HIGHER THERMAL LOSSES
- **CONFIGURATION**
 - SIMILAR TO GDS WITH TWO HEATERS
 - TURBINE PLENUM SIMILAR TO GDS
 - UTILIZES GDS SUPPORT STRUCTURE
 - Cb C-103 COUPONS AND TENSILE SPECIMENS INCLUDED
- **STATUS**
 - TURBINE PLENUM -- DETAILED AND ON ORDER
 - HEAT SOURCE AND INSULATION SYSTEM -- DETAILED
 - CONTROL SYSTEM AND HEATING ELEMENTS -- ON ORDER

TABLE XIV

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5. SUBCONTRACTOR TECHNICAL ACHIEVEMENT SUMMARY

5.1 General Electric Company

5.1.1 Introduction

This report summarizes significant events, activities, and achievements on the Brayton Isotope Power System (BIPS) Program during the program year August 1, 1975 to July 31, 1976. It covers the initial, conceptual design of the Flight System (FS) and the preliminary design of the Ground Demonstration System (GDS).

The following paragraphs summarize the major activities carried out during the year; further details can be obtained by consulting the documents listed and abstracted in Section 6.0 of this report.

5.1.2 Flight System Conceptual Design

The BIPS-FS configuration and component arrangement were studied to determine an optimized configuration. Several configurations and component orientations were evaluated; system performance, spacecraft and launch vehicle integration, and spacecraft compatibility were conducted. The FS configuration was found to be influenced primarily by the following factors:

- (a) On pad fueling requirements
- (b) HSA orientation
- (c) BRU orientation
- (d) Hot duct length (heat losses)

The selected FS configuration utilizes vertically oriented HSA and BRU units, all components internal to the radiator, and sealed covers on both ends of the radiator. This configuration provides the following advantages.

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- (a) The vertical HSA affords the most compact configuration and is desirable for fueling.
- (b) The sealed radiator permits the radiator to be filled with an inert gas to provide protection to the hot refractory components for ground handling and on-pad operation.
- (c) The vertical BRU provides compatibility with both spin stabilized and three-axis stabilized spacecraft and minimizes bearing losses for FS operation during launch.

As part of the conceptual FS design study, a materials evaluation study was performed to review the potential problems related to the use of the MJS Isotope Heat Source (IHS) with the HSA which utilizes C-103 material. This study showed that if the level of carbon monoxide or other contaminants emanating from the heat source is too high to be tolerated by the C-103 in the heat source heat exchanger (HSHX) then the development of a Pt-3008 platinum outer clad for the IHS should be pursued, and a backup effort initiated to develop a coating for the HSHX. For more detail, consult the Materials Compatibility Analysis Topical Report (GE-BIPS-03-001). Also as part of the FS Conceptual Design, a preliminary Mission Environments Document (GE-BIPS-20-001) was prepared to define the expected environments for the FS.

5.1.3 GDS Preliminary Design

For the GDS, GE is responsible for the design and fabrication (or refurbishment) of the following hardware:

- (a) The Heat Rejection Heat Exchanger (HRHX)
- (b) Three Electric Heat Sources (EHS) - GFE
- (c) Two Power Supply Consoles (PSC) - GFE

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- (d) The HSA Auxiliary Cooling System Gas Management System
(ACS-GMS)
- (e) Two EHS Loading Fixtures
- (f) The HSA Handling Sling

In addition GE will assemble the GFE HSA's into the GDS.

During this reporting year, the preliminary design was completed for Items (a) through (d) above. Approaches were defined and evaluated for the HSA/GDS assembly. Details relative to the preliminary design and analysis of the GE portion of the GDS program can be found in the Preliminary Design Review Data Package, GE-BIPS-30-001, dated June 1, 1976 and in the monthly reports which are included in the AiResearch Monthly Progress Reports, 75-311457.

5.1.4 Quality, Reliability and Safety

5.1.4.1 Quality Assurance

During this year, the Quality Program Plan (GE-BIPS-71-001) was prepared and published. Quality Engineering was involved in both the preliminary design of the GDS and the Preliminary Design Review.

5.1.4.2 Reliability

The reliability effort during the annual reporting period involved preparation of the Reliability Program Plan (GE-BIPS-72-002), the preliminary FMECA for the HSA and the HRHX (GE-BIPS-72-001), the FMECA for the GDS Ground Support Equipment (GE-BIPS-72-003), support of the GDS preliminary design and design reviews. The details of this effort can be found in the referenced documents.

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5.1.4.3 Safety

The safety effort during this reporting year involved the performance of a Transient Probability Study to determine the probability for re-entry of a spacecraft employing the BIPS coincident with a temperature excursion in the heat source due to loss of auxiliary cooling or the working fluid. The results of this study are summarized in the following table.

<u>Condition at Re-Entry</u>	Total Mission Probability	
	<u>Operation at Launch</u>	<u>Startup in Orbit</u>
No transient, or minimal temperature increase	0.079	0.079
Temperature has not exceed 3000°F on PICS	3.5×10^{-7}	3.0×10^{-7}
Temperature has exceeded 3000°F but total transient has not occurred	6.2×10^{-7}	5.8×10^{-7}
Full transient has occurred	0.00033	0.00035

The details of this study are reported in BIPS-Transient Probability Study, GE-BIPS-73-001. Additional safety effort involved the preparation of preliminary fueling flow plans for the BIPS-FS.

5.2 Thermo Electron Corporation

The primary objectives of the Multi-Foil insulation efforts (January through August, 1976) at Thermo Electron are: (1) to apply Multi-Foil thermal insulation in an effective manner to the Ground Demonstration System (GDS) and (2) to formulate the conceptual design of Multi-Foil insulation for the Flight System.

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The principal Thermo Electron GDS Multi-Foil activities were:

- o Relative insulation effectiveness experiments
 - Conventional Multi-Foil reference
 - Multi-Foil tape measurements
 - Cylindrical heat source
 - 3-inch width tape
 - 1-inch width tape
 - Elbow heat source
 - 1-inch width tape
- o Full-scale mockup of GDS built
- o Developed computer program for GDS Multi-Foil thermal analysis
- o Parametric study of Multi-Foil system heat losses performed
- o Preliminary GDS insulation design and planning completed
- o Meltdown tests of three miniature Multi-Foil assemblies
- o Detail design of BRU insulation package
- o Compatibility tests of candidate foil materials coated with zirconia

The primary conclusions drawn from the foregoing efforts are:

- o Conventional and tape Multi-Foil insulation losses are comparable (on a per layer basis).

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- o On a per layer basis, tape Multi-Foil is approximately 20 percent heavier than conventional Multi-Foil.
- o To a good approximation, the Multi-Foil (nickel layer/zirconia) heat flux, ϕ , is given by:

$$\phi \frac{\text{watt}}{\text{cm}^2} = \frac{1.06 \times 10^{-12} [T^4 - 81 \times 10^8]}{0.778 N + (1.11 \times 10^{-2}) N^2}$$

Where

N = Number of foil layers

T = Heat source temperature, K

- o The effective thermal emissivity of the Ni-ZrO₂ Multi-Foil is about 0.32.
- o Significant heat loss reduction (for a given weight of insulation) is possible by optimizing the distribution of foil layers on the GDS.
- o System thermal analysis indicates that HSA losses are a major fraction of total.
- o Multi-Foil meltdown tests suggest that additional Multi-Foil layers may be safely added to the HSA insulation.
- o Initial tests indicate that electroformed Multi-Foil insulation is approximately four times as effective as either conventional or tape Multi-Foil (on a per layer or weight basis).

- o Potential heat loss reductions are large enough and the probability of success high enough to make an investment in electroformed multi-form technology cost effective for the Flight System.
- o On the basis of foil compatibility tests at TECO, molybdenum is recommended for the hottest foils.

5.3 AiResearch Manufacturing Company of California

5.3.1 Recuperator Analyses

A series of analyses was performed to examine the behavior of the Mini-Brayton Recuperator (MBR) in the BIPS application. Results of these studies, which are described below, were used as inputs to the system studies and to establish the recuperator life and performance.

5.3.1.1 Thermal Transient Behavior

Various proposed startup sequences were examined to determine their effect on the thermal response of the recuperator. Based on a comparison of the tube plate thermal response it was determined that Start Cycle 101 conditions, as defined in AIRPHX Report 75-311279, would produce a lower thermal stress level and greater cyclic life than other possible startup modes.

Based on the recuperator inlet conditions for Start Cycle 101 conditions, a detailed transient thermal analysis of the recuperator was performed. The response of tube sheet in the presence of header bars, seal plates, manifold pan, and the manifold splitter plate was determined. Two different configurations were analyzed: inlet and outlet ports on the same side of the core assembly, and the ports on opposite sides. The results were used to identify areas with large thermal

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gradients and to propose measures to alleviate these gradients. Results of this study formed the basis for the subsequent calculation of thermal stress and cyclic life.

A study was made to compare the results of the transient analysis computer program HXT4 with data obtained from a MBR submodule test. Corrections were applied to the test data to account for thermocouple lag and radiation losses. Final results showed that there was less than 3 percent difference between measured and predicted values at steady-state and 6 percent during a transient startup. This agreement was considered satisfactory.

A topical report covering the transient analysis studies is being prepared.

5.3.1.2 Cyclic Life

The transient temperature data were used as the input to a 2-dimensioned finite element program (ANSYS) which is used to compute the resultant stresses and deflections. Maximum transient stresses were compared for two different manifold port configurations. The object of this analysis was to compute the low cycle fatigue life for several potentially critical areas in the recuperator. Both local plastic deformation and creep relaxation effects were included in the analysis. These results were used to judge the suitability of the MBR in the BIPS application.

For system startup using the 101 conditions, the recuperator, initially soaked at -10°F , is subjected to a low pressure inlet gas temperature of 1600°F instantaneously, and decreasing to 1110°F in 180 seconds. This fast startup was determined to generate large thermal gradients, and hence high thermal stresses during the transient state. It was also found that the manifold pan temperature lags noticeably behind the triangular end section of the core. Maximum stresses are developed between 90 and 180 seconds into the startup transient.

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Computed cyclic life for the critical core sections was as follows:

<u>Element</u>	<u>Cyclic Life</u>
Core	60 to 120
Splitter joint	30 to 60
Splitter-core braze joint	70 to 140
Low pressure pan-to-core joint	15 to 30
High pressure pan-to-core joint	100 to 200

It should be noted that in the core-to-manifold joints, the stack height stresses were estimated and combined with the 2-D analysis results to obtain a fatigue life estimate. A 3-dimensional finite element analysis should be performed to obtain a more reliable cycle life estimate for these critical areas.

It was concluded that port orientation has only a minor effect on the thermal stress and resultant cycle life.

5.3.1.3 Flow Arrangement

System layout studies indicated that a Z-flow configuration for the recuperator manifolds might produce a better overall arrangement. The high pressure side would retain its present U-flow arrangement. The effect of Z-flow on flow maldistribution and pressure drop was analyzed. It was determined that flow maldistribution could be reduced to 0.3 percent by using a contoured insert in the inlet manifold. The resulting total pressure drop would be increased to 0.73 percent compared to the present value of 0.70 percent. The impact on system performance by these changes is minimal. It was recommended that the revised manifold arrangement be checked for thermal stress before adopting the Z-flow arrangement.

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5.3.1.4 Thermal Growth Prediction

Thermal expansions for the MBR were defined for a 3-mount system. Temperature distribution was based on steady-state operating conditions. The data were used to define the thermal growth that must be accommodated by the mounts and the bellows system.

5.3.1.5 Mount Design

A new mount configuration was designed for the MBR. The mount was designed to be used with a spherical bearing joint which prevents the transfer of any bending moments into the core and accommodates thermal growth by rotation rather than by a sliding action. A detailed structural analysis was performed, and the allowable mount loads for a three-point mounting system were defined. The design was based on a maximum inertial load of 50 g's applied to the MBR. Detail drawings were prepared and the new mount design will be incorporated on the MBR currently being fabricated under a contract from NASA-Lewis Research Center.

5.3.2 Bellows Design

The design of all bellows assemblies for the GDS and the workhorse loop was completed. Three different types were considered: (1) single, pressure unbalanced, shear and deflection type; (2) pressure balanced, internal link type; and (3) a double bellows assembly consisting of two single bellows connected with a center spool piece. Each design was optimized to: limit the flange loads, meet the design life criteria of 7 years and 100 cycles, stay below a squirm pressure limit, and meet the envelope and installation constraints.

To accomplish this task, an existing shell analysis computer program was modified to provide parametric design data for bellows of variable geometry. An analysis was performed to refine the prediction of

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the bellows squirm pressure including the case of two bellows in series. Each bellows was checked to insure a positive safety margin for seven different structural design criteria: yield, burst, 1 percent creep, creep-rupture, squirm pressure at room and operating temperature and low cycle fatigue life.

Inputs were provided for the bellows procurement specification including (1) a definition of the bellows size; (2) axial, lateral, and rotational movements; (3) axial, lateral, and bending stiffness; (4) active stroke and hysteresis; and (5) maximum allowable stress due to pressure and thermal loading.

The preparation of a test plan designed to verify the analytical predictions was initiated. Each of the basic configurations will be tested to determine the burst/squirm pressure, creep properties, and low cycle fatigue life. A total of 28 bellows is planned for testing.

A detailed topical report covering the bellows design and test plan will be prepared.

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6. REPORT ABSTRACTS

6.1 Task 1 - Program Management

Document: 75-311376B, October 22, 1975, AIRPHX

Title: Program Plan for the BIPS Phase I Design, Fabrication, and Testing

Abstract: Defines the tasks to be accomplished, the objectives, the approach to be used, the management, drawing specifications, applicable government documents and specifications, and published documents. The appendix is an AIRPHX organizational description.

Document: 75-311574A, May 27, 1976, AIRPHX

Title: Phase I Integrated Program Plan (IPP)

Abstract: A coordinating plan between the governmental and private industry participants in the BIPS Phase I program. It contains the Master Schedule, test objectives, materials testing requirements, etc.

Document: 76-311790, March 5, 1976, AIRPHX

Title: Technical Proposal, Design and Fabrication of a Superalloy BIPS Workhorse Loop and Technical Assessment of an Optimized Superalloy Flight System

Abstract: A developmental BIPS using superalloys and a boiler-plate heater is proposed which will precede the scheduled BIPS GDS testing, provide a system shakedown and a wider range of data than possible with the GDS.

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6.2 Task 2 - FS Preliminary Design

Document: 75-311457*, August 8, 1975, First Issue, AIRPHX

Title: Monthly Progress Reports

Abstracts: (1)* pp 5-8: FS layouts, alternator field configuration, voltage regulator, MBR analysis; (2)* pp 4-7: preliminary design trade-off analysis, MBR analysis, radiator analysis, alternator field fusing schemes, output voltage study, speed control, FS conceptual control system; (3)* pp 3-7: controls, preliminary design layouts; (5)* pg 6: conceptual FS design (Mini-BRU orientation summarized in Appendix A).

Document: 75-311274B, Appendix I, March 15, 1976, AIRPHX

Title: BIPS Configuration Control Document (CCD), Appendix I

Abstract: Summarizes FS design-point operating parameters, objectives and design (provision for operation through launch, operation on a spin-stabilized platform, spacecraft integration, and the ducting system are addressed), preliminary shock and vibration design criteria, estimated performance for three configurations including influence coefficients, and system working fluid leakage rates.

Document: 76-312000, June 15, 1976, AIRPHX

Title: BIPS FS Preliminary Design Miscellaneous Notes

Abstract: A compendium of Flight System preliminary design internal memos and progress report extracts for the Brayton Isotope Power System Preliminary Design Review.

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Document: Appendices** to AIRPHX 75-311457* Technical Progress Reports
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Title: GE Technical Progress Reports

Abstracts: 2* III** State of Work; 3* I**, pp 1-5; Statement of Work; 3* I**, pg 6-:1. Program Management; 2. FS Preliminary Design (Materials Evaluation), Thermal Analysis (Emissivity Coating Requirements for a Pt-3008 Heat Source Clad), Mounting HSA Inside Radiator, Transient Thermal Analysis, Evaluation of ACS, FS Design Study; 3. GDS Preliminary Design, Preliminary Design Review; 7. Quality, Reliability, and Safety (Q&R Plans, Safety Analysis); 4* (-)**: 3. Materials Compatibility; 4. Multi-Foil Insulation Conductivity Testing; 5* B**: 3. EHS Fueling Concept; 4. Multi-Foil Insulation Conductivity Testing; 6* (-)**: 3. ACS and GSE Capabilities, GDS Assembly Critique of AIRPHX HRHX Design; 7 and 8* A**: 3. HRHX Preliminary Design, Instrumentation for HRHX, HSA, and EHS, Nickel Foil Vaporization; 8* A**: 3. GDS Assembly Planning; 9* A**: Load Capacity of HSHX Ports, HSA Interface Tolerances; 10* A**: 3. Preliminary Design Data Review, Preliminary Design of HRHX and ACS, EHS/PSC Integration with GDS, GDS Assembly Approaches, HSA thermal Losses; 11* A**: 3. Preliminary Design Data Review, EHS Integration with GDS, EHS Bakeout, HSA Assembly, GDS Assembly; 12* A**: 3. HSA/GDS Assembly, HSA Shipping Containers; 13* B**: 3. Preliminary Design Review; 4. HSA Handling Sling, HRHX Detailed Design, HSA/GDS Assembly Weld Development; 7. Fueling Ground Flow Plan.

Document: GE-BIPS-20-001, August 8, 1975

Title: Mission Environments for the Isotope Brayton Flight System
(Preliminary)

Abstract: Defines the expected mission environments for the FS based on MHW-RTG environments for LES 8/9 and MJS and engineering projections for BIPS-FS on Titan IIIC and Shuttle launch vehicles.

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Document: GE-BIPS-03-001, November 26, 1976

Title: Topical Report, Materials Compatibility Analysis, Protection of C-103 Alloy from EHS/IHS Outgassing Products

Abstract: Production of CO/CO₂ from the graphite used in the construction of the MHW-IHS can act as gaseous contaminants to the Cb C-103 components. The problem areas are defined, study objectives set, evaluation criteria set, identification of possible solutions, and recommendations for future testing and work.

6.3 Task 3 - GDS Preliminary Design and Test Plan

Document: 75-311279, May 19, 1975, AIRPHX (also Supplement 1, April 2, 1976)

Title: Transient Analysis, Isotope Brayton Flight System

Abstract: Describes the results of a transient performance study of the BIPS FS. A computer program (BRTDYN) was used which models the thermodynamic and control systems. Modes investigated were startup, shutdown, engine-alternator performance, and safeguard of system components.

Document: 75-311457*, August 8, 1975, First Issue, AIRPHX

Title: Monthly Progress Reports

Abstracts: (1)* pp 9 and 10: materials selection, bimetallic joints, alternator outgassing, GFE items; (2)* pp 7 and 8: materials, bimetallic joints; (3)* pp 7 and 8: GDS system design, test facility; (4)* pp 5-8: preliminary design layouts, GDS structural support considerations, test facility, control system preliminary design and mathematical models; (5)* pp 6-13: preliminary design layouts, GDS structural

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support considerations, test facility, control system, MBR analysis and mount design; (6)* pp 5-8: preliminary design layouts, test facility, control system (NASA start inverter and system analysis), MBR stress and cyclic life analysis, bellows analysis; (7)* pp 3-7: preliminary design layouts, structural design, test facility, control system (NASA start inverter system analysis), Mini-BRU (C-103 creep data, turbine stress analysis, motoring tests); (9)* pp 5-9: preliminary design layouts (discusses C-103 welding), structural preliminary design criteria, structural vibration design, breadboard control system is designed, recuperator mounting approved, turbine plenum welding change contemplated, Mini-BRU motoring tests conducted; (9)* pp 3-8: preliminary design layouts (a total of four possible welding methods are now identified), vibration analysis, test facility, control system analysis, bellows design, NASA controls turn-on, motoring tests, alternator off-gassing.

Document: 76-311752, June 14, 1976, AIRPHX

Title: Test Plan, BIPS GDS

Abstract: Describes the BIPS GDS test setup, instrumentation, required testing (performance and endurance) and procedural outline.

Document: 76-311937, due June 15, 1976, AIRPHX

Title: Controls Design Report, BIPS GDS Phase I

Abstract: Final Report, AiResearch BIPS GDS Controls. Includes projected performance and FMECA.

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Document: 76-311998, June 15, 1976, AIRPHX

Title: BIPS GDS Miscellaneous Design Notes

Abstract: A compendium of Ground Demonstration System internal memos and other documentation for the Brayton Isotope Power System Preliminary Design Review.

Document: 76-311972, June 15, 1976, AIRPHX

Title: BIPS GDS Preliminary Design Review Drawings

Abstract: A compendium of up-to-date drawings for the Preliminary Design Review.

Document: GE-BIPS-30-001, June 1, 1976

Title: GE Preliminary Design Review Data Package for BIPS-ERDA PDR

Abstract: Provides requirements, design description and supporting data for the preliminary design of the HRHX and ACS, the HSA/EHS/PSC Integration with the GDS, GDS Assembly Approaches and Reliability Analyses.

6.4 Task 4 - GDS Development and Detail Design

Document: 75-311457*, September 8, 1975 (First Issue), AIRPHX

Title: Monthly Progress Report

Abstracts: (3)* pg 8: recuperator outgassing assessment, materials testing program formulation; (4)* pp 8-9: cb C-103 specification

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assessment, bimetallic joint studies, SOW for alternator offgassing, Cb bellows evaluation specifications, formation of MARSCOM; (5)* pp 13-16: MARSCOM definition, bimetallic joints, turbine plenum, Multi-Foil insulation; (6)* pp 9-10: MARSCOM recommended tests, bimetallic joints, C-103 material specification to MARSCOM, received alternator offgassing test results from BCL, TECO has begun work on the contract; (7)* pp 7-9: C-103 creep data assessment, bimetallic joints, system contamination, Multi-Foil insulation; (8)* pp 10-12: C-103 creep data assessment, graphite outgassing, C-103 contamination assessment, bimetallic joints, alternate alloys, C-103 specification, MBR braze studies, C-103 ducting, alternator stator; (9)* pp 8-10 specification, bimetallic joints, MBR test plans, insulation compatibility and stability, C-103 creep tests, BIPS post-mortem analyses plans, Multi-Foil insulation.

Document: 76-311736, March 15, 1976, AIRPHX

Title: Engineering Report, Vacuum Test Facility Requirements

Abstract: Presents the results of a study undertaken to define the requirements for a reference vacuum test facility, as well as some operating procedures for the Phase I BIPS GDS.

Document: 76-311740, May, 31, 1976, AIRPHX

Title: BIPS Facility Specification

Abstract: Covers requirements for clean room and assembly area, vacuum system, instrumentation and recording, test console, working fluid management system, controls interface, vacuum dry box, HSA ACS gas management system, facilities, energies, and peripheral requirements.

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Document: SC-76-311742A, June 14, 1976, AIRPHX

Title: System Design Specification, BIPS GDS

Abstract: This is a compendium of system performance, design, development, environmental, test and operational criteria for the BIPS FS and GDS as defined by the DOD, ERDA, NASA, AIRPHX, GE, AIRLA, and all other subcontractors.

Document: 76-311773, April 8, 1976, AIRPHX

Title: Natural Frequency Analysis of the BIPS

Abstract: A computer model was used to analyze the dynamics of the BIPS. It was found that the fundamental frequencies varied from 38 to 227 Hz for the system. The built-in strengths of all the interface structures are in excess of the 25 g's limit loading criteria.

Document: 76-311903, May 14, 1976, AIRPHX

Title: Preliminary Evaluation of the Mini-BRU Turbine Plenum in Superalloy and the Currently Available Heat Exchanger for the BIPS Workhorse System

Abstract: Waspaloy can be used for the Mini-BRU turbine and nozzle assembly in a modified design. The currently available superalloy heat-source heat exchanger can be utilized in the Workhorse Loop with the recommended modification.

Document: TE4209-100-76, June 11, 1976, TECO

Title: Application of Multi-Foil Insulation to the Brayton Isotope Power System and Conceptual Design of Multi-Foil Insulation for the Flight System

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Abstract: The status of the effort to apply Multi-Foil thermal insulation in an effective manner to the Ground Development System (GDS) is reviewed. Heat loss measurements made on cylindrical and elbow heat sources using "Tape" and "Conventional" Multi-Foil indicate that the thermal losses are comparable on a per layer basis. However, use of the tape incurs a weight penalty, [per layer], of about 20 percent. The effective thermal emissivity of the nickel layer/zirconia powder Multi-Foil is approximately 0.32. The report also describes parametric studies of GDS insulation losses and a meltdown test of a Multi-Foil insulation assembly.

6.5 Task 5 - Fabrication and Assembly

Document: PSC 76-311738, May 31, 1976, AIRPHX

Title: High Vacuum Test Chamber and Pumping System Procurement Specification

Abstract: Establishes requirements for the design and fabrication of a high-vacuum test chamber, associated vacuum pumps, valves, controls and instrumentation.

6.6 Task 7 - Quality, Reliability, and Safety

Document: 75-311457*, September 8, 1975 (First Issue), AIRPHX

Title: Monthly Progress Report

Abstract: For the most part, quality, reliability and safety have been thoroughly documented in other documents. Items not covered by these documents are: (2)* pp 8-10: weld assessment update, acceptance and reliability tests; (3)* pg 9: recommends an ECS melt-down test.

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Document: 75-311221, September 30, 1975, AIRPHX

Title: System Safety Program Plan for the BIPS GDS, Phase I

Abstract: Covers safety organization, responsibilities and authority, system safety criteria, system safety tasks to be completed, documentation requirements and program control.

Document: 75-311360, September 30, 1975, AIRPHX

Title: Reliability Program Plan for the BIPS GDS, Phase I

Abstract: Covers reliability organization, authority, and responsibilities; design reliability elements; reliability engineering program elements; test program; and milestones.

Document: 75-311629, October 31, 1975, AIRPHX

Title: Preliminary Hazard Analysis for the Isotope Brayton Flight System

Abstract: Identification of hazards during all phases of the FS operation. Hazards are categorized as to negligible, marginal critical, or catastrophic.

Document: QCGI No. 137, November 19, 1975

Title: Quality Control Program Supplement for ERDA-BIPS

Abstract: Quality control program specifically for those portions of the ERDA-BIPS program not covered in QC-048, Revision 4.

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Document: 75-311665, November 30, 1975, AIRPHX

Title: Preliminary Hazard Analysis for the BIPS (Including Vacuum Test Chamber) GDS

Abstract: A summary of undesirable events which may lead to system damage or failure and/or hazard to personnel. Many items identified for the BIPS FS (75-311629) apply also to the GDS but have not generally been repeated.

Document: 76-311709, January 12, 1976, AIRPHX

Title: Preliminary Failure Modes, Effects, and Criticality Analysis (FMECA), BIPS FS

Abstract: Each of the major components or subsystems was reviewed to determine possible modes or manner of failure, then probable cause, and the effect of the failure on the system. Means of minimizing the failure mode were also investigated and recorded. The criticality of each failure was estimated.

Document: 76-311851, June 1, 1976, AIRPHX

Title: Preliminary Reliability Allocation and Estimation

Abstract: Presents a summary of the reliability allocation and estimation for a five-year reliability of 0.95 for the BIPS FS.

Document: 76-311791, June 1, 1976, AIRPHX

Title: Loop Containment (Joint Integrity) Assessment BIPS FS

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Abstract: The reliability of the ERDA BIPS FS loop containment (joint integrity) is assessed. Included is an assessment of the normal leakage rate.

Document 76-311965, May 12, 1976, AIRPHX

Title: Preliminary Failure Modes and Effects Criticality Analysis
(FMECA), BIPS GDS

Abstract: Each of the major components or subsystems was reviewed to determine possible modes or manner of failure, their probable cause, and the effect of the failure on the system. Means of minimizing the failure mode were also investigated and recorded. The criticality of each failure was estimated.

Document: 76-311971, June 10, 1976, AIRPHX

Title: BIPS Design Integrity Checklist

Abstract: Contains a listing of the 31 failure modes identified in the BIPS FS FMECA (AIRPHX 76-311709) as having the highest criticality ratings. Also listed are the 11 failure modes identified in the BIPS GDS FMECA (AIRPHX 76-311940) as being most critical. The document provides a checklist to highlight the status of actions underway to eliminate or to minimize these areas of concern.

Document: GE-BIPS-71-001, January 1, 1976

Title: Quality Assurance Plan for BIPS GDS Program, Phase I

Abstract: (See Title)

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Document GE-BIPS-72-002, December 12, 1975

Title: Reliability Program for Isotope Brayton Ground Demonstration
System Program, Phase I

Abstract: (See Title)

Document: GE-BIPS-72-001B, June 22, 1976

Title: Preliminary Failure Mode, Effects and Criticality Analysis on
the Isotope Brayton Ground Demonstration System - Heat Source
Assembly and Heat Rejection Heat Exchanger Components

Abstract: Each of the components are reviewed to determine possible
modes of failure, then probable cause, and the effect of failure on the
system. Means of minimizing the failure mode were investigated and re-
ported. The criticality of each failure was estimated.

Document: GE-BIPS-72-003A, June 22, 1976

Title: Failure Mode, Effects and Criticality Analysis on the HSA Gas
Management System and Power Supply Consoles; Components of the
BIPS-GDS Ground Support Equipment

Abstract: Each of the components are reviewed to determine possible
modes of failure, then probable cause, of minimizing the failure mode
were investigated and reported. The criticality of each failure was
estimated.

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Document: GE-BIPS-73-001, November 13, 1975

Title: BIPS-Transient Probability Study

Abstract: A study to determine the most probable state of the transient considering the worst case of a simultaneous re-entry and need for the emergency cooling system (ECS) to function properly. The test conditions for the transient test of the ECS were established from the results of this study.