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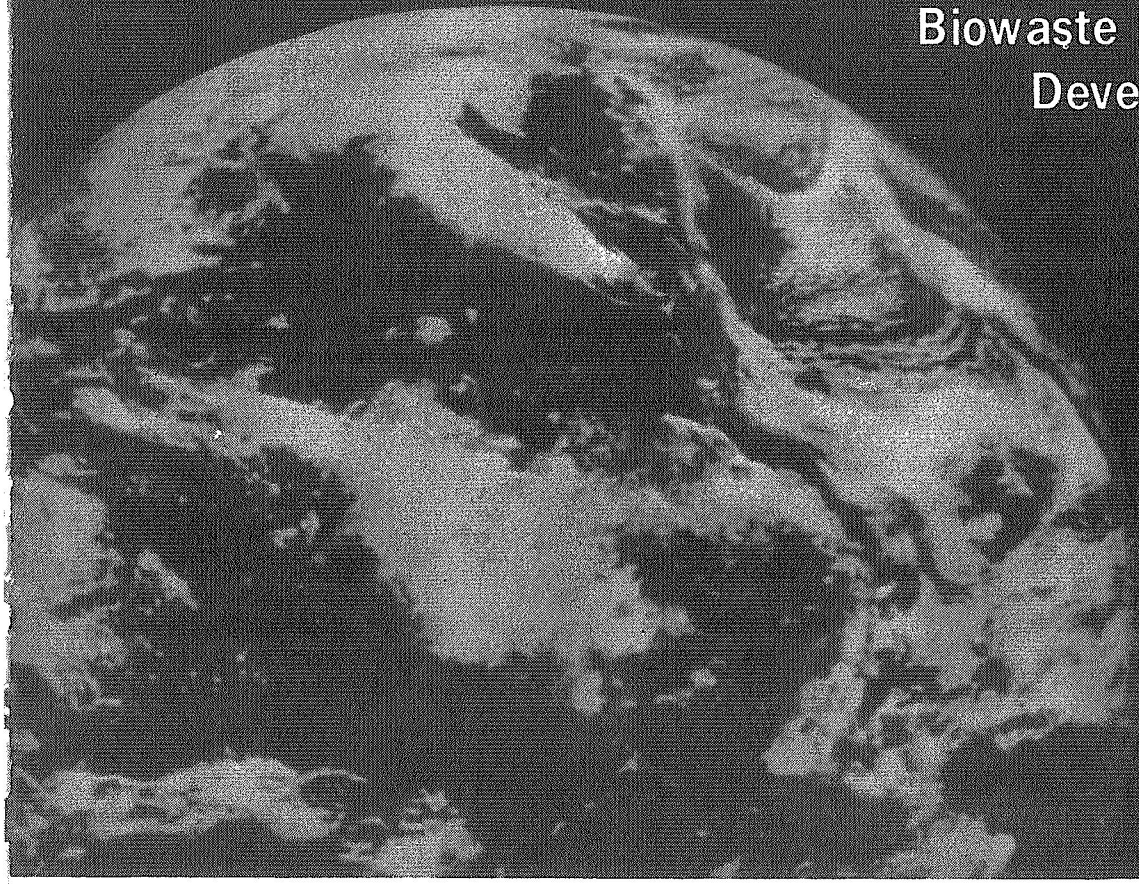
FINAL REPORT

RESISTOJET SYSTEMS STUDIES DIRECTED TO THE SPACE STATION/SPACE BASE

Volume II

Biowaste Resistojet System Development Program

CONTRACT NAS1-10127



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VOLUME II
Biowaste Resistojet System Development Program

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NASA CR 111880

PREPARED BY *R. V. Greco*

R. V. GRECO
STUDY DIRECTOR
AND

J. T. Abe

J. T. ABE
PROPULSION/REACTION CONTROL
RESISTOJET SYSTEMS STUDIES

APPROVED BY *D.E. Charhut*

D. E. CHARHUT
ASSISTANT CHIEF PROGRAM ENGINEER
SPACE STATION ENGINEERING

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

5301 Bolsa Avenue, Huntington Beach, CA 92647

PREFACE

This final Report on Resistojet Systems Studies Directed to the Space Station and Base is submitted by McDonnell Douglas Astronautics Company to the National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, as required by Contract No. NAS1-10127. The work was conducted under the technical direction of Earl VanLandingham of the Space Technology Division of Langley Research Center.

The study results are documented in a two-volume final report and a summary report.

I Station/Base Biowaste Resistojet System Design
II Biowaste Resistojet System Development Program
Summary Report

This volume presents the details of the system development program, including system technology identification, a component-through-integration-system test plan, and a resistojet thruster specification. Volume I contains the preliminary definition of the resistojet system and the supporting systems analysis. The significant results are summarized in the summary report.

Requests for further information concerning this report will be welcomed by:

D. E. Charhut
Assistant Chief Program Engineer
Space Station Engineering

R. V. Greco
Study Director
Resistojet Systems Studies

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W. G. Nelson and I. L. Schaffer, Environmental Control and Life Support
D. L. Wright, Power Distribution and Control
D. L. Endicott, Propellant Collection and Storage
K. E. Meadows, Reliability and Maintainability
L. O. Schulte, Space Station

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UNITS OF MEASUREMENT

Units, abbreviations, and prefixes used in this report correspond to the International System of Units (SI) as prescribed by the Eleventh General Conference on Weights and Measures and presented in NASA Report SP-7012. The basic units for length, mass, and time are meter, kilogram, and second, respectively. Throughout the report, the English equivalent (foot, pound, and second) are presented for convenience.

The SI units, abbreviations, and prefixes most frequently used in this report are summarized below:

Basic Units

Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	degree Kelvin	^{o}K

Supplementary Units

Plane angle	radian	rad

Derived Units

Area	square meter	m^2	
Volume	cubic meter	m^3	
Frequency	hertz	Hz	(s^{-1})
Density	kilogram per cubic meter	kg/m^3	
Velocity	meter per second	m/s	
Angular velocity	radian per second	rad/s	
Acceleration	meter per second squared	m/s^2	

Angular acceleration	radian per second squared	rad/s^2	
Force	newton	N	(kg-m/s^2)
Pressure	newton per sq meter	N/m^2	
Kinematic viscosity	sq meter per second	m^2/s	
Dynamic viscosity	newton-second per sq meter	N-s/m^2	
Work, energy, quantity of heat	joule	J	(N-m)
Power	watt	W	(J/s)
Electric charge	coulomb	C	(A-s)
Voltage, potential difference: electromotive force	volt	V	(W/A)
Electric field strength	volt per meter	V/m	
Electric resistance	ohm	Ω	(V/A)
Electric capacitance	farad	F	(A-s/V)
Magnetic flux	weber	Wb	(V-s)
Inductance	henry	H	(V-s/A)
Magnetic flux density	tesla	T	(Wb/m^2)
Magnetic field strength	ampere per meter	A/m	
Magnetomotive force	ampere	A	

Prefixes

Factor By Which Unit is Multipled	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ

SUMMARY

BACKGROUND

With long-duration manned space flights which perform sophisticated Earth-oriented and inertial experiments, increasingly stringent requirements will be imposed on the stabilization and attitude control system and the propulsion and reaction control systems (PRCS). The evaluation of the Space Station and Space Base resulted in selection of control moment gyros for primary stability control and a biowaste resistojet propulsion system to perform the orbit-keeping and CMG desaturation functions simultaneously.

Selection of the biowaste resistojet system was the result of thorough systems tradeoff studies using vehicle requirements, program guidelines and constraints and conventional cost, weight, power volume, and crew time criteria. The Space Station program, however, did not provide the in-depth evaluation required for system development.

It was the intent and objective of the study documented in this report to provide the in-depth evaluation required to develop and demonstrate a prototype biowaste resistojet system, and to provide direction for future resistojet system development and qualification programs.

INTRODUCTION

A system development program was defined as a prerequisite to the selection of a biowaste resistojet system for the Space Station and Base. The recommended approach for technological advancement to develop the biowaste resistojet system is summarized in this Volume. The approach consists of design, development, and test efforts required to achieve the major program objectives, defined as follows:

- Develop flight-weight prototype of biowaste resistojet components and assemblies with emphasis on components requiring advanced technology.

- Demonstrate performance and operating life characteristics of prototype components in a simulated resistojet system.
- Demonstrate performance, operating life, and maintainability of an integrated EC/LS-resistojet system by a systems test.

The program consists of three major efforts, as shown in Figure 1. The component design and development effort defines the activities which will establish component requirements, and the subsequent design and development of the components.

The system development test effort encompasses three major test phases: (1) component verification and interface tests, (2) system operation and life tests, and (3) integrated EC/LS-resistojet system tests (including GN&C interfaces). The integrated EC/LS-resistojet system tests will demonstrate adequacy of design concept, integrated system performance, and maintainability and reliability over the full range of operating conditions envisioned for the Space Station and Base.

The system development support effort provides the test facility modifications and the test installation design, fabrication, assembly, installation, and checkout. The test facility and test installation will be compatible with the development test effort. The program schedule and the test completion milestones noted in Figure 1 were established to permit the test results to be used on an Orbital Workshop or Shuttle flight experiment, as well as on the Space Station program. The program established was based on the MDAC biowaste resistojet system definition as the model, and is compatible with other system approaches. Advanced or improved components and assemblies can also be incorporated in the program.

The development program established was based on an evaluation of the current status of the biowaste resistojet system and the potential launch, launch date, performance, operational, and life requirements. Based on these assessments, the technology development for the system was identified in accordance with the supporting research and technology (SRT) definitions used in the Space Station program. The following SRT items were identified:

- Resistojet heater element materials.
- Biowaste resistojet fed by vaporized water.

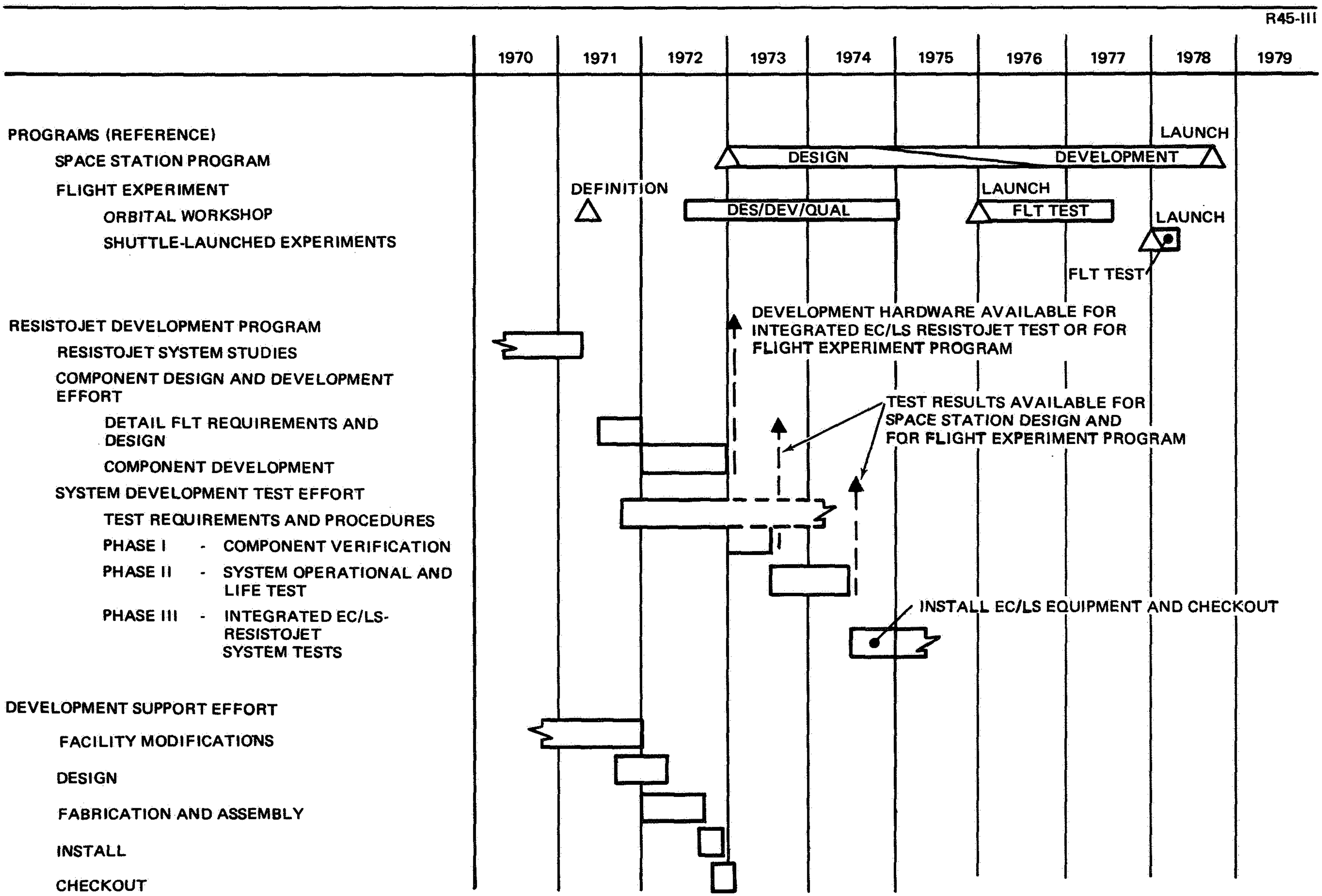


Figure 1. Biowaste Resistojet Development Program Schedule

- Water vaporizer
- Biowaste resistojet with integral water vaporizer.
- Resistojet operating characteristics verification (with actual biowastes).
- CO_2 and CH_4 compressor assemblies.

In addition, the development status of the remaining system components and assemblies was assessed and defined in a general development (GD) category.

The resistojet assembly specification was prepared to provide the performance, design, product configuration, and development test requirements for a flight-weight prototype resistojet thrustor. For flight applications, the thrustor would have to undergo only a minimum development and qualification test effort prior to flight-readiness.

VOLUME SCOPE

Book 1 - Technology Identification and Assessment

This book contains an identification and assessment of the SRT category items and development status of the hardware that apply to the resistojet system. The items are defined at the component and assembly levels.

Book 2 - Resistojet System Development Program and Test Plan

This book provides the resistojet system development program plan and a system development test plan to meet the following objectives: (1) develop prototypes of flight components and assemblies, (2) demonstrate component performance and life characteristics, and (3) demonstrate integrated EC/LS-resistojet system interface and performance characteristics.

Appendix A - Resistojet Thrustor Assembly Technical Specification

The specification provides the detailed design requirements and proposal instructions for the design, development, and procurement of a flight-weight prototype thrustor. The effort specified allows subsequent space flight applications with a minimum of effort to flight-qualify the thrustor design.

Appendix B - Components and Assemblies-Test Requirements

This appendix provides test requirements matrices for the resistojet system elements.

BOOK 1

TECHNOLOGY IDENTIFICATION AND ASSESSMENT

Section 1
INTRODUCTION

The SRT program as defined in the Space Station study (NASA Contract NAS8-25140) is to identify specific areas where advances in technology are required to avoid high risks in performance and development at the beginning of a Phase D development task without exceeding reasonable cost and schedule constraints. Solutions to these SRT problem areas assist in alleviating hardware design and development problems that might otherwise affect the Space Station. This document contains an identification and assessment of the SRT items that apply to the biowaste resistojet system of the MDAC Space Station design model. (See in-depth study in Volumes I and II of the Resistojet Systems Study, Final Report.)

The SRT definitions and categories for the purpose of the resistojet technology development identification provide continuity between the Space Station SRT program and the Resistojet Systems Study. The SRT categories are used primarily to classify items with standardized definitions in areas in which basic technology is lacking. The technical effort required for each item is noted on each of the item data sheets in Section 3 of this book. This document also contains a list of the development status of all components and assemblies in the system to provide the overall status of the hardware required for the biowaste resistojet system.

The SRT categories used in the Space Station study — research, advanced technology, advanced development, and supporting development — are used in this document. In addition, a general development category (GD), the development effort normally required in a Phase D effort, has been added to the report. Detailed data for each of the SRT items include (1) a description of the problem and proposed solution, (2) status of the technology and technical effort required, (3) benefits to the program that are anticipated, and

(4) gross estimates of schedule and cost required to develop prototype flight hardware. This information is also provided for the GD items, with the exception of estimated schedule and cost.

Section 2

SUPPORTING RESEARCH AND TECHNOLOGY CATEGORIES

The category definitions provided below are the NASA SRT program definitions and, as previously noted, are used in this report to classify the items. The effort noted in the individual item data sheets in Section 3 goes beyond the minimum effort defined in each category.

2.1 RESEARCH

Research (R) is the activity directed toward an increase in scientific and engineering knowledge. When this SRT category has a programmatic implication, it is applied rather than basic research and addresses only the conceptual phase (A) of phased project planning.

2.2 ADVANCED TECHNOLOGY

Advanced technology (AT) is the activity of advancing the state of the art in the field of methods and techniques through the application of science and engineering. Any associated hardware effort does not go beyond that required to demonstrate the validity of the advanced method or technique. The AT category of SRT is primarily concerned with the conceptual phase and has only a secondary concern with the definition phase (B).

2.3 ADVANCED DEVELOPMENT

Advanced development (AD) is the activity of developing systems, assemblies, or components which are recognized as having long development times before Phase D approval of the project in which they will be utilized. The product of the activity will be a set of specifications within the then-current state of the art which describes the hardware in the advanced development activity. The AD category of SRT is concerned with both the definition phase (B) and the design phase (C).

2.4 SUPPORTING DEVELOPMENT

Supporting development (SD) is the activity of developing backup or alternate systems, assemblies, and components, and fabrication, cost, and evaluation techniques. Advances in the state of the art may or may not be incorporated, as appropriate. The product of this activity is replacement hardware or techniques. The SD category of SRT is primarily concerned with the design phase (C).

2.5 GENERAL DEVELOPMENT

The GD category (not a NASA-defined SRT category) was added primarily as reference data to this report and to provide the status of all major system hardware items. These items are generally considered to be within the state of the art, and early development efforts are not necessary to obtain a qualifiable flight design. The determination of component interface, assembly interface, and integrated system performance may, however, require the development of prototype items in this category.

Section 3
TECHNOLOGY DEVELOPMENT STATUS

Detailed data for each SRT and GD item are presented in the data sheets in this section. Each item includes: (1) a description of the SRT or GD and development efforts required, (2) a brief discussion of the status of the technology and technical effort needed, and (3) the benefits to be derived from the effort.

For SRT items, the schedule and cost estimates are presented in Figure 2 and Table 1, respectively, for the prototype flight design and development effort. The design and development activities are scheduled to support a 1978 launch of the Space Station.

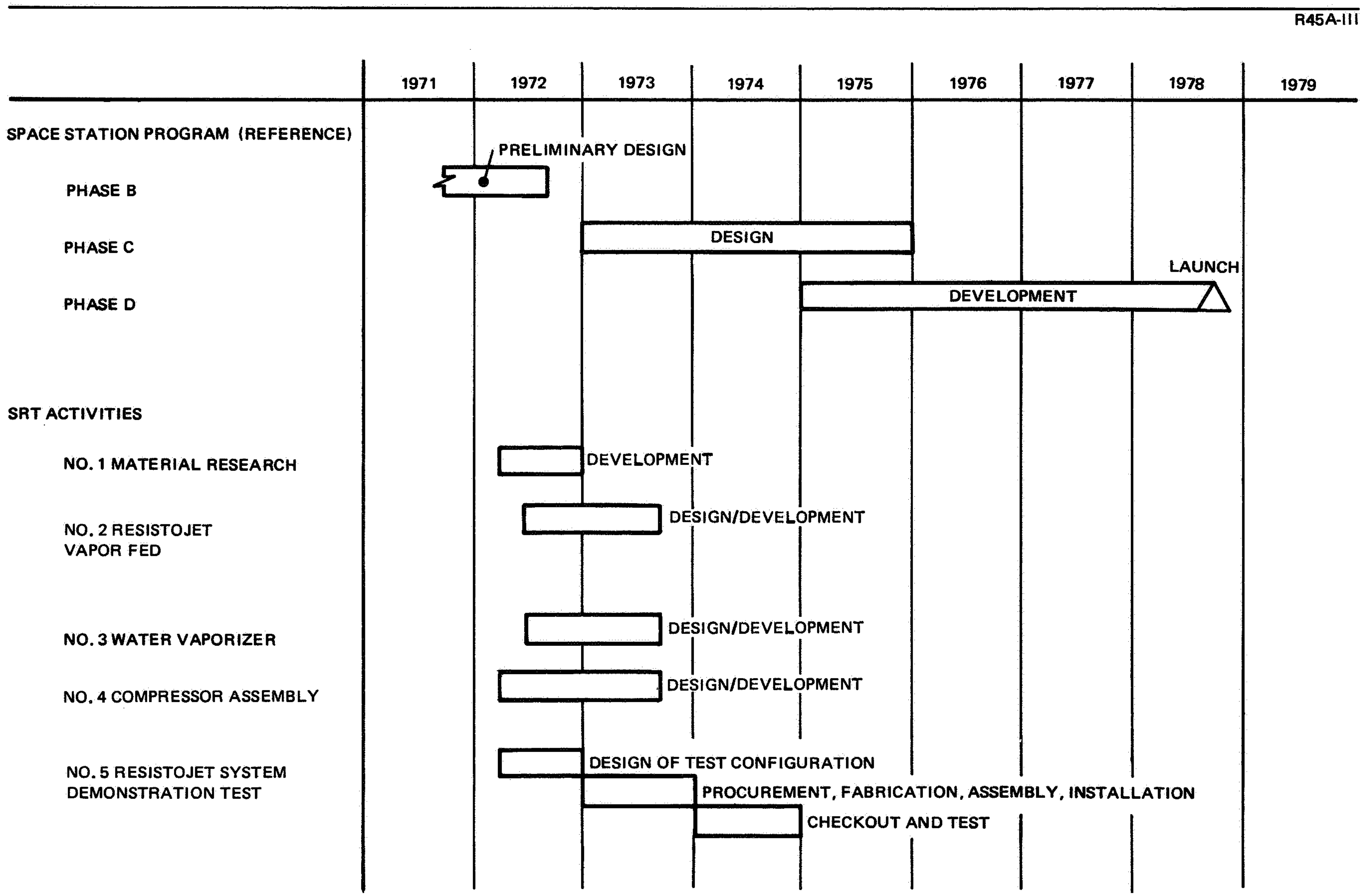


Figure 2. Design and Development Schedule

Table 1

DESIGN AND DEVELOPMENT COST ESTIMATE-SRT ITEMS

SRT Item	Cost in Millions of Dollars	Remarks
Material Research	0.1	Scheduled over nine months
Resistojet		Develop to flight-prototype status
Vapor Fed	1.2 to 2.0	Hot gas valve development required.
Water Vaporizer	0.5 to 1.0	Develop to flight-prototype status Control device needs testing.
Compressor Assemblies	0.8 to 1.2	Develop a flight-prototype assembly (CO_2 and CH_4).
Resistojet System Demonstration Test	2.0 to 3.0	Integral EC/LS-resistojet system test Component and assembly development costs are not included. It is assumed that the other SRT items will be developed and remaining hardware exists to satisfy the test requirements. Facility cost is not included, but the design, procurement, fabrication, assembly, and installation cost of the test configuration is included. All actual and related testing costs are included.
Total	4.6 to 7.3	

Note: Alternate thrustor concepts are not included.

3.1 SRT ITEM 1

Item: Resistojet Heater Element Materials

Category: Research, Applied

Technical Area: Propulsion and Power Generation

Descriptive Data: The heater material for any biowaste and water resistojet concept is required to withstand extremely high operating temperatures for long durations and multiple cycles. For the envisioned Space Station usage, the heater element must withstand approximately 1000°K (1,800°R) with methane (CH_4) and 1600°K (2,880°R) with carbon dioxide (CO_2) and water, 100,000 heating cycles, and at least two years of operating life.

Technology Available and Technical Effort Required. Heater elements have been developed for NH_3 and H_2 resistojets, but limited material testing has been accomplished for the biowaste resistojet heater.

Testing of existing high-temperature oxidation-resistant material and development of new material is recommended. Noncatalytic materials may be needed to eliminate CH_4 dissociation at 1000°K (1,800°R).

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The ability to use the available EC/LS-produced biowaste gases in a resistojet thrustor would eliminate or significantly reduce the need for propellant resupply. A higher temperature of the heater element improves resistojet performance and further reduces propellant resupply. Operation with water permits resistojet usage with potential EC/LS excess or resupplied water.

3.2 SRT ITEM 2

3.2.1 SRT Item 2a

Item: Biowaste Resistojet (CO_2, CH_4, and H_2O vapor)

Category: Advanced Technology and Development

Technical Area: Propulsion and Power Generation

Descriptive Data: The resistojet is an electrically heated rocket. The propellant is passed over a resistance-heated heat exchanger and out a nozzle to produce thrust.

With biowaste propellants available from the EC/LS system (predominately CO_2 and CH_4 with trace amounts of H_2O, H_2, and N_2), the resistojet thrustor can perform the orbit-keeping and CMG desaturation functions of the Space Station at millipound thrust levels. In addition, with some missions requiring greater amounts of propellant than that produced by the EC/LS system, there is a potential need for supplementary water (either EC/LS excess or resupplied). With an independent water vaporizer to condition the water to a superheated vapor, the resistojet design can be simplified, since only single-phase fluids pass through the thrustor assembly.

Design goals for the various propellants with the common resistojet for biowastes and water are:

- A minimum specific impulse of 175 sec for CO_2, 218 sec for CH_4, and 245 sec for H_2O.
- A nominal thrust level of 0.111N (25 mlbf)
- Two years or longer life
- 100,000 operational cycles or more (250,000 cycles required over 10 years)
- Variable power modes from zero to maximum performance power.

The detail thrustor assembly specification is provided in Appendix A of this volume.

Technology Available and Technical Effort Required. Resistojets are being developed by several companies (e.g., Avco, Marquardt, and Advance Rocket Technology), but are not operational. Further, a common thrustor for water and biowastes has not been developed, although limited testing of CH_4 and CO_2 has been accomplished.

As a minimum, a resistojet thrustor must be designed, developed, and demonstrated.

High-temperature inlet valve capabilities and satisfactory materials, performance, life, and power characteristics must be attained in a flight-type design configuration.

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. Resistojet usage of biowastes produced by the EC/LS system eliminates or significantly reduces the need for propellant resupply. In cases where sufficient biowastes are not available, water provides a safe and easily manageable propellant supplement. The low-thrust levels permit a continuous near zero-g environment for experiments. In addition, resistojet systems are inherently safe, more reliable, lighter in weight, and produce less contamination than chemical rockets.

3.2.2 SRT Item 2b

Item: Alternate Biowaste Resistojet (with Integral Water Vaporizer)

Category: Advanced Technology and Development

Technical Area: Propulsion and Power Generation

Descriptive Data: The resistojet is an electrically heated rocket. The propellant is passed over a resistance-heated heat exchanger and out of a nozzle to produce thrust.

With biowaste propellants available from the EC/LS system (predominately CO_2 or CH_4 with trace amounts of H_2O, H_2, and N_2), the resistojet thrustor can perform the orbit-keeping and CMG desaturation function of a Space Station at millipound thrust levels. In addition, with some missions requiring greater amounts of propellant than that produced by the EC/LS system, there is a potential need for supplementary water (either EC/LS excess or resupplied). With an integral water vaporizer, water can be accepted directly by the thrustor without having to be superheated to a vapor state external to the thrustor assembly. Two-phase zero-g heating problems must be overcome.

Design goals for the various propellants with the common biowaste and water resistojet include a zero-g integral water vaporizer as well as the items noted in SRT 2a.

Technology Available and Technical Effort Required. In addition to the items noted in SRT 2a, the reliability characteristics of the integral vaporizer in a zero-g environment must be determined.

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The benefits identified under SRT Item 2a are applicable. In addition, the integral water vaporizer would simplify design of the resistojet system and thrustor module.

3.2.3 SRT Item 2c

Item: Alternate Biowaste Resistojet (CO_2 and CH_4 only)

Category: Supporting Development

Technology Area: Propulsion and Power Generation

Descriptive Data: The resistojet is an electrically heated rocket. The propellant is passed over a resistance-heated heat exchanger and out a nozzle to produce thrust.

With biowaste propellant available from the EC/LS system (predominately CO_2 or CH_4), the resistojet thrustor can perform the orbit-keeping and CMG desaturation function of the Space Station at millipound thrust levels. Using only gaseous biowaste (CH_4/CO_2 only) for resistojet operations would significantly reduce the design and development problems associated with the water supplement capabilities. (See SRT Items 1, 2a, 2b, and 3.) The propellant supplement in this case would be accomplished by the high-thrust propulsion system.

The design goals for the gaseous biowaste resistojet include a minimum specific impulse of 175 sec for CO_2 and of 218 sec for CH_4.

The thrust level, life cycles, and power mode were noted in SRT Item 2a.

Technology Available and Technical Effort Required. Resistojets are being developed by several companies (e.g., Avco, Marquardt, and Advance Rocket Technology), but are not operational. Further, only limited testing of CH_4 and CO_2 thrustors has been accomplished.

The minimum development effort required is to determine the performance level and characteristics from a flight-type resistojet design for the number of cycles and life required.

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The use of EC/LS system-produced gaseous biowastes eliminates or significantly reduces the need for propellant resupply. A biowaste resistojet system used in conjunction with a monopropellant propulsion system enhances safety and reliability and produces less contamination than a pure chemical propulsion system.

3.3 SRT ITEM 3

Item: Independent Water Vaporizer

Category: Advanced Technology and Development

Technology Area: Propulsion and Power Generation

Descriptive Data: The independent water vaporizer is an electrically heated heat exchanger common to a thrustor group or module and provides the proper superheated water vapor conditions required by the vapor-fed resistojet (SRT Item 2a).

Water is desirable as a propellant supplement when the biowaste gases available are not sufficient for the required impulse or when excess biowaste water is available.

Design goals are to ensure that complete water vaporization and feed occurs upon demand by the resistojet thrustors, in a zero-g or random-g environment.

Technology Available. Virtually no experience exists with a zero-g heat exchanger analogous to the water vaporizer. One-g data are considered insufficient to provide zero-g operating characteristics.

Zero-g designs have been proposed, but verification of the concept and operational characteristics requires a significant amount of development. Analytical difficulties associated with two-phase flow and heat transfer will complicate development, particularly verification of the zero-g requirement.

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The use of excess water from the EC/LS system eliminates or significantly reduces the need for propellant resupply, and water can provide a safe and easily manageable propellant supplement for the system. This vaporizer is required for the resistojet concept identified under SRT Item 2a.

3.4 SRT ITEM 4

Item: CO_2 and CH_4 Compressor Assemblies

Category: Advanced Development

Technology Area: Propulsion and Power Generation

Descriptive Data: These biowaste gas (CH_4 and CO_2) compressors are used to provide operational independence for both the EC/LS and biowaste resistojet systems. In addition, compression reduces the propellant storage volume and is beneficial to control of flow to the resistojets.

The design of the compressor assemblies is to accomplish the following:

- Maintain EC/LS outlet conditions required
- Provide sufficient biowastes to the storage accumulator so that the EC/LS and resistojet systems can operate independently of each other. Overall assembly compression required is 10:1 and 20:1 for CO_2 and CH_4, respectively.
- Two years or longer of operation for a total propellant flow of 3630 kg (8000 lb) of CO_2 and 2180 kg (4800 lb) of CH_4 over the two years of operation.

The CH_4 compression is to be accomplished with two separate compression pumps. The first is a continuously operating low-pressure ratio (2.7:1) compressor/blower. This is needed to maintain a constant outlet condition at the EC/LS-CH_4 interface (Sabatier outlet). The outlet of the low-pressure ratio CH_4 blower is to an intermediate accumulator [~27.6 by 10^4 N/m^2 (~40 psia) accumulator pressure]. The second CH_4 compressor then can be common with the single CO_2 compressor required.

For CO_2 collection and storage, CO_2 is compressed from the EC/LS-CO_2 accumulator, which allows intermittent compression at approximately 20.7 x 10^4 N/m^2 (30 psia) minimum. The second CH_4 and the CO_2 compressor require a nominal 10:1 compression ratio for storage in the 207 x 10^4 N/m^2 (300 psia) nominal 276 x 10^4 N/m^2 (400 psia) maximum accumulators feeding the resistojet thrustors.

This approach allows the compressors to be operated at low-duty cycle (~10 percent), eliminates thermal problems, and allows a relatively short operating life, high-compression ratio compressor to be used. This concept allows design concepts which are within the state of the art to be used, but the size, methods and application are new.

Technology Available and Technical Effort Required. Basic compressor and blower technology is available to design and develop satisfactory compressor assemblies, but it has not been demonstrated for this type of use. The primary tasks will be to scale down existing designs and provide adequate dynamic seals and lubrication to meet the specific requirements of the resistojet system. A primary design goal (high ratio compressor) is to eliminate or minimize the contamination of the biowastes with compressor lubricants and to obtain a minimum of two years of continuous life for the blower.

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The compression of the EC/LS system biowastes permits the independent operation of both the EC/LS and the resistojet systems. Furthermore, storage of the gases can be accomplished with reduced volumes and lower system dry weight.

3.5 SRT ITEM 5

Item: Resistojet System Demonstration Test

Category: Advanced Development

Technology Area: Propulsion and Power Generation

Descriptive Data: The envisioned resistojet thrustor will utilize EC/LS system biowastes (predominantly CO_2 with trace amounts of H_2O, N_2, and O_2) and CH_4 (with trace amounts of H_2O, H_2, and N_2) along with any other contaminants from the molecular sieve, Sabatier reactor, and the biowaste resistojet collection, storage, and feed assembly.

The resistojet thrustor development in general will be run with commercial grades of CO_2 and CH_4, with limited tests to simulate the EC/LS and resistojet system outputs to the thrustor. However, the identification and simulation of actual propellants will be difficult.

Technology Available and Technical Effort Required. Limited data have been generated to identify the EC/LS system output; further, the identification and simulation would always be difficult. Development testing and demonstration of satisfactory EC/LS-resistojet operation would be prudent, using an integrated EC/LS-biowaste resistojet system test to verify thrustor compatibility with actual biowastes and with the propellant feed system(s).

Programs and Projects Affected. Space Station and Space Base programs.

Benefits. The advantages and potentials of a biowaste resistojet have been previously noted.

3.6 GD ITEM 1

Item: CO_2 and CH_4 Pressure Regulators

Category: General Development

Technology Area: Propulsion and Power Generation

Descriptive Data: The CO_2 and CH_4 biowaste gases are stored in nominally 207 by 10^4 N/m^2 (300 psia) accumulators and the accumulator pressure will vary over a range of approximately 69 by 10^4 to 276 by 10^4 N/m^2 (100 to 400 psia). With these conditions, a pressure regulator is needed to provide constant inlet pressure to the resistojet thrustor for flow control. The regulator must satisfy only the pressure tolerance required and the regulator flow rate is not critical so long as it provides the minimum flow required by the thrustor(s). A 34.5 by $10^4 \pm 1.0$ by 10^4 N/m^2 (50 ± 1.5 psia) regulator is considered to be satisfactory.

Technology Available and Technical Effort Required. Propulsion systems of Apollo, Saturn, Minuteman, and other space vehicles use regulators similar to that needed by the resistojet system. However, it is considered desirable to scale down the size (flow capability) and to demonstrate long-life capabilities and compatibility with biowaste propellants.

3.7 GD ITEM 2

Item: Valve (CO_2, CH_4, and H_2O)

Category: General Development

Technical Area: Propulsion and Power Generation

Descriptive Data: The biowaste resistojet system requires numerous valves for isolating storage tanks and compressors, for separating CO_2, CH_4, and water assemblies, and for protection against malfunctions. Standard solenoid valves require continuous power, while latch valves need only a momentary activation signal, eliminating valve heating and power drain.

Technology Available and Technical Efforts Required. Although Apollo uses a similar type of valve, they are much larger than those needed for the Space Station resistojet system. It is desirable to scale down the size of an existing design to minimize weight and envelope requirements and verify compatibility with propellants.

3.8 GD ITEM 3

Item: Positive Expulsion Water Tankage Assembly

Category: General Development

Technology Area: Propulsion and Power Generation

Descriptive Data: A water-supplemented resistojet system would need a zero-g positive water expulsion tankage assembly. With water, rubber-type positive bladder expulsion devices should prove satisfactory to provide adequate cycle and storage life, even though other techniques are available. Positive displacement metal bellows are applicable and provide the additional benefit of easier gauging of water quantity.

Technology Available and Technical Effort Required. Positive expulsion devices have been used on manned flight and for attitude control propulsion systems. No major development problems should exist.

3.9 GD ITEM 4

Item: Power Conditioning Unit

Category: General Development

Technology Area: Electronics and Control

Descriptive Data: The resistojet thrustor requires electrical power to heat the gaseous biowastes and water to obtain the desired performance. The power supplied from the main electrical bus must be conditioned and regulated to provide the proper voltage for the thrustor-heater interface and the required current levels. The power conditioning unit includes power switches, current regulators, current sensors, and comparators to control power to each thrustor or thrustor module. The power switch and comparator for control of current level is commanded by signals generated by a flight-control computer program. The comparator, in turn, controls the current output to the thrustor heater element.

No major development problems are anticipated for the resistojet power conditioning and control equipment.

Technology Available and Technical Effort Required. Current knowledge of electrical design is adequate, although some breadboard and packaging development will be required for a flight design. No major problems exist with the technology available.

3.10 GD ITEM 5

Item: Switching Assembly

Category: General Development

Technology Area: Electronics and Control

Descriptive Data: The resistojet system requires various power switches to supply power to thrustor valves, compressors, and isolation valves. These power switches, normally grouped into various switching assemblies, are initiated by a command signal from the flight-control computer or safing logic circuits to control and protect the system.

Technology Available and Technical Effort Required. Current knowledge of electrical design is adequate; however, some breadboard and packaging development will be required for a flight design. No major problems exist with the technology available.

3.11 GD ITEM 6

Item: Resistojet System Operation and Control Computer Program

Category: General Development

Technology Area: Electronics and Control and Propulsion and Power Generation

Descriptive Data: The resistojet system power level and operating commands are determined through the use of flight-control computer programs. The GN&C system monitoring CMG gimbal angles, accelerometer, and EC/LS-resistojet status data are fed to a system flight-control computer program. This program determines and initiates the resistojet system and thrustor operations in flight. The computer provides the signals via the Space Station data bus and decoder to the electrical equipment supplying power to the system valves, thrustors, and compressors.

Technology Available and Technical Effort Required. No new technology is required. The development of the flight-control computer program involves establishing the relationship between the GN&C system, vehicle dynamics and EC/LS-resistojet system operations, programming these analytical relationships, and verifying the operation of the program.

3.12 GD ITEM 7

Item: Miscellaneous (filters, check valves, pressure switches, relief valves, orifices, etc.)

Category: General Development

Technology Area: Propulsion and Power Generation

Descriptive Data: Various miscellaneous hardware items are required, as noted in the resistojet system design. These items, even though they do not affect the primary system performance, provide necessary functions, and therefore must be developed prior to qualifying a total system.

Technology Available and Technical Effort Required. These items exist for various flight systems. For the biowaste resistojet system (low-flow requirements), many of the items can be redesigned to minimize weight, power, and volume. Development effort for resistojet system applications should be similar to any bipropellant or monopropellant program effort.

BOOK 2

BIOWASTE RESISTOJET SYSTEM

DEVELOPMENT PROGRAM PLAN

Section 1
INTRODUCTION

This section presents a program plan for development of a biowaste resistojet propulsion system. This plan is based on the system application to perform the orbit-keeping and CMG desaturation functions on advanced manned spacecraft. The biowaste resistojet system utilizes the gaseous biowastes available from the EC/LS system and was selected to provide near zero-g conditions, minimize external contamination, and provide flexibility in altitude, inclination, and orientation. In addition, a biowaste resistojet system provides the advantages of (1) useful gaseous and water biowastes disposal, (2) reduced resupply of propellant, (3) increased crew comfort by minimizing noise and vibration, and (4) enhanced reliability and maintainability.

The biowaste resistojet system development program plan is the recommended approach to provide expeditious technology advancement. The major objectives of the program are:

- Develop a prototype of a flight-weight biowaste resistojet system, components, and assemblies with emphasis on components requiring advanced technology development.
- Demonstrate prototype component performance and operating life characteristics in a simulated resistojet system.
- Demonstrate prototype integrated EC/LS-resistojet system performance, operating life, and system maintenance in an integrated system.

The program plan consists of three major efforts, as shown in Figure 1.

The component design and development effort defines the activities which will establish component requirements and the subsequent design and development of the components.

The system development test effort encompasses three major test phases: (1) component verification and interface tests, (2) system operational and life tests, and (3) integrated EC/LS-resistojet system tests, including GN&C interfaces. The Integrated EC/LS-resistojet system tests will demonstrate the adequacy of design concepts, performance of integrated subsystems, and maintainability and reliability over the range of operating conditions envisioned for the Space Station and Base.

The system development support effort provides the test facility modifications and the test installation design, fabrication, assembly, installation, and checkout. The test facility and test installation will be compatible with the development test effort. The program schedule and the test completion milestones noted in Figure 1 were established to permit the test results to be used on an Orbital Workshop or Shuttle flight experiment, as well as on the Space Station program. The MDAC biowaste Resistojet System Study definition will be used as the model, and is compatible with other system approaches. Advanced or improved components and assemblies can also be incorporated in the system.

Section 2
SYSTEM DESCRIPTION

The EC/LS system design concept for MDAC's Space Station, as noted in Reference 1, dictates the type and quantity of propellants needed to perform the functions which could be accomplished at low thrust. The resistojet concept provides the least development risk for a low-thrust device. The resistojet system described below is based on a 12-man, 10-m (33-ft) diameter, 10-year-life Space Station, launched by an Intermediate-21 vehicle (Saturn S-IC and S-II stages).

2.1 SYSTEM MODEL

The MDAC design model of the Space Station resistojet system uses EC/LS system-produced biowaste gases (CO_2 and CH_4) and water as a propellant supplement for resistojet thrustors. These thrustors have a thrust level of 0.111N (0.025 lb) and are used in a high-duty cycle mode (25 to 80 percent) to provide station orbit maintenance and CMG desaturation. The thrustors are located in modules, with four modules at each end of station (Figure 3). The gas storage tanks are located in the forward unpressurized (but pressurizable) compartment. The assembly features are summarized in Figure 4.

The system has the following overall characteristics:

Weight: 259 kg (570 lb)

Volume: 2.78 m^3 (100 ft^3)

Power: 100 to 400 w (average).

The biowaste resistojet system shown schematically in Figure 5 consists of compressors, water vaporizers, accumulators, supplementary propellant (water) tankage, regulator, thrustors, with the necessary valves and

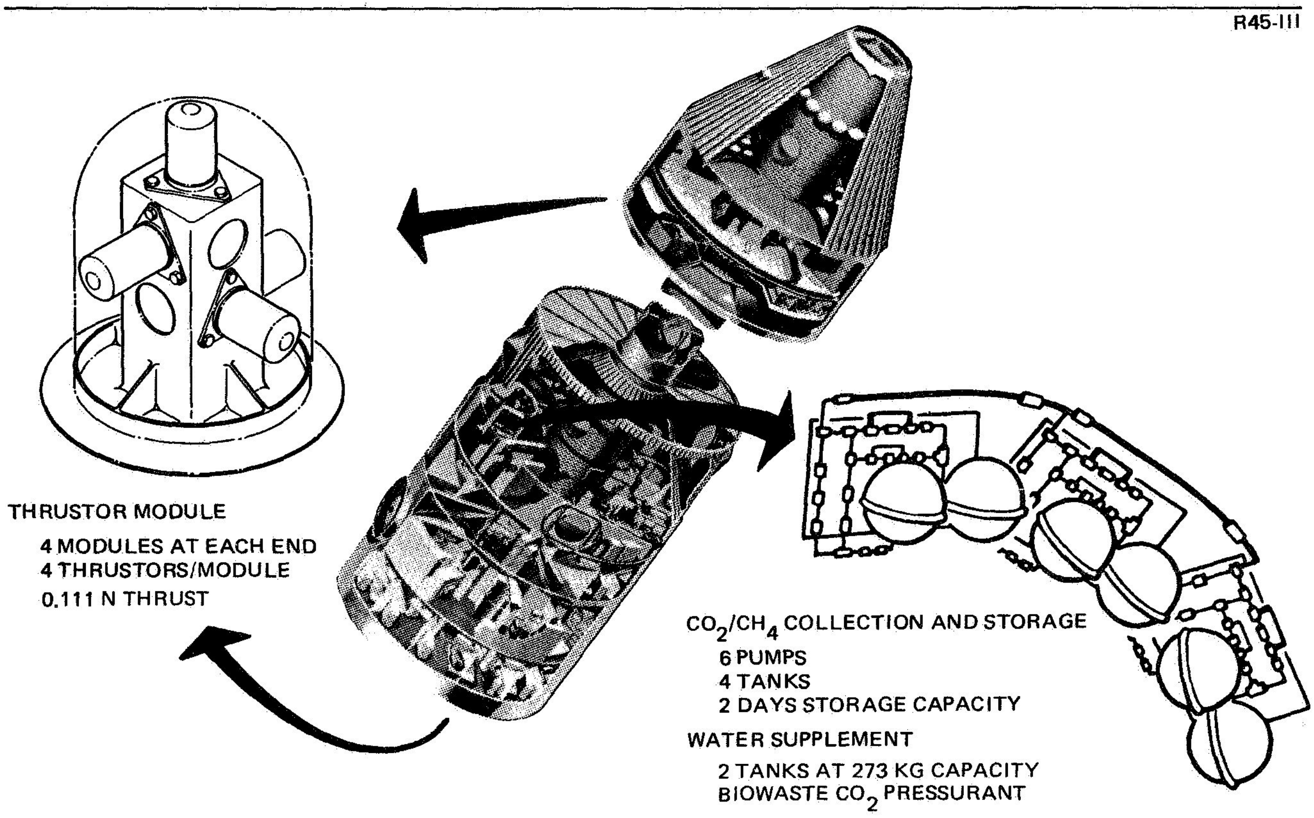


Figure 3. Resistojet Propulsion System Installation and Design Features

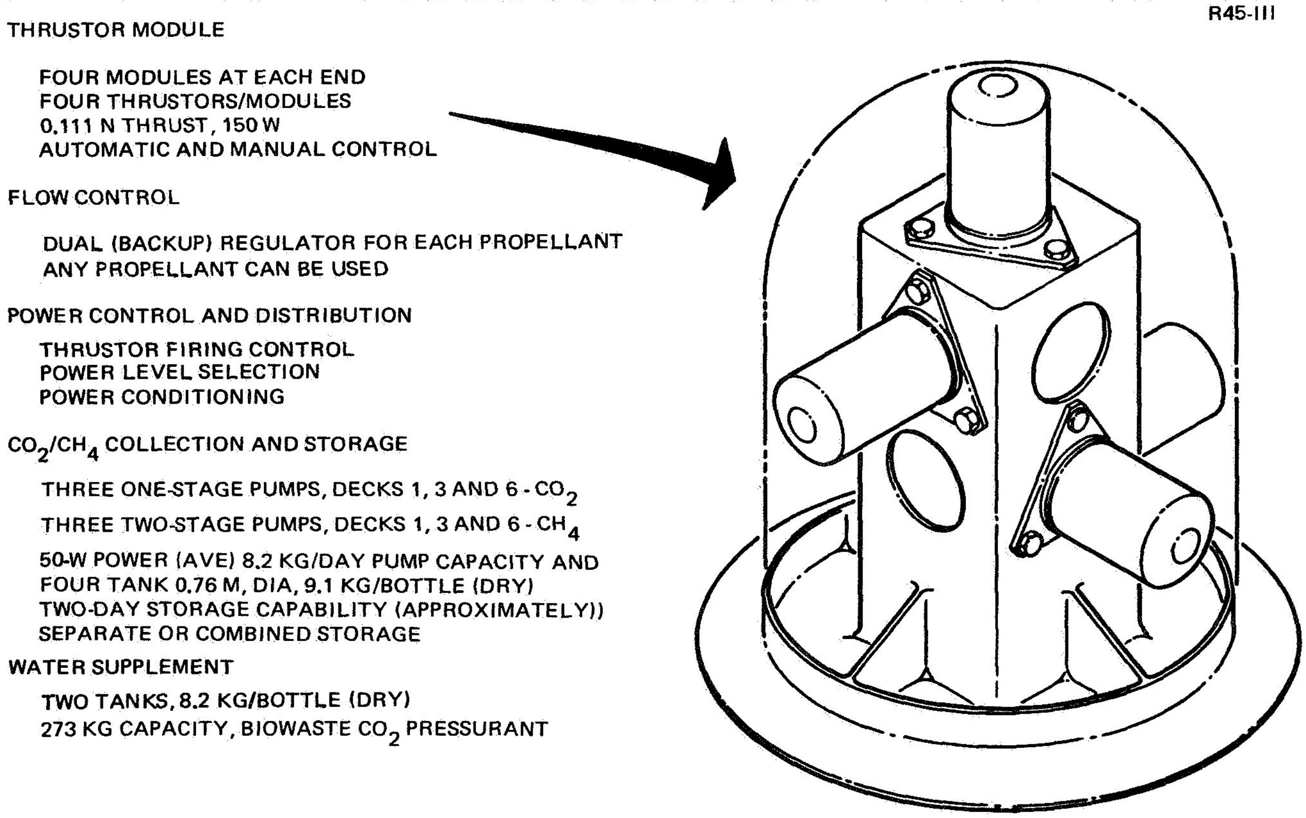
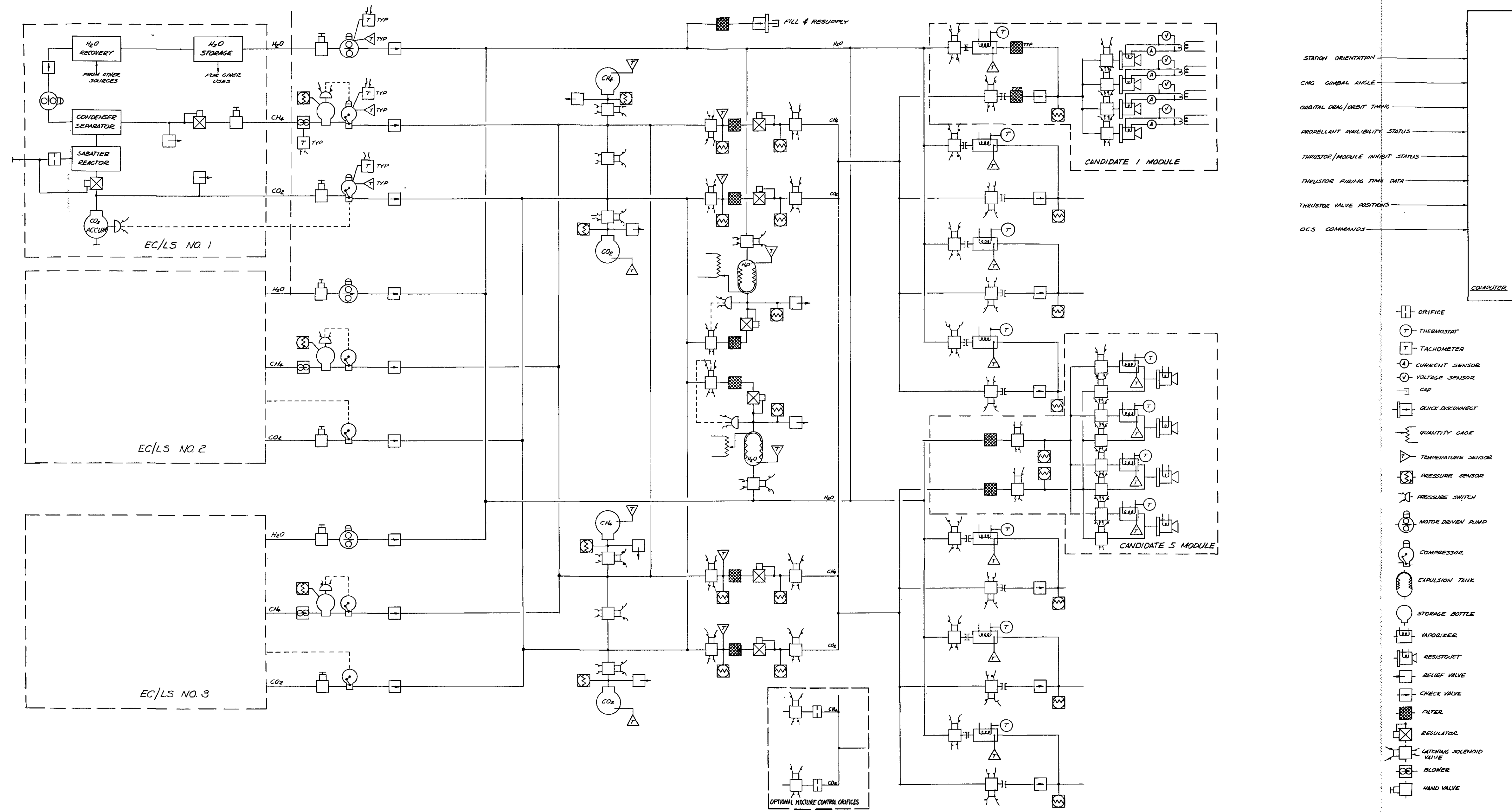


Figure 4. Low Thrust System Major Assembly Features

- Part 1 -



H2O RECOVERY
FROM OTHER SOURCES
H2O STORAGE
FOR OTHER USES
CONDENSER SEPARATOR
SABATIER REACTOR
CO2 ACCUM
EC/LS NO. 1
EC/LS NO. 2
EC/LS NO. 3
H2O
CH4
CO2
TYP
FILL & RESUPPLY
OPTIONAL MIXTURE CONTROL ORIFICES
CANDIDATE 1 MODULE
CANDIDATE 5 MODULE
STATION ORIENTATION
CMG GIMBAL ANGLE
ORBITAL DRAG/ORBIT TIMING
PROPELLANT AVAILABILITY STATUS
THRUSTOR/MODULE INHIBIT STATUS
THRUSTOR FIRING TIME DATA
THRUSTOR VALVE POSITIONS
OCS COMMANDS
COMPUTER
ORIFICE
THERMOSTAT
TACHOMETER
CURRENT SENSOR
VOLTAGE SENSOR
CAP
QUICK DISCONNECT
QUANTITY GAGE
TEMPERATURE SENSOR
PRESSURE SENSOR
PRESSURE SWITCH
MOTOR DRIVEN PUMP
COMPRESSOR
EXPULSION TANK
STORAGE BOTTLE
VAPORIZER
RESISTOJET
RELIEF VALVE
CHECK VALVE
FILTER
REGULATOR
LATCHING SOLENOID VALVE
BLOWER
HAND VALVE

- Part 2 -

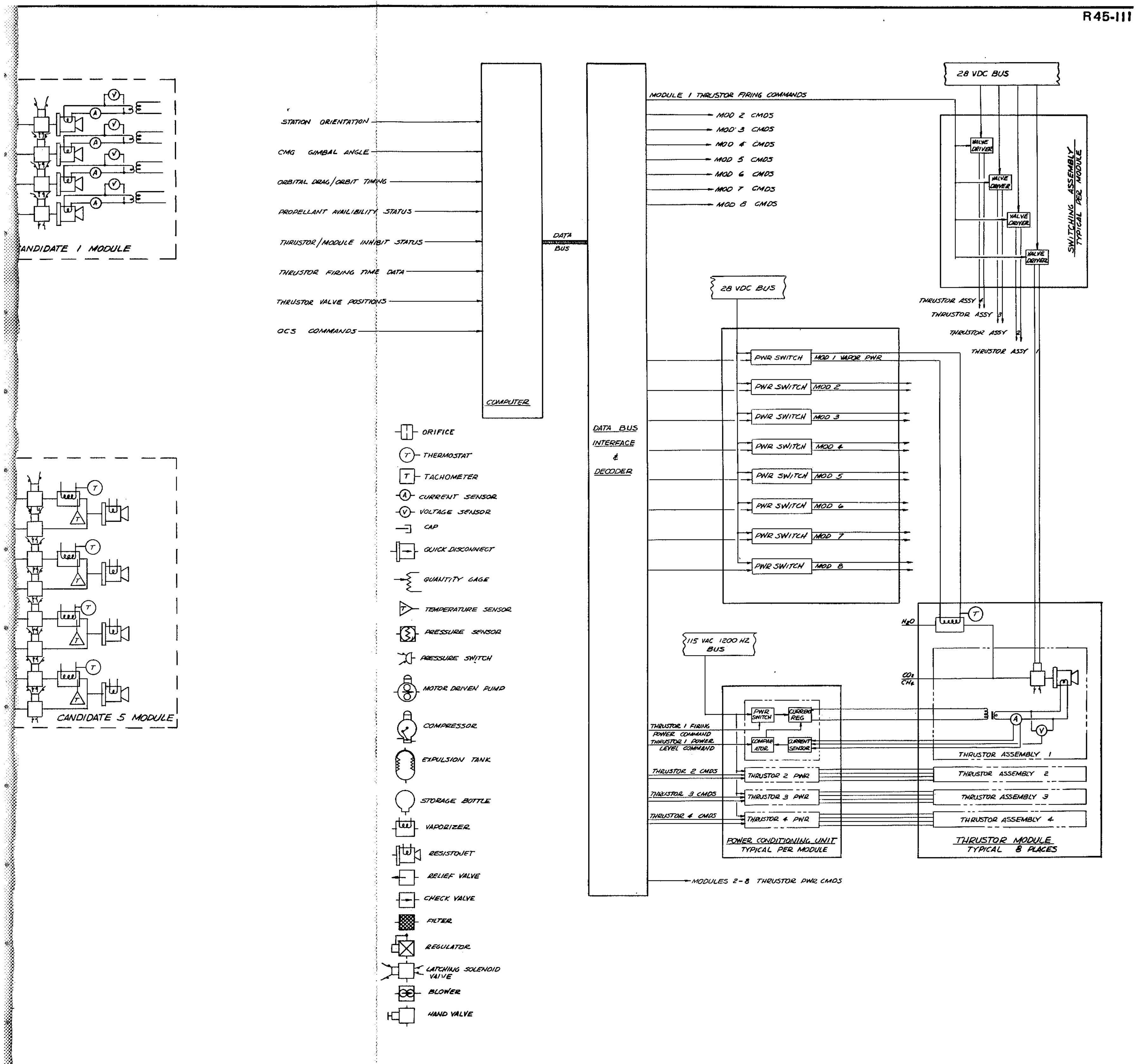


Figure 5. Space Station Resistojet System Schematic

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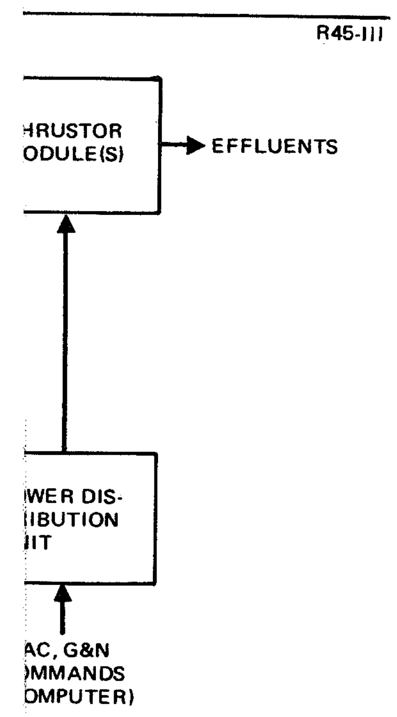


instrumentation for operations. The system design will permit the biowaste gases to be used or stored at all times with supplementary water available when needed. This arrangement with compressors and accumulators ensures independent operation of the EC/LS and resistojet systems. Thus, at any given time, propellant and thrustor usage can be determined by impulse requirements and operational constraints, and is not dictated by EC/LS system production rate. The combination of varying solar activity and number of attached modules results in a 1335 to 11,150 N-sec/day (300 to 2500 lb-sec/day) impulse range at a 456 km (246 nmi) orbit. Since the biowaste gases will produce 3120 to 15,000 N-sec/day (700 to 3370 lb-sec/day), maximum flexibility is clearly desirable. The capability for this range of impulse is obtained by proper selection of power level for the resistojet.

The biowaste system consists of five major assemblies: (1) collection and storage; (2) water supplement; (3) flow control; (4) thrustor; and (5) power distribution and control.

The functional relationships between these assemblies and the interfaces with other subsystems are shown in Figure 6 and the major assembly characteristics were noted in Figure 4. These assemblies are described in the following sections.

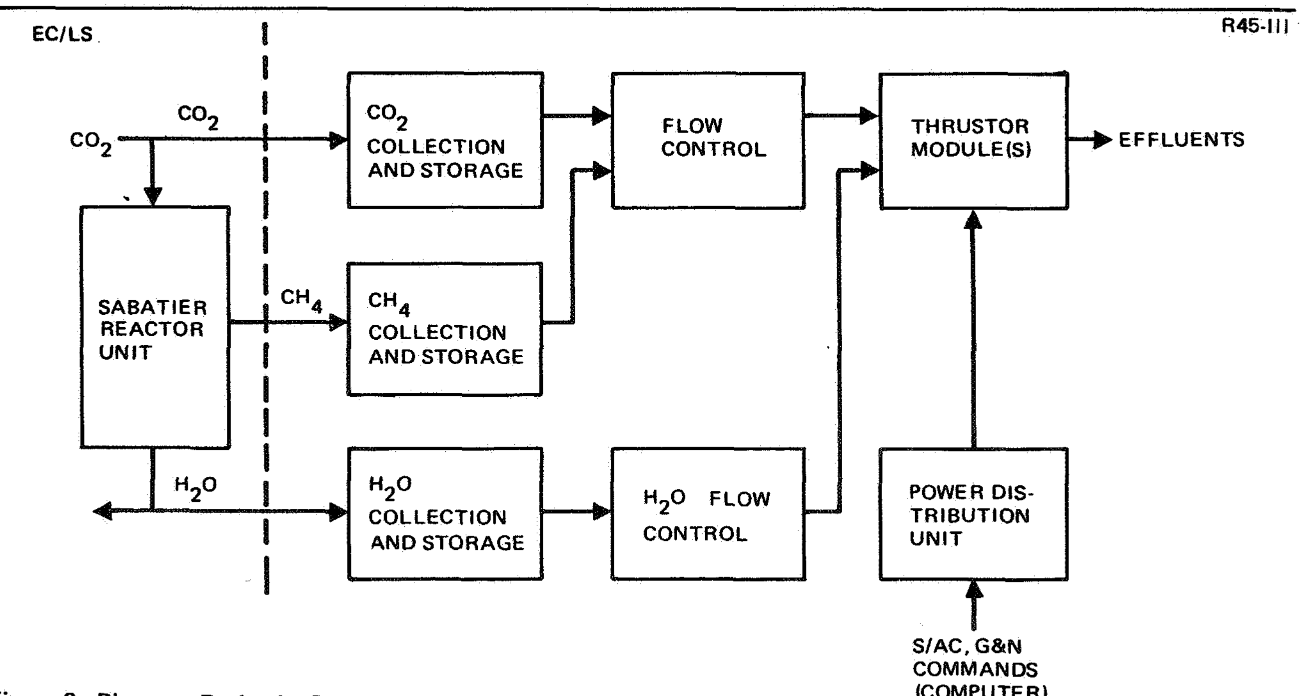


Figure 6. Biowaste Resistojet Propulsion System Functional Schematic

2.1.1 Collection and Storage Assembly

This assembly collects, pumps, and stores the biowaste gaseous outputs from the EC/LS system. Accumulation and storage provisions for the gases is necessary to smooth out EC/LS transients, collect gases when dumping is undesirable, and provide propellant during EC/LS maintenance or off-nominal crew size. However, since the Sabatier outlet pressure is only 10.3 by 10^4 N/m^2 (15 psia), compression pumping is required for storage in reasonable volumes.

This is accomplished by compressing the gases from 10.3 by 10^4 N/m^2 (15 psia) to 207 by 10^4 N/m^2 (300 psia) by two-stage compression (2.7:1 blower and 10:1 piston compressor) and storage in one of two 0.76-m (2.5 ft) diameter accumulators. CO_2 is compressed from 21.5 by 10^4 - 28 by 10^4 N/m^2 (31 to 42 psia) to 207 by 10^4 N/m^2 (300 psia) by a single stage 10:1 piston pump and stored in one of two 0.76-m (2.5-ft) diameter accumulators. Dual accumulators are required to provide reliability for each gas. Dual pumping and tankage and complete cross feed provisions allow maximum maintainability, flexibility, and reliability, without making the assembly unduly complex. Each tank and pump is capable of replacement, but valves and instrumentation are replaceable as modular units.

2.1.2 Water Supplement Assembly

During most of the station life, the impluse requirements can be easily met with the biowaste gases. However, when the demand exceeds supply, heating of the CO_2 to 1600°K (2880°R) will produce additional impulse. For larger increases, a supplemental propellant must be used. The CH_4 cannot be heated above 1000°K (1800°R) or it may dissociate, forming carbon and causing severe deterioration of thrustor performance.

Water was selected as the supplemental propellant because it is easy to resupply and is compatible with the thrustors. In addition, increasing wetness of food could provide a readily available supply without necessitating a separate water resupply.

Carbon dioxide is the best source of pressurant for water expulsion because it is readily available. The flow demand is negligible (<0.05 kg/day), and the weight and complexity of tapping into the biowaste collection assembly is considerably less than the weight and complexity of storing and resupplying a separate pressurant gas.

2.1.3 Flow Control Assembly

The flow control assembly regulates and controls propellant flow (thrustor inlet pressure). All regulators and valves will be accessible and removable. This assembly is one of the key items for automatic checkout, fault isolation, and the like.

2.1.4 Thrustor Modules

The Space Station biowaste resistojet system has eight thrustor modules (Figures 3 and 4), four at each end, with each containing four thrustors for a total of 32 thrustors. The thrustor module also includes provision for isolation during maintenance or repair.

The number and location of thrustors allows operation in any orientation (horizontal, POP, inertial, or attitude trim) with little if any penalty. In addition, this arrangement includes complete redundancy in all operating modes, which permits repair to be scheduled at a convenient time, rather than requiring immediate attention.

Thrustor operation is initiated by commands from the power control assembly, which simultaneously opens thrustor valves, sets power level, and turns on the heater element. The power level fixes heater current and thus chamber temperature, which determines specific impulse.

Resistojet thrustors are inherently reliable devices, the heating element being the only critical part (in a reliability sense). The corrosive nature of hot gases, in general, plus the potential presence of solid carbon, limits the resistojet thrustor life. Tests on ammonia and hydrogen have been demonstrated to 8000 hr of operation (Reference 2), and by proper selection of heater material, the biowaste thrustor should attain or exceed the same useful life. The 8000 hr is equivalent to one-to-two years of operation at 50 to 90 percent duty cycle. With the duty cycle indicated, periodic thrustor replacement will be necessary. This makes thrustor arrangement critical, and the small thrustor size makes replacement of the thrustor module attractive. This is the current design baseline concept.

The resistojet system is compatible with all resistojet thrustor concepts (References 3 and 4). The power control and flow control assemblies will be used to provide the required operating conditions for the thrustor.

2.1.5 Power Distribution and Control

Control required for resistojet system operations is accomplished by utilizing the onboard data management system computer and the system control computer programs to obtain the various input parameters to provide the output commands to the system. The input data come from GN&C, EC/LS, onboard checkout, and resistojet systems. The computer determines the impulse, number of thrustors, duty cycle, propellant, and power level, and provides the commands and signals necessary for system operations. These commands control the power-conditioning units and switching assembly which provide power to the system by way of a data bus and decoder (Figures 7 and 8).

The computer also allows the flexibility necessary to schedule water usage during peak requirement periods as well as lower power levels to minimize power consumption in minimum impulse years.

2.2 SYSTEM OPERATION

System operation consists of two distinct functions; propellant collection and system usage. Overall system operation and control consists of the three major functions listed below.

A. Thrustor Selection. The thrustor arrangement provides at least two (and usually more) different potential thrustor combinations for each operating mode and each orientation. The stability and control system logic will determine thrustor pairings based on orientation, but additional logic is required to select the actual thrustors to use; i.e., if a thrustor or thrustor module is inhibited (malfunctioning heater, valve, isolation valve closed, etc.), then that unit cannot be used. Therefore, two primary and

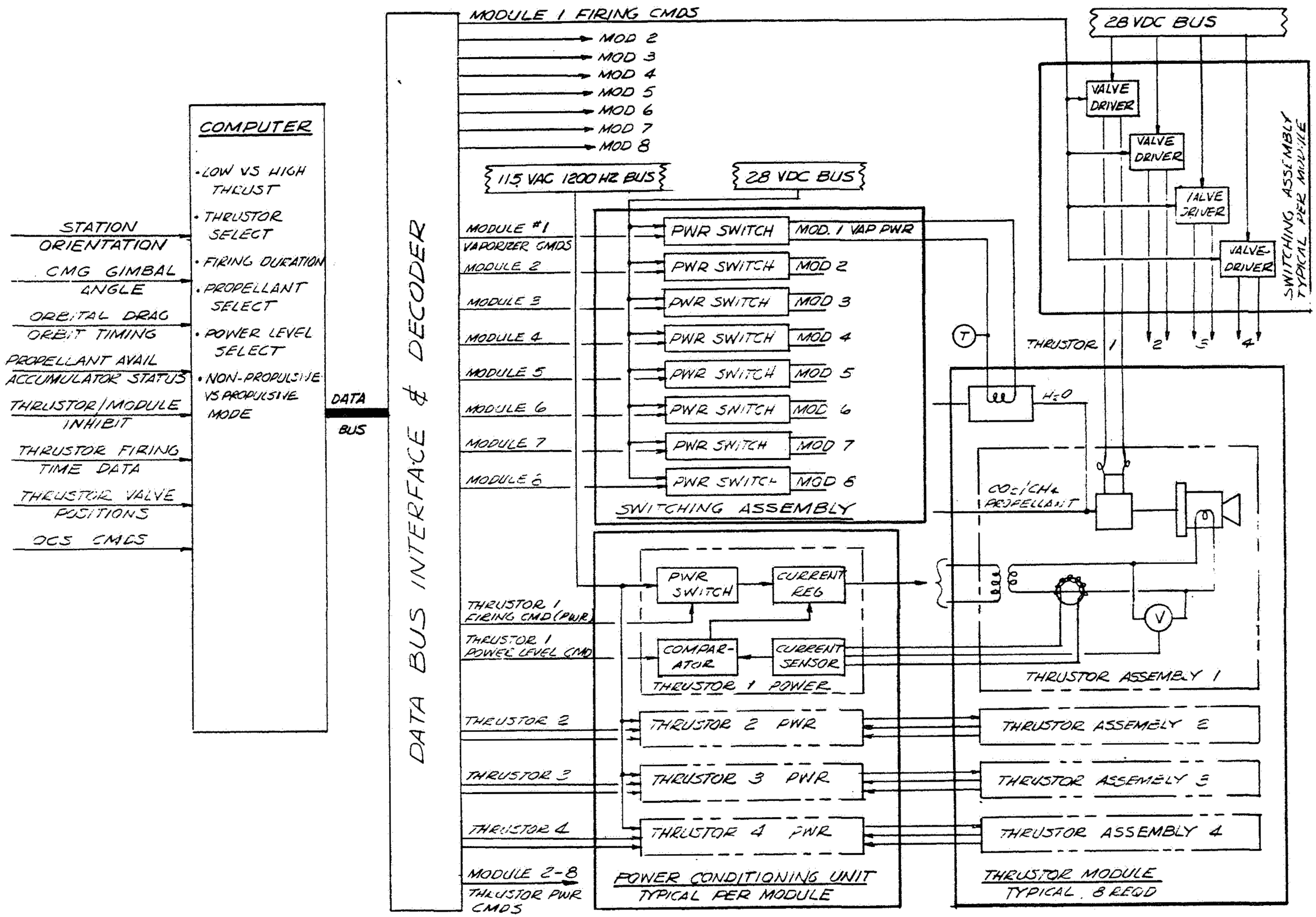
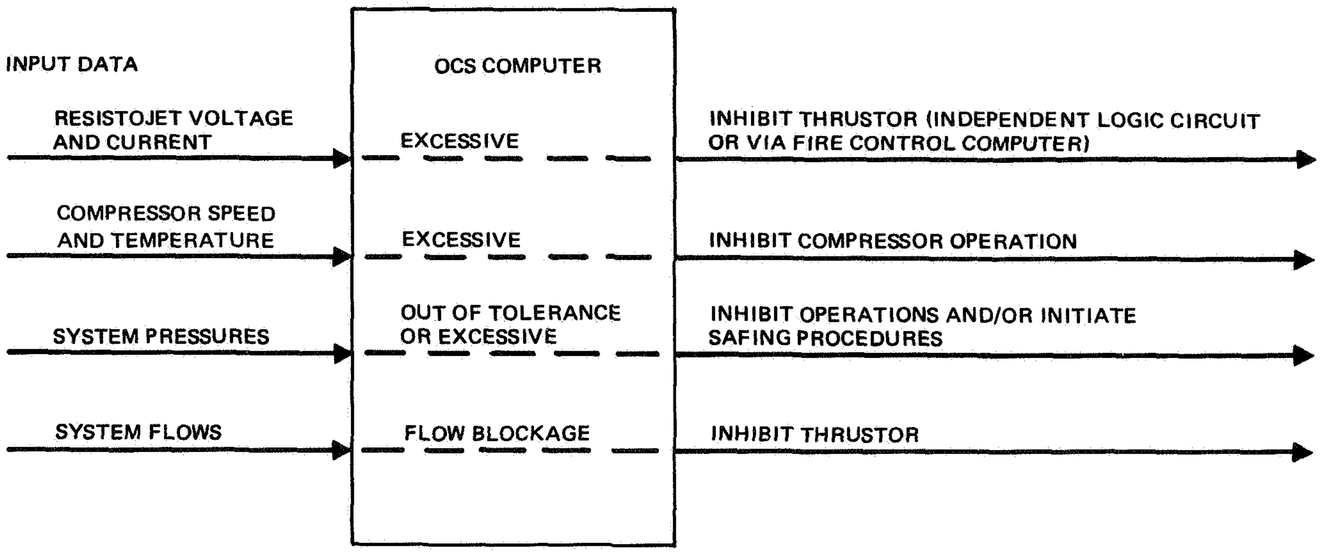


Figure 7. Resistojet Thrustor Controls and Power Distribution Diagram



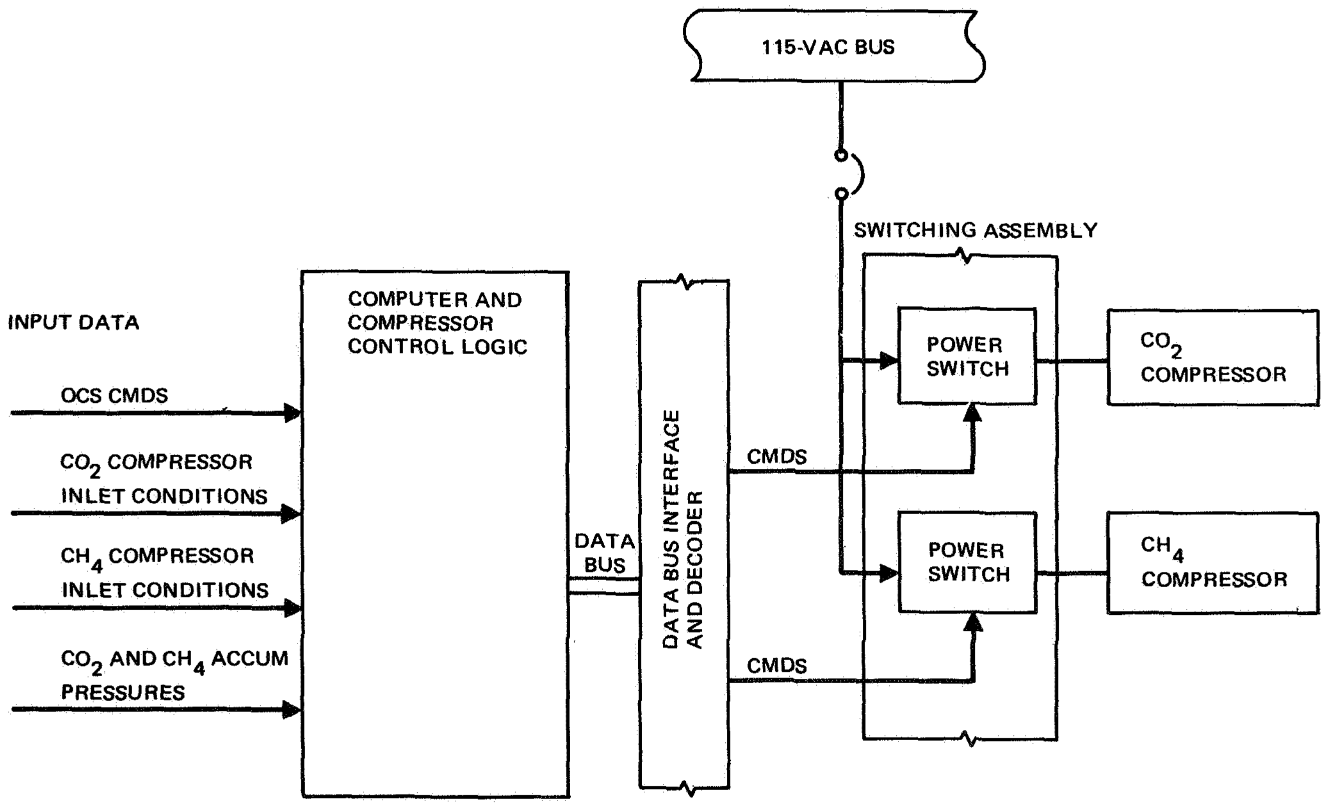


Figure 8. Compressor/OCS Control/Power Distribution Diagram

one secondary (backup) sets of thrustors will be determined for each operating mode (orbit-keep, dump, etc.). If there are no inhibits, the set with the least total firing time will be used. In the event neither a primary nor the secondary set is available, the crew shall be notified of the loss of capability.

B. System Status. Normal system operation is fully automatic and requires crew participation only for periodic status checks, equipment checkout, and possible participation in trend analysis (most trend analysis will be done automatically or by ground personnel). Operational status checks and trend analysis occur once a day or less for the purpose of determining system status, verifying performance, and spotting potential trouble areas. Items included in status and trend analysis are:

1. Valve positions (all valves).

2. Pump speed.

3. High and low-pressure manifold pressures.

4. Storage tanks pressure and temperatures.

5. Propellant usage history.

6. Thrustor usage history.

7. Thrustor power consumption.

8. Vaporizer usage.

9. Electronics (not yet defined).

Other functions done during these operations are functional check, leak detection, command/response, calibration, life history. A total of 250 measurements is required to ensure system operation.

C. Thrustor and Propellant Selection and Control. Updates of impulse requirements occur once per orbit, and at this time it is necessary to review impulse requirements and system status, and generate control commands for the next orbit. This includes the logic for incorporating the water supplement and mixed propellants provisions as well as normal propellant usage.

Section 3
IDENTIFICATION OF DEVELOPMENT REQUIREMENTS

The system design identified previously and shown schematically in Figure 5 can in most instances use proven component and assembly designs. However, advances in technology and development are needed to make the biowaste resistojet thrustor, water vaporizer, and high-compression-ratio compressor assemblies available. The SRT efforts and the development status of the system's mechanical and fluid components and assembly are assessed in Book 1 of this volume and are summarized in Table 2. With the status indicated for the system's mechanical and fluid components and assemblies, the component development effort will consist of advanced technology and development, scaling down of existing component designs, verifying and demonstrating long-life capabilities, and development of light-weight components that will withstand flight-type dynamic environments.

The electrical assembly equipment design needs are relatively simple and well within the state of the art; therefore, early development of the electrical equipment is not considered necessary. The electrical assembly design approach was previously shown in Figures 7 and 8 for the independent water vaporizer concept. The integral vaporizer and thrustor concept is similar, except that the electrical interface requirements depend on the number of power circuits needed for the heater and vaporizer elements. The electrical design approach and requirements are strongly dependent on Space Station power system design, the onboard computer capabilities, and vehicle electrical design approaches, and are therefore subject to greater program changes than the mechanical and fluid components. Development effort for electrical equipment design for a given set of flight requirements will be associated with packaging and integrating the detail design components to provide the various interface power and signals necessary to control the system operation. In addition to component and assembly development

Table 2 (page 1 of 3)

RESISTOJET SYSTEM TECHNOLOGY STATUS
(See Book 1 of this volume)

Components and Assemblies	Status	Remarks
CH_4 Collection and Storage Assembly		
CH_4 Compressor Assembly	Advanced Technology and Development	High Compression Ratio; Low Inlet Flow
Storage Bottle	State of the Art	Titanium
Relief Valve	State of the Art	Frangible Disc with Poppet
Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
Filter	State of the Art	5/10 μ Rating
CH_4 Regulation Assembly		
Filter	State of the Art	5/10 μ Rating
Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
Pressure Regulator	State of the Art	34.5 by $10^4 \pm 0.1$ by 10^4 N/m^2 (50 ± 1.5 psia) Outlet. Scaled down from Saturn/Apollo or Minuteman Design.
CO_2 Collection and Storage Assembly		
CO_2 Compressor Assembly	Advanced Technology and Development	High Compression Ratio; Low Inlet Flow

Table 2 (page 2 of 3)

RESISTOJET SYSTEM TECHNOLOGY STATUS
(See Book 1 of this volume)

Components and Assemblies	Status	Remarks
CO_2 Collection and Storage Assembly (cont'd)		
Storage Bottle	State of the Art	Titanium
Relief Valve	State of the Art	Frangible Disc with Poppet
Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design.
Filter	State of the Art	5/10 μ Rating
CO_2 Regulation Assembly		
Filter	State of the Art	5/10 μ Rating
Pressure Regulator	State of the Art	50 $\pm$ 1.5 psia outlet. Scaled down from Saturn/Apollo Design
Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
H_2O Collection and Storage Assembly		
H_2O Positive Expulsion Tank	State of the Art	Rubber Bladder should be satisfactory
CO_2 Relief Valve	State of the Art	Frangible Disc with Poppet
H_2O Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design.

Table 2 (page 3 of 3)

RESISTOJET SYSTEM TECHNOLOGY STATUS
(See Book 1 of this volume)

Components and Assemblies	Status	Remarks
H_2O Collection and Storage Assembly (cont'd)		
CO_2 Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
H_2O Quick Disconnect	State of the Art	Manual Self-sealing
CO_2 Dump Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
Filter	State of the Art	5/10 μ Rating
Thrustor Module Assembly		
Thrustor Assembly	Advanced Technology and Development	Common biowaste (gas) and water vapor fed thrustor
Vaporizer	Advanced Development	350°F Steam, Power Flow Sequencing required
Filter	State of the Art	5/10 μ Rating
CO_2 Module Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
CH_4 Module Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design
H_2O Module Isolation Valve	State of the Art	28 vdc Latching Valve. Scaled down from Saturn/Apollo Design

needs, system integration and life demonstration tests are considered to be desirable to provide greater confidence in the biowaste resistojet system selected for the Space Station and to provide technology data for future resistojet system designs.

The implementation of a system development program will require an identification of the system operational characteristics and duty cycles. The development of a system control and simulator program would provide these data. This program would provide the system operational characteristics envisioned for the Space Station. During the integration and life demonstration test, this program, using simulated inputs, would provide a total envisioned usage range of operating commands and the resulting demonstration of system operations.

Section 4
PROGRAM PLAN

The recommended approach to meet the development and advanced technology objectives for a biowaste resistojet propulsion system is defined in this program plan. The program recommended consists of three major efforts:

A. Component Design and Development. Defines activities needed to establish component requirements and subsequent subcontractor design and development effort.

B. Development Test. Encompasses all the test requirements and testing to be performed at NASA-Langley Research Center (LaRC) from component verification level through integrated system testing, which includes EC/LS and GN&C system interfaces. The major phases of this test program are:

   Phase I: Component Verification and Interface Tests

   Phase II: System Operational and Life Tests

   Phase III: Integrated EC/LS-Resistojet System Tests.

C. System Development Support. Provides the design, fabrication, assembly, and installation of the test facility, test installation, and special test equipment required for conducting the system development tests. Included in this effort is the development of a system control computer program to determine realistic thrustor firing and system requirements.

The program will result in a significant advancement of the development status of the biowaste resistojet propulsion system by demonstrating the design concept adequacy, performance of the integrated system, and reliability over the range of envisioned operating conditions.

The major program efforts and test phases are delineated in the following sections. The objectives and their implementation are defined to provide the total overall guidance for each effort.

4.1 COMPONENT DESIGN AND DEVELOPMENT

The detail design requirements of the components will be established and a detailed evaluation made of existing electrical and mechanical components to determine the need for development activities. The determination of the components and assembly design and development requirements will establish vendor and subcontractor design and development efforts. The component and assembly development will be for design and development of prototype flight-weight units to meet the performance requirements and to withstand critical dynamic environments which may be detrimental.

4.1.1 Purpose and Objectives

The primary objective of this effort is to define the requirements which will be used to design and then develop the components of the biowaste resistojet propulsion system. The primary emphasis will be placed on the components requiring advanced technology development-the biowaste resistojet thrustor assembly, the CO_2 and CH_4 compressor assemblies, and the water vaporizer. These advanced components and assemblies for the selected resistojet system design model were identified in detail in Book 1 of this volume of the final report.

Other mechanical and electrical components in the system and their development status were previously identified in Table 2.

4.1.2 Scope

The component development effort is to encompass all mechanical and electrical componentry. The primary tasks in this effort include the definition of requirements as well as the actual development of components.

A. Requirements Definition. All components will be evaluated to determine the requirements imposed by the resistojet system. Primary and secondary performance requirements and interface requirements will be determined. The nominal and off-nominal range of operating conditions will be specified. The requirements will be summarized and specifications prepared for the design and development of prototype flight components for the systems development test effort.

B. Component Development. The specifications will be used for competitive procurement of the components. The design and development effort required to obtain prototype flight components is included in this task. Typical component and assembly test requirements, which must be satisfied in a flight development program to provide the confidence needed to commit the design to qualification tests, are included in Appendix B of this volume. These summary test requirements are for the major equipment identified in the system design model.

4.1.3 Implementation

Initial emphasis is to be placed on the components requiring advanced technology development. The thrustors, compressors, and vaporizer assemblies represent the critical portions of the system in terms of advanced technology development required. These items, as a minimum, must be developed to perform system development tests. Furthermore, the requirements for these components can be firmly established based on the EC/LS interface definitions, the quantities and constituents of the available biowastes, and the system usage. The remaining mechanical components can be simulated without significantly affecting the system performance. However, it is desirable to have all the components designed and developed to a prototype flight status. The electrical equipment, as previously discussed, is well within the state of the art, so breadboard special test equipment can be built to provide the electrical power and control needed for the tests. Electronic power distribution, regulation, and switching equipment can be developed independently after a firm definition of resistojet and spacecraft electrical interface requirements becomes available.

4.2 SYSTEM DEVELOPMENT TESTS

The tests performed in this effort will utilize the breadboard test unit with prototype flight components. The design of the breadboard test unit will allow each component to be individually tested to verify performance and component-interface compatibility during Phase I tests. The components will then be operational and life-tested at an assembly or system level during Phase II tests. Phase III system tests will be conducted using the outputs of the EC/LS molecular sieve and Sabatier reactor. On completion of this effort, the adequacy of the design concept of the operational system, the performance of the integrated system, and its reliability over the range of envisioned operating conditions will be demonstrated.

4.2.1 Phase I: Component Verification and Interface Tests

The component verification and interface tests conducted during this phase will vary with each component. The system test configuration described in Section 6.1 is to be designed to allow for components and assemblies to be tested with varying inlet and outlet conditions to provide the desired simulation of conditions needed to verify performance. Furthermore, these tests will provide an early evaluation of system operational characteristics. All tests envisioned, with the exception of the resistojet thrustors, are to be conducted at local ambient pressure and temperature conditions. Resistojet thrustor(s) or thrustor modules will be tested in a simulated vacuum environment.

4.2.1.1 Objectives

The major objectives of this test phase are listed below and include checkout and operations needed prior to conducting the component tests.

A. Develop checkout procedures and verify startup and shutdown sequences, including facilities, GSE, and special test equipment.

B. Develop adequate simulation of supply conditions for the EC/LS and biowaste resistojet system interface.

C. Verify component and assembly operation and performance characteristics under nominal and off-nominal conditions.

D. Establish component and assembly interaction with other system elements.

   1. Establish system operational performance.

   2. Determine impacts on other components and assemblies.

4.2.1.2 Scope

The componentry required in the resistojet system test configuration is determined in this test phase. The simulator program is not applicable to this phase. The tasks to be performed during this phase are to establish test requirements and procedures, verify component performance by tests, and evaluate the test results.

A. Test Requirements and Procedures. The test requirements and procedures required for this phase will be prepared. These test requirements will be revised and updated in accordance with the component development effort and systems testing effort.

B. Component Performance Verification Tests. The components will be tested in accordance with the established test requirements and procedures; nominal and off-nominal performance will be verified as well as component interface characteristics. Tests are to be conducted on individual components and assemblies, while installed in the breadboard test unit.

C. Component Test Evaluation. The test results will be used to verify design adequacy and performance. The test data will also be used to evaluate component interaction with other system elements. This evaluation will permit revision and updating of system operational and performance characteristics.

4.2.2 Phase II: System Operational and Life Tests

The system operation and life will be demonstrated during this phase. The components developed in the component design and development effort and tested in Phase I will be used in Phase II. The components will be installed in the breadboard system test unit, which will then be used to demonstrate and evaluate the system operational and life characteristics. The tests will be run to simulate various typical resistojet firings and duty cycles, accumulator pressure variations, water supplement, and the like, with emphasis on life and reliability.

4.2.2.1 Purpose and Objectives

The primary objectives of this test phase are: (1) to verify checkout procedures prior to starting the tests; (2) to verify operating characteristics and performance of components and assemblies; and (3) to demonstrate long-term operation and performance by life and reliability testing. In these tests, various duty cycles, pressure variations, biowaste mixtures, and water supplements will be simulated.

4.2.2.2 Scope

This test phase is for the demonstration of the operation and life of the resistojet system design. The results are applicable to both the Space Station and Base design models. These tests should demonstrate the feasibility and adequacy of a flight-weight prototype design to meet the life and reliability needs. The control signal preprogrammed on magnetic tape or the simulator program can be used during this phase for automatic control. The computer program is to be developed as part of the system development support effort. The tasks to be performed during this phase are to determine the test requirements and procedures, conduct the operation and life tests, and evaluate the test results.

A. Test Requirements and Procedures. The test requirements and test procedures for this phase will be prepared. These documents will also include the checkout, startup, and shutdown procedures.

B. System Operational and Life Tests. The system with prototype flight components will be tested to determine and verify the system operational and life characteristics. Nominal and off-nominal performance, various duty cycles, and various propellant combinations will be tested.

C. System Test Evaluation. The test results will be used to verify design adequacy, performance, and life and reliability characteristics. The results will also be used to evaluate component interaction with other system elements. Operational limitations and capabilities of the system are to be determined.

4.2.3 Phase III: Integrated EC/LS-Resistojet System Tests

The integrated EC/LS-resistojet system tests are to be conducted during this phase to verify satisfactory interface conditions. The breadboard test unit will be used, with the EC/LS equipment being added to supply the CO_2 and CH_4 propellants in lieu of the gaseous K-bottles used in Phase I and II tests. With the addition of interface EC/LS equipment to the resistojet breadboard test unit, the interface conditions and characteristics of the two systems can be verified and evaluated. The control signals, preprogrammed on magnetic tape or the actual simulator program, can be used for this phase.

4.2.3.1 Purpose and Objectives

The primary objectives of this test phase are: (1) to continue to demonstrate long-term operation and performance; (2) to demonstrate satisfactory interface conditions at the EC/LS and resistojet system interface with an operational resistojet system; (3) to verify EC/LS operation over the interface conditions provided by the resistojet system; and (4) to demonstrate satisfactory system control-computer program interface conditions with GN&C and data management inputs.

4.2.3.2 Scope

This test phase will verify and demonstrate satisfactory EC/LS-resistojet system interface conditions with the selected design approach. The results are applicable to both the Space Station and Base design models. The control computer program developed in the system development support effort will be used for automatic test controls. The tasks to be performed during this phase are to determine test requirements and procedures, test the integrated EC/LS-resistojet system, and evaluate the test results.

A. Test Requirements and Procedures. The test requirements and procedures for this phase will be prepared. These documents will also include the checkout, startup, and shutdown procedures for the EC/LS equipment, the ancillary GN&C, and other equipment for the test operations.

B. Integrated EC/LS-Resistojet System Tests. The breadboard test unit will also be used in this test phase with the EC/LS equipment supplying the CO_2 and CH_4 propellants in lieu of gaseous K-bottles. The tests will determine whether satisfactory EC/LS-resistojet interface conditions exist. The interface characteristics with nominal and off-nominal performance, various duty cycles, and propellant combinations will be determined. In addition, the operation of the control computer program with GN&C and data management inputs will be verified.

C. Test Evaluation. The test results will be used to determine the interface design adequacy, performance, and general operating characteristics. The results will also be used to evaluate component interaction with other system elements.

4.2.4 System Development Test Implementation

4.2.4.1 Phase I

With the development of advanced technology components, a resistojet system development test program can be conducted which will demonstrate satisfactory design and interface characteristics of a flight system. The initial Phase I tests can be run with these components. They are to be installed in the breadboard test unit, with K-bottles supplying CO_2 and CH_4. The breadboard unit with adjustable regulators can simulate any of the major component outputs and the component can thus be missing from the installation. The missing component will be replaced with an interconnecting tube arrangement to allow testing of other downstream components, except for the vaporizer.

The number of thrustors to be installed for this phase may vary from one (the minimum required for life demonstration) to four (the maximum number of thrustors fired at once).

4.2.4.2 Phases II and III

The Phase II and Phase III tests utilize the same breadboard configuration installation. The test unit is supplied with CO_2 and CH_4 from K-bottles during Phase II and is to be adapted to accept the EC/LS equipment for Phase III testing. During Phase II and III tests, automatic control of the system firing operations is to be provided by the control computer program results or by adapting the simulator program to be used during these tests.

Section 5

SYSTEM DEVELOPMENT SUPPORT

The design, fabrication, assembly, and installation of the facilities, the system test configuration, and special equipment for conducting the system development tests at LaRC are defined in this effort. Also included in this effort is the development of a system control computer program to simulate the relationships of the various interfaces and the system and thrustor operations in-flight.

The test configuration is to be designed to simulate the MDAC Space Station resistojet system design model. The configuration should be capable of being modified to satisfy improved or updated system concepts. The test unit will be configured to include prototype components and assemblies needed to provide a functional simulation of the fluid portion of the system design model, but line routings will not be duplicated. Power distribution and control equipment interfacing with the propulsion components and assemblies can be provided with special equipment, with flight designs provided when appropriate. The test installation will satisfy the operational requirements of the Space Station system design model. Special test and flight instrument parameters will be needed to measure and monitor operation of the system and its elements during the tests. The test installation and special test equipment should be designed with flexibility, so that they can be modified as necessary throughout the development program.

The facility modifications are needed to adapt existing facilities at LaRC for the system development tests.

5.1 PURPOSE AND OBJECTIVES

The purpose of this effort is to provide the facilities, the breadboard unit, the special test equipment, the test control equipment, and other equipment needed to perform the system development test program.

The control computer program is to provide realistic on-orbit characteristics of the design model. The results when preprogrammed on magnetic tape or used direct from a program will provide automatic control capability of the system during Phase II and III tests.

5.2 SCOPE

This effort is to encompass all the test-related design, fabrication, assembly, and installation activities needed to support the system development program, and includes the control computer program development effort. These items needed are described in Sections 6 and 7. The primary tasks in this effort are described in the following list.

A. Facilities. Existing facilities at LaRC are to be used in performing the system development test effort, with additions and modifications for the resistojet system development program. A description of basic requirements of the facilities is given in Section 6.

B. Prototype System Design. The three system development test phases are to be conducted using a breadboard test unit. The design, with adjustable regulators and adapters, will allow the components to be tested individually, in assemblies, or as part of the total system.

C. Control Computer Program. This computer program will be used to determine operational characteristics and duty cycles of the system. Inputs include the various parameters influencing system operation (e.g., control moment gyro, gimbal angles, vehicle orientation, and orbital drag, EC/LS and resistojet system status data). These parameters will be used to compute the duty cycle or commands for system operations. The program will be used to provide typical and worst-case system operational duty cycles or characteristics and to control the Phase II and III tests automatically.

D. Procurement. The test components, instrumentation, pressure vessel, and other equipment needed for the test configuration and installation will be procured to satisfy the design requirements.

E. Special Test Equipment. The electrical and mechanical special test equipment needed in conjunction with the test unit will be designed and built to satisfy the test objectives.

F. Fabrication, Assembly, Installation, and Checkout. The facilities, test unit, special equipment and other supporting equipment will be fabricated, assembled, installed, and checked out so that the test program outlined can be performed.

5.3 IMPLEMENTATION

The facility modifications are being made by LaRC in anticipation of the development program. Results of this program plan and the resistojet study will provide the basic guidelines needed for the facility, the breadboard test unit, the special test equipment, instrumentation, and the control and data acquisition requirements. The design, fabrication, procurement, assembly, and installation of the test unit and support facilities and equipment needed for performing the test program must be accomplished in parallel with the component development activity. Figure 1 shows the schedule and effort required for the various items.

The breadboard test unit can be used for all three phases of testing; however, in cases where components are missing, adjustable regulators and tube adapters will be used to simulate or create the missing component outputs.

Development of the computer program is a two-fold effort: (1) development of the analytical relationships (by equations) of the various parameters affecting thrustor selection, and (2) actual software development. The program is to be developed in parallel with the mechanical components. This program will use CMG and station orbital and orientation data, EC/LS system interface data, and resistojet system status data to determine which thrustors and how many are to be fired, their firing duration, power level, and the propellants to be used. The program can be used in the operational and life tests and in the integrated EC/LS-resistojet system tests to verify system control under realistic duty cycles. Actual development of the flight control computer program, the software, depends on specific spacecraft design characteristics, data management system computer selection (multipurpose or individual computers), and spacecraft-level tradeoffs for distribution of computational activities.

Section 6
TEST FACILITY AND INSTALLATION

The system development test configuration for the first two test phases will consist of the breadboard which functionally simulates the Space Station resistojet system, a test cell with a vacuum chamber, a test control center, an instrumentation center, special test equipment, and additional support facilities. The resistojet system portion of the test configuration of Phase III (the integrated EC/LS-resistojet test configuration) is identical to the configuration for phases I and II, except the EC/LS interfacing equipment to supply CO_2 and CH_4 will be installed in the breadboard unit in lieu of the K-bottles. (See Figures 9 and 10.)

Facility No. 1294 at LaRC will be devoted to resistojet system development tests. The test configuration described is for the Space Station design model; however, the Space Base configuration differs in only the thrust level (50 millipounds) and in the number of collection and storage assemblies required. The components are to be capable of satisfying both design models.

6.1 RESISTOJET SYSTEM TEST CONFIGURATION

The resistojet system test unit schematic shown in Figures 9 and 10 with the independent water vaporizer design concept will simulate the operating conditions of the propulsion components and assemblies. A slight modification of this would also satisfy the integral vaporizer thrustor approach. The test unit, as shown, will satisfy the system test configuration and installation requirements for all three phases. With the adjustable regulators recommended, this installation will basically allow components to be left out or tested apart from the total system. The details of interconnecting lines, adapters, and valves are to be established during the detail test installation design to satisfy daily or weekly tests scheduled.

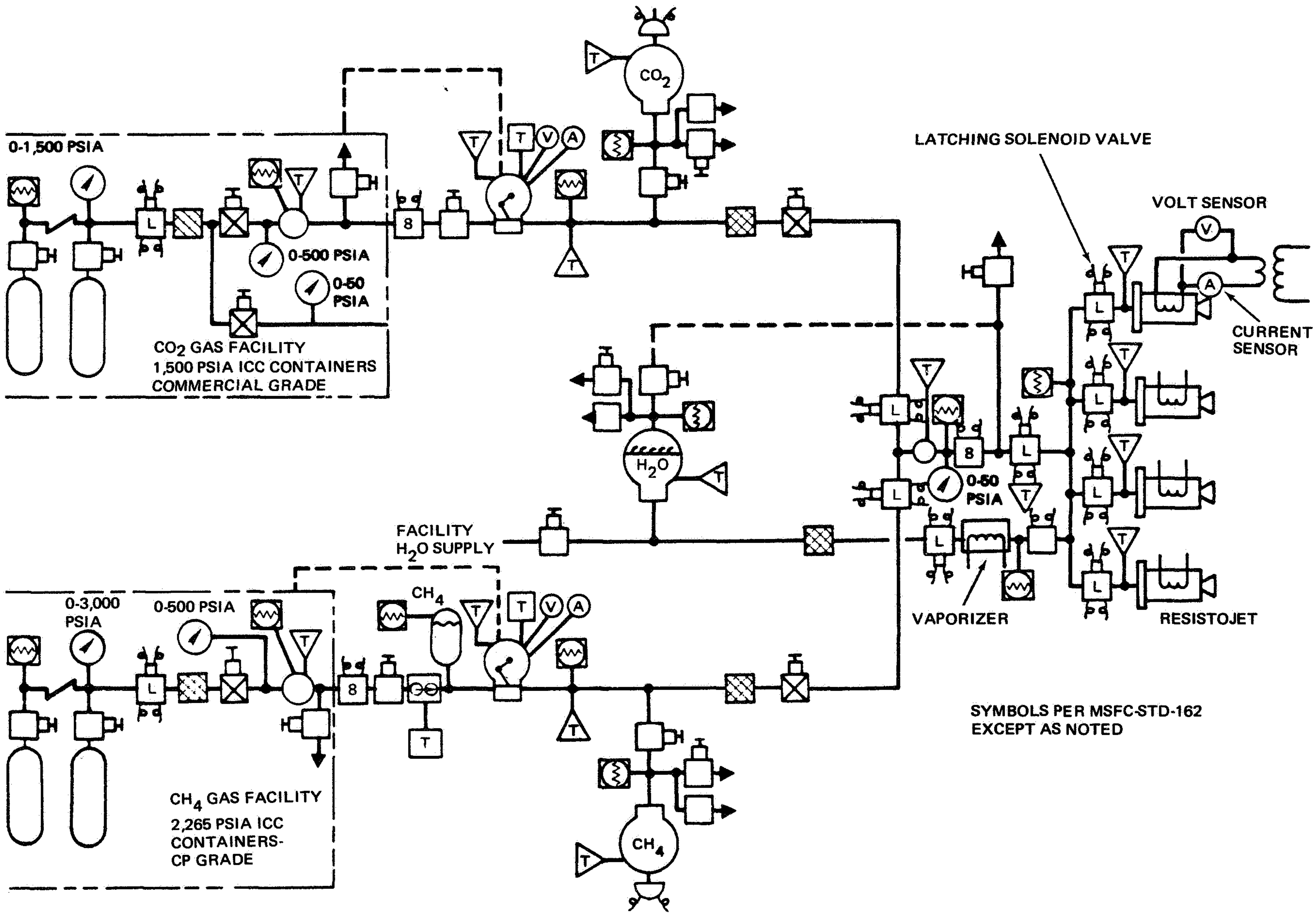


Figure 9. Schematic, Resistojet System - Test Phase I and II

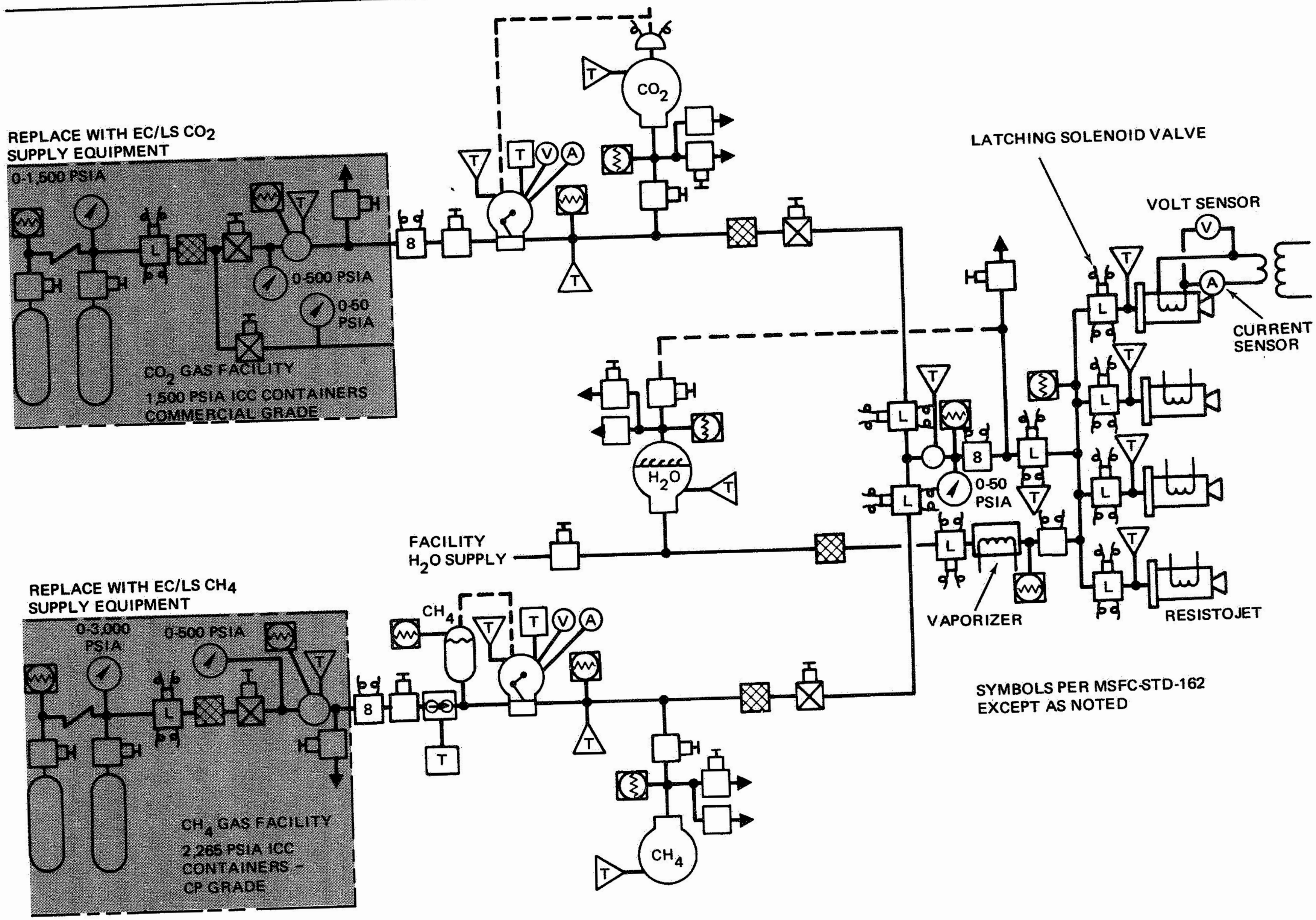


Figure 10. Schematic, Integrated EC/LS Resistojet System Test

The schematics of the test configuration and flight-system block diagram and schematics provided in Section 2 show the relationship of the flight components, assemblies, and modules to the test unit. With these relationships, design flexibility is retained to install any prototype component, assembly, or module in lieu of using special equipment or off-the-shelf test hardware. For power control and distribution equipment, it was recommended earlier that special test equipment provide the electrical power, but prototype flight equipment can be used, if so desired.

The test configuration should allow for up to four resistojet thrustors to be installed. Four thrustors firing at once is the maximum required in the MDAC biowaste resistojet systems model; however, growth of the thrust level and mass flow should be considered, at twice Space Station requirements, for the Space Base. Initially, it is assumed only one thrustor will be used and additional thrustors added as required.

The propellant collection and feed assemblies will provide a realistic duplication of the flight assembly dynamic flow characteristics, with the use of prototype compressors, simulated storage volumes, and ground-type adjustable regulators providing the flight-regulation requirements, as well as any other desired thrustor inlet conditions. The propellants for the resistojet system and life tests will be of a commercial type supplied from ICC-approved K-bottles. (C. P. grade 99.1 percent CH_4, and commercial grade CO_2 is recommended for the tests). This test configuration can also satisfy the Space Base requirements, since the basic design and flow capacity, except for thrustors, should satisfy any needs of the envisioned Space Base design requirements for 48 men. Multiple collection and storage assemblies are used in the Space Base design model.

The water supplement capability in the test unit design is simulated with only the CO_2 pressurization and thrustor feed conditions in flight being duplicated. This is more than satisfactory to demonstrate water supplement capabilities.

The test installation will be completely housed in the test cell and will be in a normal room or test cell environment, without any special conditioning required. An exception is the thrustors, which will be installed in the vacuum chamber. For safety and to simulate normal Space Station temperature conditions, it is recommended that the test installation be maintained between 278 and 311°K (40 and 100°F) and high-pressure bottles designed to appropriate safety codes.

The system plumbing lines are to be long enough to preclude any need for special propellant conditioning equipment; i. e., the surrounding cell environment should be satisfactory, while the pressure losses in the system line should be negligible.

6.2 TEST CELL

An existing circular centrifuge test cell (LaRC Facility No. 1294) is being modified for the resistojet system development tests. The test cell consists of approximately 111 m^2 (1200 ft^2) of floor area, with a 1.21-m (4-ft) diameter by 2.43-m (8-ft) long vacuum chamber planned for installation in the cell. The test cell will contain the necessary test fixtures to install the test unit and test equipment needed for the development tests of the Space Station design model; however, growth potential should be retained for the Space Base design. Appropriate electrical power, environmental control, and ventilation equipment will be provided at the facility. Test cables, electrical J-Boxes, lighting, intercom stations, and the like will be included.

6.3 TEST CONTROL CENTER

The primary test control center will be located in the instrumentation room in the building adjacent to the test cell. Manual control panels for the system and its elements can also be provided in the test cell area. Control of the system and facilities required during a test will normally be accomplished from the primary test control center. Test operation from the control center will be limited to event-sequencing and manual control and monitoring. The capabilities for automatic control by computer or preprogrammed tape and for computer data acquisition exist nearby in Building 1271 and will be utilized for portions of the test program.

6.4 INSTRUMENTATION CENTER

The instrumentation center will be located in the same room as the test control center. The instrumentation center will contain the signal conditioning, recording, and remote control equipment. The instrumentation center will contain facilities for permanent recording and readout of instrumentation data of the types required.

6.5 ADDITIONAL SUPPORT FACILITIES

Additional support facilities required for maintaining, installing, servicing, and storage of K-Bottles are to be provided by existing LaRC facilities. At least the following will be required:

A. A gas storage area for compressed gases (K-Bottles).

B. A maintenance and assembly area for cleaning and maintenance work on the system hardware.

C. A preinstallation component and assembly checkout area.

Section 7
DATA ACQUISITION

All instrumentation signals and control functions will be hardwired to and from the test cells, test control center, instrumentation center, and computer facility. The test control center will contain equipment to control the system and the test cell support facilities. The instrumentation center will contain the standard signal conditioning and most of the recording equipment needed. The instrumentation for the system tests is discussed in Section 7. 3.

7. 1 TEST CONTROL CENTER

The following equipment for module tests will be provided in the test control center (TBD, examples only):

A. System test control console.

B. Facilities control console.

C. Recorders (TBD channels).

D. Thermocouple reference junction system (TBD channels).

E. Power supplies for transducer excitation (5 and 28 volts dc).

F. Programmable distribution unit.

G. Safety officer's console (public address system and master intercommunication panel).

H. Rectifier (28 volts dc, 200 amperes).

I. Test control center cable network.

J. Event recorders (TBD channels)

7.2 INSTRUMENTATION CENTER

The instrumentation center will contain the following equipment (TBD examples only):

A. Signal conditioning and dc amplifier (TBD channels).

B. Constant bandwidth FM system (TBD channels).

C. Wideband FM system (TBD channels).

D. Recorders (TBD channels, strip charts, oscillograph or magnetic tape).

E. Programmable distribution unit.

F. Instrumentation center cable network.

An instrumentation calibration and control capability will be needed for remote control of the drive motors on all recorders and to provide for prerun and postrun calibration sequencing. These remote control functions may be automatically initiated by the sequencer controls during an automatic firing phase of the program.

7.3 MEASUREMENT REQUIREMENTS LIST

The measurement requirements tentatively established for the resistojet system breadboard test configuration are listed in Table 3. Additional measurements required will be associated with the facility, the EC/LS equipment for integrated tests, and the electrical and mechanical GSE and special equipment needed in support of the various tests. The final instrumentation requirements are to be established during the detail design effort.

The test configuration instrumentation is based on the test unit schematics (Figures 9 and 10) and a growth factor of at least 20 percent should be used in sizing the instrumentation capability at the LaRC test facility. The recording requirements at this time are optional, depending on equipment availability; however, real-time recording using magnetic tape, oscillograph, or strip charts is needed in addition to an event recorder.

Table 3 (page 1 of 3)

MEASUREMENT REQUIREMENTS LIST

Parameter	Range	Accuracy (In Percent)	Frequency Response (Samples per Sec)
Pressure Transducers			
CO_2 Pressures			
Supply	0 to 1035 by 10^4 N/m^2 (0 to 1500 psia)	±3	1.0
Compressor Inlet	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	1.0
Compressor Outlet	0 to 207 by 10^4 N/m^2 (0 to 300 psia)	±2	1.0
Accumulator	0 to 207 by 10^4 N/m^2 (0 to 300 psia)	±2	1.0
CH_4 Pressures			
Supply	0 to 2070 by 10^4 N/m^2 (0 to 3000 psia)	±3	1.0
Compressor Inlet	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	1.0
Compressor Outlet	0 to 207 by 10^4 N/m^2 (0 to 300 psia)	±2	1.0
Accumulator	0 to 207 by 10^4 N/m^2 (0 to 300 psia)	±2	1.0
H_2O Ullage Pressures	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±2	1.0
Vaporizer Outlet	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	1.0
Control Regulator Outlet	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	1.0
Propellant Manifold	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	1.0
Pressure Gauges			
CO_2 Supply	0 to 1035 by 10^4 N/m^2 (0 to 1500 psia)	±3	NA
CH_4 Supply	0 to 2070 by 10^4 N/m^2 (0 to 3000 psia)	±3	NA
CO_2 Supply Regulator	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	NA
CH_4 Supply Regulator	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	NA
H_2O Pressure Regulator	0 to 69 by 10^4 N/m^2 (0 to 100 psia)	±1	NA
Feed Regulator Outlet	0 to 69 by 10^4 N/m^2 (0 to 100 psia	±1	NA

Table 3 (page 2 of 3)

Parameter	Range	Accuracy (In Percent)	Frequency Response (Samples per Sec)
Temperatures			
CO_2			
Compressor Inlet	255 to 311°K (0 to 100°F)	±2	1.0
Compressor	255 to 422°K (0 to 300°F)	±2	0.5
Compressor Outlet	255 to 367°K (0 to 200°F)	±2	0.5
Storage Accumulator	255 to 367°K (0 to 200°F)	±2	0.5
CH_4			
Compressor Inlet	255 to 311°K (0 to 100°F)	±2	1.0
Compressor	255 to 422°K (0 to 300°F)	±2	0.5
Compressor Outlet	255 to 367°K (0 to 200°F)	±2	0.5
Storage Accumulator	255 to 367°K (0 to 200°F)		
H_2O Storage	255 to 311°K (0 to 100°F)	±2	0.5
Evaporator	255 to 533°K (0 to 500°F)	±1	0.5
Control Regulator Outlet	255 to 311°K (0 to 100°F)	±2	1.0
Thrustor Inlet	255 to 533°K (0 to 500°F)	±2	0.5
Miscellaneous			
CO_2 Flow	0 to 0.0044 N/sec (0 to 0.001 lb/sec)	±1	1.0
CH_4 Flow	0 to 0.0044 N/sec (0 to 0.001 lb/sec)	±1	1.0
H_2O Flow	0 to 0.0044 N/sec (0 to 0.001 lb/sec)	±1	1.0
Regulator Outlet Flow	0 to 0.0044 N/sec (0 to 0.001 lb/sec)	±1	1.0
CO_2 Compressor Speed	TBD	TBD	TBD
CH_4 Compressor Speed	TBD	TBD	TBD
CO_2 Compressor Volt	TBD	TBD	1.0
CO_2 Compressor Current	TBD	TBD	1.0

Table 3 (page 3 of 3)

Parameter	Range	Accuracy (In Percent)	Frequency Response (Samples per Sec)
CH_4 Compressor Volt	TBD	TBD	1.0
CH_4 Compressor Current	TBD	TBD	1.0
Resistojet Heater Voltage (4)	TBD	TBD	1.0
Resistojet Heater Current (4)	TBD	TBD	1.0
Vaporizer Volt	TBD	TBD	1.0
Vaporizer Current	TBD	TBD	1.0
Events			
Isolation Valves (4)	28 ± 5 vdc	NA	1.0
Thrustor Valves (4)	28 ± 5 vdc	NA	1.0
CO_2 Pressure Switch	28 ± 5 vdc	NA	1.0
CH_4 Pressure Switch	28 ± 5 vdc	NA	1.0

NOTE: GSE, Special Test Equipment and Facility Instrumentation to be determined.

APPENDIX A

RESISTOJET THRUSTOR ASSEMBLY

TECHNICAL SPECIFICATIONS

Section 1
SCOPE

This specification establishes the requirements for performance, design, and development of equipment identified as the resistojet thrustor assemblies, hereinafter referred to as thrustors. The thrustors use independently fed gaseous biowastes (CO_2 or CH_4) or water, either in the liquid or vapor form. The water-fed thrustor shall have an integral water vaporizer section in the thrustor assembly, while the vapor-fed thrustor will be supplied superheated water vapor from an independent vaporizer assembly. In addition, the two thrustor configurations shall consist of a valve, heating element and heater chamber, nozzle, and miscellaneous hardware. One of these thrustor concepts is to be developed to a prototype flight status to advance the resistojet system technology for manned spacecraft applications. The thrustors require primary input from the guidance, navigation, and control system for firing commands and power-level selection.

The thrustor shall be of a flight-weight prototype design to be used for ground tests. The flight-weight prototype design and development effort defined shall allow subsequent space flight applications, with a minimum development effort applied prior to flight-qualification of the thrustor design. The thrustor shall be one of the following configurations:

Configuration	Requirement
-1	The thrustor fed by vaporized water. All paragraphs except those applicable only to the -501 configuration.
-501	The integrated water vaporizer (liquid-fed) thrustor. All paragraphs except those applicable only to the -1 configuration.

Section 2
APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and other detailed content of Sections 3 and 4, the detailed requirements of Section 3 and 4 shall be considered to supersede requirements of these documents.

SPECIFICATIONS

Military

MIL-A-8625B	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-B-5087B	Bonding, Electrical, and Lightning Protection for Aerospace Systems
MIL-C-5541A	Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys
MIL-C-6021E	Casting, Classification and Inspection of
MIL-E-5151A Change 1	Qualification Test for Engines, Rocket Liquid Propellant
MIL-E-6051C 17 June 1960	Electrical-Electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon Systems
MIL-F-7190 Amendment 1	Forgings, Steel, for Aircraft and Special Ordnance Applications
MIL-I-6181D 25 Nov 1959	Interference Control Requirements, Aircraft Equipment

MIL-R-11468 24 Sep. 1951	Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel
MIL-R-45774 Amendment 1	Radiographic Inspection, Soundness Requirements for Fusion Welding in Aluminum and Magnesium Missile Components
MIL-S-5002A Amendment 1	Surface Treatment and Metallic Coatings for Metal Surfaces of Weapon Systems
MIL-S-7742A	Screw Threads Standard, Optimum Selected Series; General Specification for
MIL-S-8879 21 Sep 1960	Screw Threads, Controlled Radius Root with increased Minor Diameter, General Specification for
MIL-S-38130 30 Sep 1963	Safety Engineering of Systems and Associated Subsystems and Equipment; General Requirements for
MIL-T-152B Amendment 1	Treatment, Moisture and Fungus Resistance of Communications Electronic, and Associated Electrical Equipment
MIL-T-9107 Amendment 7	Test Results, Preparation of
MIL-W-5088A	Wiring, Aircraft, Installation of
MIL-W-8611A	Welding, Metal Arc and Gas, Steels and Corrosion and Heat Resistant Alloys, Process for
MIL-W-16878D Supplement 1A	Wire, Electrical, Insulated, High Temperature

STANDARDS

Military

MIL-STD-143A	Specifications and Standards, Order of Precedence for the Selection of

MIL-STD-447 28 May 1959	Definition of Interchangeable, Substitute, and Replaceable Items
MIL-STD-453 Change 1	Inspection, Radiographic
MIL-STD-454A Notice 1 and 2	Standard General Requirements for Electronic Equipment
MIL-STD-461A	Electromagnetic Interference Requirements for Equipment
MIL-STD-810A	Environmental Test Methods for Aerospace and Ground Equipment
MS 20995B	Wire, Lock
MS 33540C	Safety Wiring, General Practice for

Federal

FED-STD-209 16 Dec 1963	Clean Room and Work Station Requirements, Controlled Environment

LaRC Process Specifications

TBD	Cleaning Requirements
TBD	Welding, Fusion, Aluminum and Magnesium

BULLETINS

ANA Bulletin 400 Amendment 2	Electronic Equipment: Aircraft and Guided Missiles, Applicable Documents

OTHER PUBLICATIONS

TBD

Copies of specifications, standards, drawings, bulletins, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

Section 3
REQUIREMENTS

3.1 PERFORMANCE

3.1.1 Functional Characteristics

3.1.1.1 Primary Performance Characteristics (Vacuum)

The performance requirements and characteristics are based on thrustor operation with propellants specified in Section 3.3.3.2 (CO_2, CH_4 and liquid or vapor H_2O).

3.1.1.1.1 Steady-State Performance. For purposes of this specification, steady-state firing performance is defined as the performance obtained after equilibrium thrustor firing conditions are reached and is exclusive of the instrumentation and recording errors.

3.1.1.1.1.1 Minimum Specific Impulse. The minimum measured steady-state vacuum specific impulse shall be as follows for each of the propellants specified in Section 3.3.3.2 and when operating throughout the conditions of Section 3.1.1.2.1:

CO_2	175 sec
CH_4	218 sec
H_2O	245 sec

3.1.1.1.1.2 Minimum Total Impulse/Sec. The steady-state vacuum total impulse per second of firing for any of the propellants specified and when operating throughout the conditions specified in Section 3.1.1.2.1 shall be at least 0.11 N-sec/sec (25 mlb-sec/sec).

3.1.1.1.1.3 Total Impulse Reproducibility. The steady-state thrustor-to-thrustor and test-to-test total impulse reproducibility over any firing duration of five seconds or greater shall be within one percent for any given set of conditions specified in Sections 3.1.1.2.1 and 3.1.1.2.2.

3.1.1.1.1.4 Vacuum Duty Cycle. The thrustor shall be capable of meeting the requirement of this specification when performing any firing vacuum duty cycle consistent with Section 3.1.2.3.

3.1.1.2 Secondary Performance

3.1.1.2.1 Operating Conditions. The thrustor shall operate in accordance with the requirements of this specification throughout the full range of its operating conditions with the propellants specified in Section 3.3.3.2.

3.1.1.2.1.1 Propellant Supply Pressure. The propellant supply pressure required at the thrustor inlet during steady-state operation shall not exceed 34.5 by 10^4 N/m^2 (50 psia) and may vary over a range of 2.0 by 10^4 N/m^2 (2.9 psia).

3.1.1.2.1.2 Propellant Supply Temperature

3.1.1.2.1.2.1 -1 Configuration. The range of propellant supply temperatures during steady-state operation will be 278 to 311°K (40 to 100°F) at the thrustor inlet for CO_2 and CH_4, and will be 422 to 458°K (300 to 365°F) for H_2O (vapor).

3.1.1.2.1.2.2 -501 Configuration. The range of propellant supply temperatures during steady-state operation will be 278 to 311°K (40 to 100°F) at the thrustor inlet for CO_2, CH_4, and H_2O (liquid).

3.1.1.2.1.3 Maximum Thrustor Valve Temperature. The thrustor valve temperature (coil) shall not exceed (TBD by the contractor) °F during steady-state operation.

3.1.1.2.1.4 Thrustor Outer Wall Temperature. The thrustor outer wall temperature during steady-state operation and when installed in a thrustor module at 367°K (200°F) and in a space vacuum environment shall not exceed 478°K (400°F) with the maximum design power setting specified in Section 3.1.1.2.3.5.2.1.

3.1.1.2.1.5 Supply Voltage. The supply voltage at the terminals of the thrustor supplying power to the heater will vary within ±5 percent of the design AC rms voltage setting specified in Paragraph 3.1.1.2.3.5.2.1. The supply voltage at the terminals of the thrustor valves and valve position switch will be 20 to 36 volts dc as specified in Paragraphs 3.1.1.2.3.5.1.1.1.1 and 3.1.1.2.3.5.1.1.1.2.

3.1.1.2.2 Maximum Operating Conditions. The thrustor shall operate safely without any subsequent degradation in performance throughout the range of the following maximum operating conditions and with the propellants specified in Section 3.3.3.2.

3.1.1.2.2.1 Propellant Supply Pressure. The propellant supply pressure at the thrustor inlet during firing operations shall be within the range of 10.35 by 10^4 to 207 by 10^4 N/m^2 (15 to 300 psia).

3.1.1.2.2.2 Propellant Supply Temperature

3.1.1.2.2.2.1 -1 Configuration. The range of propellant supply temperatures during firing operations shall be 222 to 322°K (-60 to 120°F) at the thrustor inlet for CO_2 and CH_4, while the supply temperature range for vaporized water shall be 408 to 478°K (275 to 400°F).

3.1.1.2.2.2.2. -501 Configuration. The range of propellant supply temperatures during firing operations shall be 278 to 322°K (40 to 120°F) at the thrustor inlet for CO_2, CH_4, and H_2O (liquid).

3. 1. 1. 2. 2. 3 Supply Voltage. The voltage at the terminals of the thrustor supplying power to the heater shall be no more than 10 percent greater than the maximum voltage specified in Section 3. 1. 1. 2. 3. 5. 2. 1.

3. 1. 1. 2. 3 <u>Operational Performance</u>

3. 1. 1. 2. 3. 1 Starting and Stopping. The thrustor shall start safely and reliably upon receiving an external electrical signal for valve actuation and heater power throughout the range of the maximum operating conditions specified in Section 3. 1. 1. 2. 2 and with the various propellants specified in Section 3. 3. 3. 2. Thrustor shutdown shall be reliably achieved under all operating conditions upon receiving an electrical valve closing signal and removal of heaterpower.

3. 1. 1. 2. 3. 2 Proof. The thrustor shall withstand a proof pressure of (TBD by the contractor) without damage or degradation of performance.

3. 1. 1. 2. 3. 3 Burst. The thrustor shall withstand a minimum of (TBD by the contractor) without bursting.

3. 1. 1. 2. 3. 4 Leakage

3. 1. 1. 2. 3. 4. 1 <u>External</u>. The external leakage exclusive of fittings shall not exceed 1. 0 standard cubic centimeters per hour (scch) helium gas at nominal operating pressure. External leakage per fitting shall not exceed 1×10^{-3} standard cubic centimeters per minute (sccm) helium gas at nominal operating pressure.

3. 1. 1. 2. 3. 4. 2 <u>Internal</u>. The internal leakage past any thrustor valve shall not exceed 100 standard cubic centimeters per hour (scch) helium gas at nominal operating pressure.

3.1.1.2.3.5 Electrical

3.1.1.2.3.5.1 <u>Thrustor Valve and Valve Position Switch</u>

3.1.1.2.3.5.1.1 Voltage

3.1.1.2.3.5.1.1.1 <u>Operating</u>

3.1.1.2.3.5.1.1.1.1 Actuating Coils. The valve actuating coils shall be capable of operating within the requirements of this specification upon application of a command pulse of 20 to 36 volts dc for a minimum of 10 milliseconds duration and shall remain in that position until commanded to the reset position. The valve shall operate within the requirements of this specification throughout the temperature range of from 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.1.1.2 Valve Position Indicator Switch. The valve position indicator switch shall be capable of operating within the requirements of this specification throughout a supply voltage range of 4 to 36 vdc and throughout the temperature range of from 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.1.2 <u>Pull-In</u>

3.1.1.2.3.5.1.1.2.1 Opening Coil. The valve must open upon an actuating coil pull-in command pulse being applied of 18 vdc and must not operate at 5 vdc throughout the temperature range of 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.1.2.2 Closing Coil. The valve must close upon an actuating pull-in command pulse being applied to the closing coil of 18 vdc and a minimum of 5 vdc throughout the temperature range of from 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.1.3 Continuous Duty. The valve shall be capable of having each coil continuously energized with a minimum of 36 vdc for at least 5 minutes without fluids flowing and from an initial temperature of 322°K (120°F) without damage. The position indicator switch circuitry shall be capable of being continuously energized for 180 days with a minimum of 36 vdc and from an initial temperature of 322°K (120°F) without damage.

3.1.1.2.3.5.1.1.4 Inductive Transient Suppression. Inductive transient suppression circuitry shall be provided to ensure transient conditions as necessary to meet the requirements of this specification. Transient peak voltage in both opening and closing coils shall not exceed +37 volts peak or -6 volts peak. The suppression circuit shall also be designed in such a manner that should failure occur, it shall normally fail open, or if failed shorted, be capable of being burned open in less than 100 milliseconds while drawing 5 to 15 amperes of current. Following failure of the suppression circuit, the valve shall be capable of operation without suppression.

3.1.1.2.3.5.1.2 Current

3.1.1.2.3.5.1.2.1 Operating

3.1.1.2.3.5.1.2.1.1 Actuating Coils (Opening and Closing). The operating current of the valve actuating coils shall not exceed 1.5 amperes maximum at 36 vdc throughout the temperature range of from 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.2.1.2 Position Indicator Switch. The operating current of the valve position indicator switch shall not exceed 250 milliamperes at 36 vdc throughout the temperature range of from 278°K (40°F) to the maximum valve temperature of TBD.

3.1.1.2.3.5.1.3 Power Quality. The valve electrical elements shall withstand ±100 volts superimposed on a minimum line voltage of 36 vdc for at least 10 microseconds.

3.1.1.2.3.5.1.4 Capacitance. The capacitance between each solenoid coil and ground shall not exceed 0.01 microfarad.

3.1.1.2.3.5.1.5 Position Switch Contact Chatter. Maximum contact open time, including contact bounce, resulting from the environments of Section 3.1.2.4.1 shall be 10 microseconds.

3.1.1.2.3.5.1.6 Load. With the thrustor valve held rigid at its mounting points, the thrustor shall be capable of meeting all of the specification performance requirements when a torque of 2.5 kg m maximum is applied through the center of the fluid fittings of the valve and normal to the fitting centerline.

3.1.1.2.3.5.2 Thrustor Heater Element(s). The thrustor heating element(s) shall provide the heat and conditioning necessary for the various propellants specified in Section 3.3.3.2 to obtain the performance required in Section 3.1.1.1 and the thrustor life requirement of Section 3.1.2.3 in any attitude and random gravity field of 0 to 1g.

3.1.1.2.3.5.2.1 Power. The thrustor heater element(s) shall operate with ac power from zero volts ac to the maximum design power setting(s) (TBD by the contractor).

3.1.1.2.3.5.2.2 Continuous Duty (Nonoperating). The heater element shall be capable of being energized from an initial condition of 290°K (70°F) with the rated maximum design power setting(s) for a minimum duration of (TBD by the contractor) or until the maximum operating heater temperatures are obtained without fluid flow in a seal level or vacuum environment.

3.1.1.2.3.5.3 Thrustor Heater Transformer(s). The thrustor heater transformer(s) shall operate over a range of input voltages of 0 to the maximum voltage of TBD required for heater operation. The supply voltage from the transformer(s) to the thrustor terminals will be controlled to ±5 percent of the required value.

3.1.1.2.3.5.3.1 Efficiency. (TBD by the contractor).

3.1.1.2.3.5.3.2 Power Quality. (TBD by the contractor).

3.1.1.2.3.5.4 Voltage and Current Instrumentation. The thrustor voltage and current instrumentation shall be capable of operating within the requirements of this specification throughout the temperature range of from 278°K (40°F) to the maximum temperature induced by thrustor operations, and shall provide mutually isolated outputs in accordance with Paragraphs 3.1.1.2.3.5.4.1 and 3.1.1.2.3.5.4.2.

3.1.1.2.3.5.4.1 Current Sensor. The current sensor shall be capable of monitoring the heater element(s) rms ac current from 0 to 10 percent above the maximum design current required by Paragraph 3.1.1.2.3.5.2.1 to within ±1 percent. The sensor will provide a 0 to 5 volt analog signal proportional to the rms current measurement range.

3.1.1.2.3.5.4.1.1 Linearity. The linearity requirement shall be satisfied if all points fall within the two lines drawn at ±2 percent of full scale and parallel to a line of best fit at 295°K (70°F).

3.1.1.2.3.5.4.1.2 Response. The output requirements of Paragraph 3.1.1.2.3.5.4.1 shall be met within 100 milliseconds following the start of monitored current flow, the application of supply voltage, or any change in current.

3.1.1.2.3.5.4.1.3 Output Impedance. The maximum output impedance of the current sensor shall be (TBD by the contractor).

3.1.1.2.3.5.4.1.4 Output Signal Isolation. The output signal of the current sensor shall be isolated from the monitored heater current by one megohm minimum.

3.1.1.2.3.5.4.2 Voltage Sensor. The voltage sensor shall be capable of monitoring the rms ac voltage impressed across the heater element from 0 to the maximum rated design voltage required by Paragraph 3.1.1.2.3.5.2.1 to within ±1 percent. The sensor will provide a maximum of a 0 to 5 volt analog signal proportional to the rms voltage measurement range.

3.1.1.2.3.5.4.2.1 Isolation. The output signal shall have short circuit isolation protection from the monitored voltage of at least one kilohm.

3.1.1.2.3.5.4.2.2 Operating Life. The sensors shall satisfy all the requirements specified in Paragraph 3.1.2.3.1.

3.1.2 Operability.

3.1.2.1 Reliability.

The thrustor shall have a minimum reliability rating goal of 0.9945 while operating within the requirements imposed by this specification for the thrustor life specified in Section 3.1.2.3.

3.1.2.2 Maintainability

3.1.2.2.1 Maintenance and Repair Cycles. Scheduled maintenance shall not be required during the service life of the equipment.

3.1.2.2.2.1 Cleaning. The design and construction of the thrustor shall allow for complete cleaning to meet the requirements of TBD (LaRC cleaning specification) without impairing the operational performance parameters in these specifications.

3.1.2.2.2.2 Securing Devices. The thrustor shall be designed and constructed so that no parts work loose during installation or operation. All adjustments which may be provided shall be capable of being securely locked for all operating and test conditions specified herein.

3.1.2.3 Thrustor Life

3.1.2.3.1 Operating Life. The thrustor shall satisfy all requirements, when operating throughout the conditions specified in Sections 3.1.1.2.1 and 3.1.1.2.2 over an accumulated number of 250,000 starts and an accumulated burning time of 3.7 by 10^4 hours. Firing durations shall range from 1 to 180 minutes. The thrustor shall operate in any attitude and random gravity field between 0 and 1g.

3.1.2.3.2 Service Life. All specified performance requirements for the thrustor shall be met after 10 years of continuous exposure to the propellants specified in Section 3.3.3.2 and throughout a temperature range of 278 to 322°K (40°F to 120°F) when pressurized to the operating pressure of Paragraph 3.1.1.2.1.1.

3.1.2.4 Environmental

The thrustor shall function in accordance with all the requirements of this specification after being subjected to the environmental conditions in the following paragraphs. The environments are to be considered independently as well as in any combinations specified in Paragraphs 3.1.2.4.1.1, 3.1.2.4.12, 3.1.2.4.1.4, and 3.1.2.4.3.

3.1.2.4.1 Vibration, Shock, and Acoustics

3.1.2.4.1.1 Random Vibration. The thrustor shall withstand a random vibration excitation for 3 minutes along each of the three mutually perpendicular principal axes. The random vibrations shall have an approximate Gaussian amplitude distribution and a peak-to-rms ratio of at least three. The excitation shall be applied over the frequency interval from TBD to TBD as follows: TBD.

3.1.2.4.1.2 Shock (Launch). The thrustor shall withstand transient shock loading approximated by TBD, applied along the three principal orthogonal axes of the thrustor, with an initial peak value of TBD g and a damping of 1 percent.

3.1.2.4.1.3 Shock (On-Orbit). The thrustor shall withstand omnidirectional shock as defined by the shock spectrum resulting from a TBD g, TBD millisecond terminal peak sawtooth pulse. Responses at frequencies less than TBD Hz need not be considered.

3.1.2.4.1.4 Acoustics. The thrustor shall withstand a random noise environment with an overall sound pressure level (spl) of TBD db for 3 minutes. The random noise shall have an approximate Gaussian amplitude distribution and a peak-to-rms ratio of three or more. The overall spl shall have a spectrum shape, as measured with octave band filters, over the frequency range from 37.5 to 9600 Hz as follows: TBD.

3.1.2.4.2 Vacuum. The thrustor shall be capable of satisfying the requirements of this specification when exposed to a pressure of 10^{-7} mm Hg or less during its service life specified in Paragraph 3.1.2.3.2.

3.1.2.4.3 Acceleration. The thrustor shall withstand zero to TBD g constant acceleration for two minutes in either direction along each of the three principal orthogonal axes.

3.1.2.4.4 External Environmental Operating Temperature. The thrustor shall operate in an external space environment which will subject it to temperatures of TBD to TBD °K during its service life specified in Paragraph 3.1.2.3.2.

3.1.2.4.5 Nonoperating.

3.1.2.4.5.1 Sand and Dust. The thrustor shall be capable of withstanding exposure to windblown sand and dust equivalent to exposure for 6 hours in a sand and dust chamber as described in Method 510.1 of MIL-STD-810 without failure or degradation of performance. This requirement shall be met with all ports capped.

3.1.2.4.5.2 Temperature. The thrustor shall be capable of withstanding a nonoperating temperature range of 211 to 345°K (-80° to +160°F) for shipping, handling, and storage without failure or degradation of performance.

3.1.2.4.5.3 Bench Handling Shock. During handling, the unpackaged thrustor shall be capable of withstanding the shock derived from a pivot drop of 4 inches or 45 degrees on any face on which the thrustor could be placed without failure or degradation of performance.

3.1.2.6 Transportability

The normal modes of transportation to be considered shall include air, rail, and truck.

3.1.2.6.1 Vibration (Transportation). The packaged thrustor shall withstand a sinusoidal vibration spectrum in accordance with Figure 11 without failure or degradation of performance.

3.1.2.6.2 Shock (Transportation). The thrustor shall be packaged to withstand the transportation shock levels given in Table 4 and handling shocks resulting from loading and unloading drops as indicated in Table 5 without failure or degradation of performance.

3.1.2.6.3 Altitude (Transportation). The thrustor shall be capable of meeting the performance requirements of this specification after being shipped by air at an altitude of 15,020 m (50,000 ft) for eight hours.

3.1.2.7 Human Performance

Not applicable.

3.1.2.8 Safety

The thrustor shall be designed for inherent safety through the selection of appropriate design features and proven qualified components, materials, processes, and operating principles. Identified Class III and Class IV

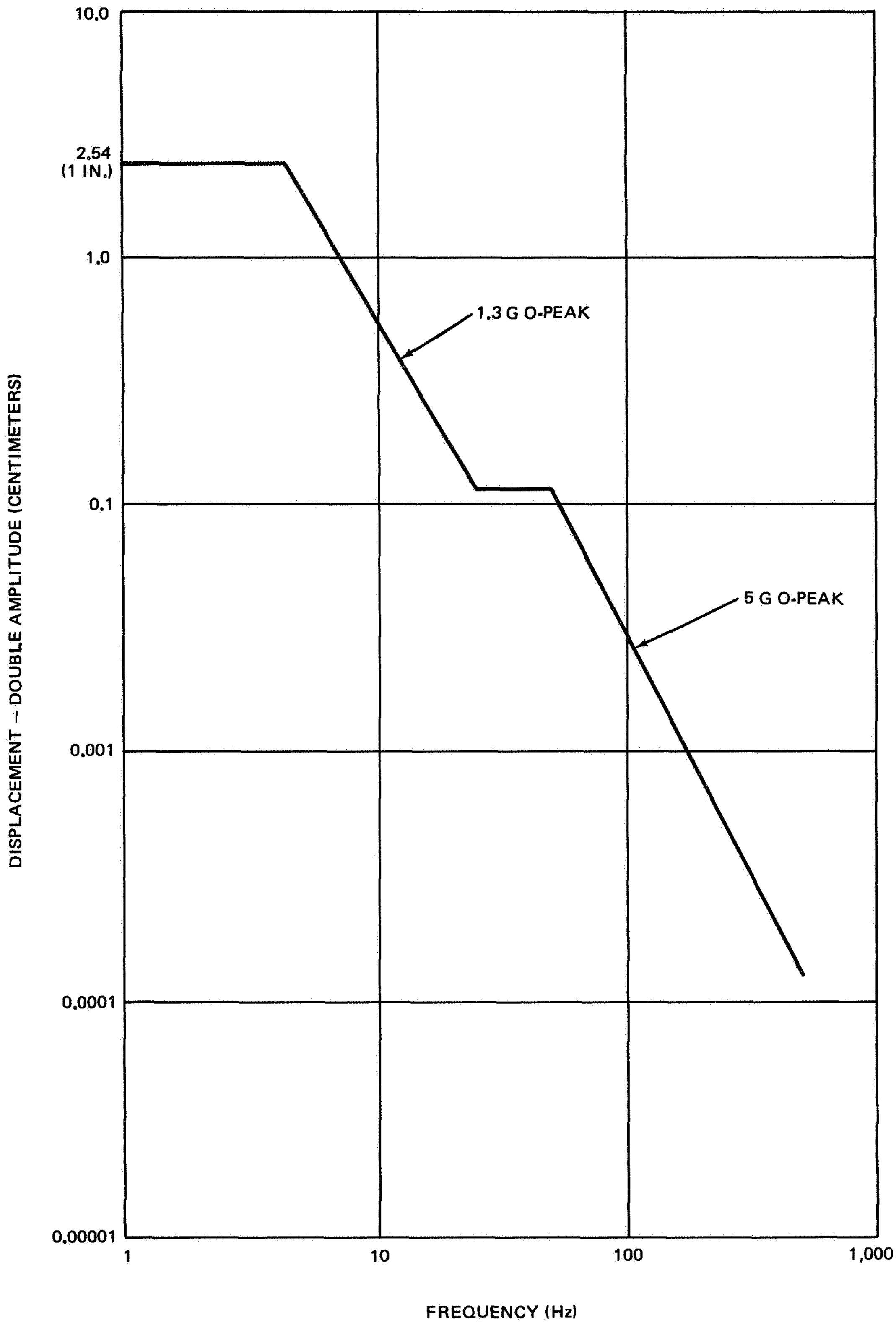


Figure 11. Sinusoidal Vibration Levels for Equipment Transported by Common Carrier

Table 4

AVERAGE SHOCK LEVELS IN G's EXPERIENCED DURING TRANSPORTATION

Shock Environment	Gross Weight Shipping Configuration	Mode of Transportation				
			Truck			
		Rail	Improved Road	Rough Road	Cargo Aircraft	Cargo Vessel
	0 to 113 kg (0 to 250 lb)	65 (max)	10		8	1.5
	Duration (milliseconds)	10 to 50	8 to 40		0.8 to 40	0 to 40

Table 5

HANDLING SHOCK LEVELS

Gross Weight Not Exceeding	Dimensions on Any Edge or Diameter Not Exceeding	Free-Fall Cornerwise Drop Test (Height of Drop)	Edgewise Rotational Drop Test (Height of Drop)	Cornerwise Rotational Drop Test (Height of Drop)	Incline Impact Test (Impact Velocity)
Kilogram	Meters	Meters	Meters	Meters	m/s
22.7 (50 lb)	0.914 (36 in.)	0.558 (22 in.)	TBD	TBD	TBD

hazards (Paragraph 3.2.6.2.1, System Failure Hazard Classification, of MIL-S-38130) shall be reduced or eliminated through design optimization.

3.1.2.8.1 Flight Safety. The thrustor shall perform safely for the required number of cycles and under the operating conditions specified herein. Each thrustor shall be capable of performing in a safe, stable, and reliable manner.

3.1.2.8.2 Ground Safety. The valve shall be designed to prevent incorrect installation.

3.1.2.8.3 Nuclear Safety. Not applicable.

3.1.2.8.4 Personnel Safety. Personnel safety provisions shall be made in addition to following standard industrial safety practices.

3.1.2.8.5 Explosive or Ordnance Safety

3.1.2.8.5.1 Electrical. All electrical devices shall be made ignition-proof in accordance with MIL-STD-810, Method 511.1. Electrical components shall not provide an ignition source for the explosive mixture of hydrocarbons of 1 to 6 percent of fuel (by weight) in the air.

3.2 COMPONENT DEFINITION

3.2.1 Interface Requirements

3.2.1.1 Schematic Arrangement

The electrical schematic of the valve shall be in accordance with (TBD by contractor).

3.2.1.2 Detailed Interface Definition

3.2.2 Mechanical. (TBD by the contractor)

3.2.3 Electrical. (TBD by the contractor)

3.3 DESIGN AND CONSTRUCTION

3.3.1 General Design Features

The thrustor shall be designed and constructed so that all requirements of this specification shall be met.

3.3.1.1 Envelope Dimensions

The overall dimensions of the thrustor shall be within the limits specified (TBD by the contractor).

3.3.1.2 Weight

The weight of the thrustor shall be the minimum weight attainable without degradation of performance or reliability.

3.3.1.3 Thrust Misalignment

The geometric thrust vector shall be within .00436 rad (0.25 deg) of the normal to the plane of the thrustor mounting flange.

3.3.1.4 Attitude

The thrustor shall be operable in any attitude under Earth-gravitational or space-on-orbit random gravitation field of zero to 1g.

3.3.1.5 Threads

All threads shall be in accordance with MIL-S-7742 or MIL-S-8879.

3.3.1.6 Wrench Holding Surfaces

Wrench holding surfaces or other methods shall be provided where required for assembly or disassembly of the thrustor and attachment of associated fittings. If wrench flats are provided, the height of the flat shall be determined by the amount of applied force and shall be sufficient to prevent the flat from being damaged.

3.3.2 Selection of Specifications and Standards

Specifications and standards for the identification and control of materials, parts, and processes of the thrustor shall be selected in accordance with MIL-STD-143. Only those documents listed in ANA Bulletin 400 shall be interpreted as Group I in accordance with MIL-STD-143. Government agency specifications and standards other than those listed in the ANA Bulletin shall be interpreted as Group III in accordance with MIL-STD-143. All specifications and standards other than those established and approved for use by the NASA must be approved by LaRC prior to incorporation into the thrustor specification.

3.3.3 Materials, Parts, and Processes

All materials, parts, and processes shall be compatible with the performance and environmental criteria for the thrustor. Manufacturing processes and associated materials used on off-the-shelf hardware or hardware previously developed on other Government contracts shall be acceptable provided the hardware meets all other requirements of this specification.

3.3.3.1 Lockwire

Lockwire used for securing parts or adjustments shall conform to MS 20995. The method for installation shall be in accordance with MS 33540.

3.3.3.2 Propellants

The thrustor(s) shall be compatible with the gaseous biowaste CO_2 and CH_4 generated by the environmental control and life support system and with distilled water used as a propellant supplement. For the purpose of this specification, commercial grades of the gaseous propellants shall be used.

3.3.3.2.1 Carbon Dioxide. Carbon Dioxide shall be in accordance with commerical grade, 99.5 percent CO_2.

3.3.3.2.2 Methane. Methane shall be in accordance with C.P. Grade, 99.1 percent CH_4.

3.3.3.2.3 Water (H_2O Vapor) -1 Configuration Only. Water shall be distilled, deionized, and filtered through a filter of a minimum size of 10 microns, and shall be vaporized prior to injection in the -1 configuration.

3.3.3.2.4 Water (H_2O Liquid) -501 Configuration Only. Water shall be distilled, deionized, and filtered through filter of a minimum size of 10 microns'.

3.3.3.3 Insulation

3.3.3.3.1 Insulation Resistance. The insulation resistance shall be greater than 100 megohms at 500 ±50 volts dc when measured between all insulated points and the thrustor case at 295 ±5.56°K (70 ±10°F).

3.3.3.4 Dielectric Strength

Insulation shall withstand a potential of 1000 volts alternating current rms at 60 Hz applied for 1 minute between all insulated points. The leakage current shall not exceed 200 microamperes when measured between insulated points and the thrustor case at 295 ±5.56°K (70 ±10°F).

3.3.3.5 Wiring

Electrical wiring between the receptacle and internal electrical components shall be in accordance with MIL-W-16878.

3.3.3.6 Castings

Castings shall be in accordance with MIL-C-6021, Class 1A Grade B.

3.3.3.7 Forgings

Forgings shall be in accordance with MIL-F-7190.

3.3.3.8 Metals

All metals except electrical contact materials shall be corrosion-resistant or suitably protected to prevent corrosion during the specified service life and storage life.

3.3.3.8.1 Nonferrous. Nonferrous materials shall be used for all metallic parts of the thrustor except where ferrous materials are essential.

3.3.3.8.2 Nonmagnetic. Nonmagnetic metals shall be used for all metallic parts of the thrustor except where magnetic metals are essential.

3.3.3.9 Nonmetallic Parts

Nonmetallic parts shall not have a corrosive or corrosion-inducing effect on other materials when exposed to conditions normally encountered in service. Fungus nutrient materials shall not be used unless absolutely necessary. Fungus nutrient materials, when used, shall be treated in accordance with MIL-T-152.

3.3.3.10 Lubricants

The use of lubricants and sealants shall be kept to a minimum. Lubricants and sealants used shall be submitted to LaRC for approval and be shown on the assembly drawing after approval.

3.3.3.11 Welding Corrosion Resistant Steel

Welding shall be done in accordance with MIL-W-8611 or LaRC-approved equivalent. Radiographing shall be performed in accordance with MIL-STD-453, and inspection as per MIL-R-45774, Class III or LaRC approved equivalent.

3.3.3.12 Finish

3.3.3.12.1 Corrosion Resistant Steel. Corrosion resistant steels shall be passivated in accordance with MIL-S-5002 or LaRC approved equivalent.

3.3.3.12.2 Aluminum Alloy. Aluminum alloy parts shall be anodically treated, externally, in accordance with MIL-A-8625 or LaRC approved equivalent or finished in accordance with MIL-C-5541.

3.3.3.12.3 Plating. No cadmium or zinc plating shall be used on any components.

3.3.3.13 Protective Treatment

Materials that are subject to deterioration when exposed to climatic and environmental conditions likely to occur in service shall be protected against such deterioration in a manner that will in no way prevent compliance with the performance requirements of this specification. Protective coatings that will chip, crack, or scale with age or in the extremes of climatic and environmental conditions specified herein shall not be used.

3.3.3.14 Processing

All surfaces in contact with the propellants shall be processed at a LaRC approved certified source.

3.3.3.15 Soldering

Soldering shall be in accordance with MIL-STD-454, Requirement 5.

3.3.4 Standard and Commercial Parts

Standard parts and components shall be used whenever they are suitable for the purpose and shall be identified by part number where practical. Commercial utility parts, such as screws, bolts, nuts, and cotterpins, may be used providing they have suitable properties and are replaceable by a standard part without alteration. In an application for which no suitable standard parts or components are available on the date of the invitation for bids, commercial parts and components may be used provided they conform to the requirements of this specification.

3.3.5 Moisture and Fungus Resistance

3.3.5.1 Humidity

The thrustor shall be capable of withstanding the requirements of Method 507.1 of MIL-STD-810 without failure or degradation of performance.

3.3.5.2 Fungus

The thrustor shall be capable of withstanding the requirements of Method 508.1 of MIL-STD-810 without failure or degradation of performance.

3.3.6 Corrosion and Metal Parts

Metallic parts shall not have corrosive or corrosion-inducing effects resulting in degradation of their function when exposed to conditions normally encountered in service.

3.3.6.1 Salt Fog

The thrustor shall be capable of withstanding the requirements of Method 509.1 of MIL-STD-810 except that a 20 percent (by weight) salt spray solution shall be used rather than a 5 percent solution for a period of not less than 50 hours without failure or degradation of performance.

3.3.7 Interchangeability and Replaceability

Interchangeability and replaceability shall be as defined in MIL-STD-447. Maximum use shall be made of common parts such as valves in which one unit or component can be utilized for several functions. Connectors, fasteners, piping, tubing, and other items shall be designed so that satisfactory interchangeability can be accomplished for many of them.

3.3.8 Workmanship

Workmanship shall be as required to meet the design and performance requirements specified in this document.

3.3.9 Electromagnetic Interference

The design requirements incorporated to ensure electromagnetic compatibility shall be in general accordance with MIL-1-6181 and MIL-STD-461A for electromagnetic interference and susceptibility, and with MIL-B-5087 for electrical bonding. Electrical cables shall be routed, grouped, and spaced to minimize electromagnetic incompatibilities. Sensitive electrical circuits shall be shielded and the shields grounded in a manner to eliminate interference from and susceptibility to the shielded conductor; the grounding arrangement shall be adequate for direct current audio, and radio frequency circuits. The design shall be suitable to tolerate the electromagnetic environment imposed by the Space Station program in accordance with MIL-E-6051.

3.3.10 Identification and Marking

3.3.10.1 Identification

Electrical wire and cables shall be identified in accordance with Paragraph 3.9.3, Wire and Cable Identification, Subparagraphs C, D, E, F1, and F3 of MIL-W-5088. Where imprinted identification cannot be affixed, identification shall be established on the Interface Control Drawing,

3.3.10.2 Serialization

Each thrustor shall have a different serial number. Gaps in serial number sequence are permissible, but the serial number order must conform to the release for production.

3.3.11 Storage

Storage, preservation, and packaging procedures shall be in accordance with TBD LaRC specification.

3.3.11.1 Packaged

The thrustor, as received by LaRC in its shipping container, shall be in accordance with TBD LaRC specification.

3.3.11.2 Unpackaged

The thrustor, when removed from its shipping container, shall meet all the requirements of this specification for the service life specified in Paragraph 3.1.2.3.2.

Section 4

QUALITY ASSURANCE PROVISIONS

4.1 GROUND DEVELOPMENT TEST PROGRAM

The ground development testing program shall consist of engineering tests and evaluation. The ground development test program is performed to provide the confidence that the thrustor can meet the requirements set forth in Section 3 of this specification in qualification tests. If comparable development or qualification tests have been successfully completed on an item of similar design, certified results of tests which demonstrate compliance with the requirements of this document shall be submitted for approval. Approval of the certified test results by LaRC will negate the requirements for performing the tests. The ground test plan shall be submitted to and approved by LaRC prior to the start of any tests.

LaRC shall reserve the option of providing representation to observe and furnish recommendations regarding any and all phases of the design, testing, and manufacture of this thrustor. LaRC will indicate activities they wish to observe. The contractor shall give timely notification of time and place of the occurrence of the activity.

The contractor shall furnish to LaRC at the specified times various test documents and reports pertaining to quality assurance. Each of these documents shall contain the following essential information as applicable, as well as any other pertinent data.

A. Test Agency Approval. Test facilities or agencies employed for conducting the tests specified herein shall require prior approval by LaRC.

B. Test Specimens. The test specimens selected for evaluation tests by the contractor shall be prototype production articles fabricated from materials, methods, processes, tooling, and components easily convertible to production methods. Acceptance test and quality control procedures shall be employed. The configuration of all test specimens shall be verified by the contractor. Each test article shall be permanently identified by numbers or letters to permit identification of individual specimens. After completion of testing, all test specimens shall be held in bonded storage until LaRC provides direction for disposition.

C. Test Equipment. The contractor's test equipment description shall provide the following minimum information:

1. Descriptive name.
2. Manufacturer's name.
3. Manufacturer's model number.
4. Serial number.
5. Range and accuracy.
6. Frequency of calibration.
7. Date of last calibration.

D. Automatic Recording Equipment. Automatic recording equipment of adequate response shall be used to obtain data during conditions of thrustor operation required for the evaluation of thrustor operation.

E. Cleanliness. The thrustor shall be cleaned before testing unless previously cleaned and packaged at a certified source, in accordance with TBD (LaRC cleaning specification).

F. Test Media

The following propellants shall be utilized in the development of the thrustor:

1. Carbon Dioxide, in accordance with Commercial Grade, 99.5 percent CO_2, as specified in Paragraph 3.3.3.2.1.
2. Methane, in accordance with C.P. Grade, 99.1 percent CH_4 as specified in Paragraph 3.3.3.2.2.
3. Water (liquid or vapor) distilled, deionized, 10-micron filtered, as specified in Paragraphs 3.3.3.2.3 and 3.3.3.2.4.

G. Ambient Atmospheric Conditions. Tests shall be made at local atmospheric conditions, except for specified operational and environmental tests required to demonstrate compliance with design requirements.

H. Environmental Testing Tolerances. The maximum allowable tolerances on environmental test conditions, exclusive of instrumentation tolerances, shall be as follows unless otherwise specified:

1. Altitude TBD by the contractor.

2. Shock, ± 10 percent.

3. Vibration amplitude, ±1.5 db when measured with a 50 Hz or narrower filter, from 10 to 500 Hz and ±3 db from 500 to 2,000 Hz.

4. Relative humidity, ±6 percent.

5. Sound pressure level, $^{+10}_{-0}$ db (1/3 octave bands).

6. Acceleration, ±10 percent.

7. Static pressure ±3 percent.

I. Calibration. Each instrument and other apparatus upon which the accuracy of test results depends shall be periodically calibrated in accordance with (TBD by the contractor) to guarantee data acquisition system accuracy of ±2 percent of the specified steady-state value of the measurement. Calibration records shall be maintained and shall be made available to representatives of LaRC upon request.

J. Temperature Stabilization. Temperature stabilization shall be defined as the state at which further temperature change is at a rate of no greater than 1.2°K per minute for a continuous time period of not less than 3 minutes.

K. Test Documentation. Test documentation shall be in accordance with MIL-STD-831.

L. Operating Time. All operating time shall be recorded in the log book.

M. Test Fixture and Instrumentation. During any test which requires operation of the thrustor, the unit shall be installed in a suitable test fixture. Instrumentation shall be provided for measurement and recording, as applicable, of:

1. Input current.

2. Input voltage.

3. Inlet pressure.
4. Flow rate.
5. Thrust.
6. Temperature.
7. Test cell pressure.

4.2 ENGINEERING TEST AND EVALUATION (DEVELOPMENT TESTS)

Demonstration and evaluation tests (development tests) shall be conducted to determine design feasibility, functional characteristics, technological data, and to verify assembly and fabrication techniques. The tests shall be oriented (1) to verify that the design requirements of Section 3 have been met, (2) to indicate critical areas where design improvements are required, and (3) to demonstrate that the thrustor will be capable of successfully passing qualification. Primary failure modes and critical environments shall be identified. When deficiencies are found, corrective action, which may include retest, shall be implemented.

4.2.1 Definition: Demonstration Test

Demonstration tests shall be performed utilizing prototype hardware. The purpose of demonstration tests is to determine functional characteristics, technological data, and environmental limitations of the thrustor for design evaluation purposes. These tests shall identify failure modes and critical environments and shall ultimately demonstrate sufficient confidence in the design to commit the thrustor to evaluation testing.

4.2.2 Definition: Evaluation Tests

These tests shall determine if the thrustor complies with requirements and shall ultimately demonstrate sufficient confidence in the design to commit the thrustor to qualification testing. Thrustors used during these tests shall be prototypes of production hardware.

4.2.3 Requirements

4.2.3.1 Outline of Test Program Plan. The contractor shall submit to LaRC the test program outline based on the pertinent requirements specified in Sections 3 and 4 of this document, with the final outline submitted not later than 30 days after ATP. The detailed test program plan shall describe the test methods and procedures and give a summary of the objectives of proposed tests and shall be submitted for approval to LaRC prior to the tests. The data developed by these tests should supply LaRC with all needed information to evaluate the design suitability and performance capability of the thrustor, within the limits of the ground testing program.

The test plan shall include but not be limited to all phases of test procedures and methods to be used from selection of materials and components through the various stages of assembly up to and including the testing of prototype units. In particular, the test plan shall include:

A. The number of thrustors to be tested.

B. The sequence of tests.

C. Description of all test apparatus.

D. Instrument calibration data, including accuracy figures.

E. Description of facilities to be used for testing.

F. Response of automatic recording equipment, if used.

4.2.3.2 Report of Development Tests. Within 30 days following completion of the tests, a factual, detailed report conforming to the requirements set forth in this section and containing all pertinent test data shall be furnished to LaRC by the contractor. The report shall include but not be limited to the following: (1) complete records of the tests including data sheets, (2) performance curves, (3) chronological test log, (4) schematic drawings, if applicable, (5) photographs, (6) inspection reports and all other significant data. The report shall be signed by a responsible officer of the contracting firm or a representative authorized to sign for him. MIL-E-5151 and MIL-T-9107 shall be used as guides.

4.2.3.3 Primary Test Objective. As a minimum, the proposed thrustor development program shall include satisfactory verification of the following requirements by tests:

Paragraph	Requirement
3.1.1.1	Primary Performance
3.1.1.2	Secondary Performance
3.1.2.3.1	Operating Life
3.1.2.4.1.1	Random Vibration
3.1.2.4.1.2	Shock

All other requirements in Section 3 shall be verified by either analysis or inspection of the prototype design.

Section 5
PREPARATION FOR DELIVERY

Not applicable.

Section 6
NOTES

Hz	Cycles per second
db	Decibels
°K	Degrees Kelvin
°F	Degrees Fahrenheit
g	Standard acceleration due to gravity, 9.85 m/sec^2 or 32.174 ft/sec^2
N/m^2	Newton per square meter
psia	Pounds per square inch absolute
rms	Root mean square
rss	Root sum square
spl	Sound pressure level
N	Newton
lbf	Pound force
kg	Kilogram
lbm	Pound mass
scch	Standard cubic centimeters per hour
sccm	Standard cubic centimeters per minute
mm Hg	Millimeters of mercury
vdc	Volts, direct current
vac	Volts, alternating current
sec	Second
kg m	Kilogram-meter
TBD	To Be Determined

APPENDIX B

COMPONENTS AND ASSEMBLIES - TEST REQUIREMENTS

TEST REQUIREMENT SUMMARY

Title: Resistojet Thrustor Assembly

Brief Description: CO_2 and CH_4 thrustor consisting of heater and chamber, inlet valve and filter, and instrumentation. The thrustor shall also operate with superheated water vapor.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical and mechanical		X				X	
Proof	414×10^4 N/m^2 @ operating temperature			X	X		X	
Burst	828×10^4 N/m^2 @ operating temperature			X	X		X	
Pressurization Cycles	Part of life/cycle tests			X		X		
Mechanical Properties	Material Evaluation			X	X		X	
Temperature	278 to 311°K	X	X	X		X		
Leakage	TBD							
Vibration and shock	TBD							
Zero-g								
Electro-magnetic Interference	Generated and Susceptibility		X			X		
Performance	Specific impulse, flow (ΔP)	X	X	X		X		X
Life/Cycles	250, 000 cycles, 3.7×10^4 hours firing (goal)		X			X		
Response	Repeatibility		X			X		
Off-Limit	No permanent degradation		X			X		X
Propellant Expulsion	10 years (test and analysis)	X	X	X			X	
Continuous Operation	Valve, electrical			X				

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

TEST REQUIREMENT SUMMARY

Title: Water Vaporizer

Brief Description: Independent water vaporizer provides H_2O vapor to the common biowaste resistojet thrustor.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical		X			X		
Proof	414×10^4 N/m^2 operating temperature			X	X		X	
Burst	828×10^4 N/m^2 operating temperature			X	X		X	
Pressurization Cycles								
Mechanical Properties	Material evaluation			X	X		X	
Temperature	278 to 311 °K inlet	X	X	X		X		
Leakage	TBD		X				X	
Vibration and Shock	TBD		X				X	
Zero-g	Performance/flow (no liquid at outlet)		X			X		
Electro-magnetic Interference	Generation					X		
Performance	Transient and steady heat flux, flow, etc. (zero-g)		X			X		
Life-Cycles	2 years or greater/50,000 cycles							
Response	Heating transients (zero-g) repeatibility		X			X		
Off-Limit	No permanent degradation (zero-g)					X		
Propellant Expulsion	10 years (test and analysis)	X	X	X			X	
Continuous Operation								

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.
3. Zero-g development tests are mandatory to verify satisfactory operational requirements characteristics.

TEST REQUIREMENT SUMMARY

Title: Compressor Assembly

Brief Description: High-compression-ratio compressor assemblies used to compress CO_2 and CH_4 provided by the EC/LS equipment.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical and mechanical		X			X	X	
Proof	414×10^4 N/m^2		X		X		X	
Burst	828×10^4 N/m^2		X		X		X	
Pressurization Cycles	TBD		X				X	
Mechanical Properties								
Temperature	278 to 311 °K	X	X	X		X		
Leakage	TBD		X		X		X	
Vibration and Shock	TBD		X		X		X	
Zero-g								
Electromagnetic Interference	Generation		X			X		
Performance	Compressor Characteristics (10:1 CO_2, 20:1 CH_4)	X	X	X		X		
Life-Cycles	2 years or greater/TBD					X		
Response	Start transients		X			X		
Off-Limit	No permanent degradation		X			X		
Propellant Expulsion	10 years (test and analysis)	X	X	X			X	
Continuous Operation	TBD Hr			X		X		

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

TEST REQUIREMENT SUMMARY

Title: Water Expulsion Tank Assembly

Brief Description: Positive expulsion H_2O storage and supply tankage for water supplement capability.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Expulsion		X				X	
Proof	69×10^4 N/m^2		X		X		X	
Burst	138 to 10^4 N/m^2		X		X		X	
Pressurization Cycles	Shell only (1000 cycles)		X		X	X		X
Mechanical Properties	Expulsion device (evaluation)	X	X	X		X		
Temperature	278 to 311 °K	X	X	X		X		
Leakage	TBD		X			X		
Vibration and Shock	TBD		X		X	X		
Zero-g								
Electro-magnetic Interference								
Performance	Expulsion characteristics (flow/ΔP)	X	X	X		X		X
Life/Cycles	100 expulsion cycles		X			X		X
Response								
Off-Limit								
Propellant Expulsion	10 years (test and analysis)	X	X	X			X	
Continuous Operation								

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.
3. Zero-g or negative one-g demonstration required.

TEST REQUIREMENT SUMMARY

Title: Pressure Regulator

Brief Description: CO_2 and CH_4 resistojet inlet supply pressure control.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Regulation		X			X		
Proof	414×10^4 N/m^2		X		X		X	
Burst	828 to 10^4 N/m^2		X		X		X	
Pressurization Cycles	Part of life/cycle tests		X			X		
Mechanical Properties								
Temperature	278 to 311°K	X	X	X		X		
Leakage	TBD		X				X	
Vibration and Shock	TBD		X		X		X	
Zero-g								
Electromagnetic Interference								
Performance	Regulator characteristics (flow, ΔP)	X	X	X		X		
Life/Cycles	Simulated duty cycle, 2 years or greater		X			X		X
Response								
Off-Limit	No permanent degradation and nominal loss of performance	X	X	X		X		
Propellant Expulsion	10 years (test and analysis)	X	X	X		X		
Continuous Operation								

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

TEST REQUIREMENT SUMMARY

Title: Isolation Valve - Latching

Brief Description: System control valves for various CO_2, CH_4, and H_2O usages (isolation, control, switching, etc.).

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical and mechanical		X			X		
Proof	414×10^4 N/m^2		X		X		X	
Burst	828 to 10^4 N/m^2		X		X		X	
Pressurization Cycles	10,000		X		X		X	
Mechanical Properties								
Temperature	278 to 311°K	X	X	X		X		
Leakage	TBD	X	X	X			X	
Vibration and Shock	TBD		X				X	
Zero-g								
Electromagnetic Interference	Generated and susceptibility					X		
Performance								
Life/Cycles	2 years or greater/500,000 cycles(goal)		X			X		X
Response	100 milliseconds or less (repeatibility)	X	X	X		X		
Off-Limit	No permanent degradation	X	X	X		X		
Propellant Expulsion	10 years (test and analysis)	X	X	X			X	
Continuous Operation	Electrical power applied		X				X	

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

TEST REQUIREMENT SUMMARY

Title: Power Conditioning Unit

Brief Description: Power switch, current regulator, current sensor, comparator to control thrustor heater power requirements.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical		X				X	
Proof								
Burst								
Pressurization Cycles								
Mechanical Properties								
Temperature	278 to 311 °K	X	X	X		X		
Leakage								
Vibration and Shock	TBD		X				X	
Zero-g								
Electromagnetic Interference	Generation and susceptibility		X			X		
Performance	Regulation and control ± 2 percent		X			X		X
Life/Cycles	3.7 x 10^4 hours (goal), 250,000 cycles		X			X		X
Response	Repeatibility		X			X		
Off-Limit	High voltage		X			X		X
Propellant Expulsion								
Continuous Operation	Applied voltage, 3.7 x 10^4 hours (goal)		X			X		
Vacuum	No performance degradation		X			X		

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

TEST REQUIREMENT SUMMARY

Title: Switching Assembly

Brief Description: Power switches to control thrustor valve, compressors, etc.

TEST REQUIREMENTS MATRIX:

Test	Remarks	Low Temperature	Room Temperature	High Temperature	Structural	Operating	Nonoperating	Repeat Cycle
Functional	Electrical continuity, resistance, etc.		X				X	
Proof								
Burst								
Pressurization Cycles								
Mechanical Properties								
Temperature	278 to 311 °K	X	X	X		X		
Leakage								
Vibration and Shock	TBD		X				X	
Zero-g								
Electromagnetic Interference	Generation and susceptibility		X			X		
Performance								
Life/Cycles	250, 000 off-on-off cycle		X			X		X
Response	Repeatibility		X			X		
Off-Limit	High-voltage - no degradation of performance		X			X		
Propellant Expulsion								
Continuous Operation								
Vacuum	Electrical		X			X		

Notes:

1. All components receive pre and post test.
2. Functional includes, where applicable, electrical and mechanical test of performance characteristics.

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS
CORPORATION

5301 Bolsa Avenue, Huntington Beach, CA 92647