N93-26974

NEP POWER SUBSYSTEM MODELING

Nuclear Propulsion Technical Interchange Meeting

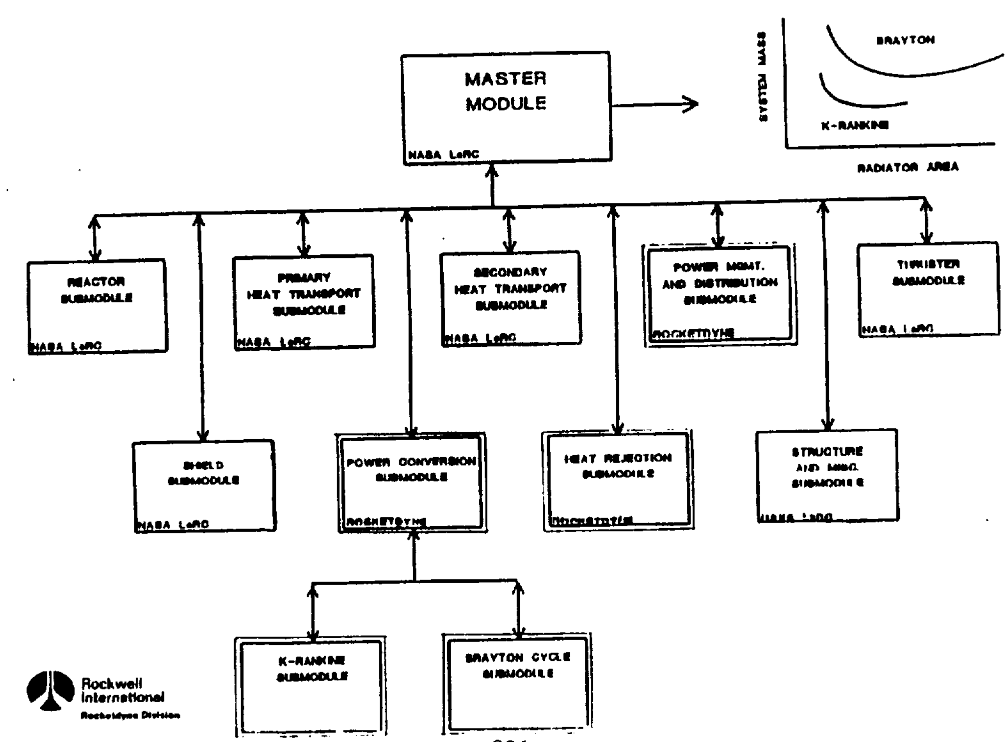
October 20-23, 1992

NASA-Lewis Research Center
Plum Brook Station

Rockwell International
Rocketdyne Division

The Nuclear Electric Propulsion (NEP) system optimization code consists of a master module and various submodules. Each of the submodules represents a subsystem within the total NEP power system. The master module sends commands and input data to each of the submodules and receives output data back. Rocketdyne was responsible for preparing submodules for the power conversion (both K-Rankine and Brayton), heat rejection, and power management and distribution.

NEP SYSTEM OPTIMIZATION CODE



Rockwell International
Rocketdyne Division

The basic objective of each task was to perform detail performance modeling for selected subsystems of an NEP system. The output of each task is software (computer disk) and a users manual providing a detailed model description, limitations, assumptions, and inputs and outputs.

TASK ORDER OBJECTIVES AND OUTPUT

TASK OBJECTIVES

- CHARACTERIZE AND PERFORM DETAILED MODELING OF SELECT SUBSYSTEMS FOR A NUCLEAR ELECTRIC PROPULSION SYSTEM
  - POWER CONVERSION
    - LIQUID METAL RANKINE
    - GAS COOLED BRAYTON
  - HEAT REJECTION
  - POWER PROCESSING AND DISTRIBUTION

TASK OUTPUT

- SOFTWARE AND USERS MANUAL DESCRIBING DETAILED MODELS USED
- SUFFICIENT DETAIL TO PROVIDE THE FOLLOWING ON THE COMPONENT AND SUBSYSTEM LEVEL
  - MASS
  - PERFORMANCE
  - DIMENSIONS
  - PHYSICAL OPERATING CONDITIONS
  - RELIABILITY

C-4

GROUND RULES AND REQUIREMENTS

GENERAL
- POWER LEVEL RANGE - 100 kWe TO 10 MWe
- OPERATING LIFETIME - 2 TO 10 YEARS
- OPERATING ENVIRONMENT - LOW EARTH ORBIT TO INTERPLANETARY SPACE
- TECHNOLOGY TIME FRAME - 2005 TO 2020

K-RANKINE
- TURBINE INLET TEMPERATURE - 800 TO 1500 K
- TEMPERATURE RATIO - 1.25 TO 1.6
- TURBINE TYPE - AXIAL FLOW
- WORKING FLUID - POTASSIUM

BRAYTON
- TURBINE INLET TEMPERATURE - 1200 TO 1500 K
- TEMPERATURE - 2.5 TO 4.0
- TURBINE TYPE - AXIAL AND RADIAL FLOW
- WORKING FLUID - He AND HeXe

HEAT REJECTION
- TEMPERATURE RANGE - 750 TO 1250 K (K-RANKINE), 300 TO 1000 K (BRAYTON)
- RADIATOR TYPE - HEAT PIPE
- HEAT PIPE WORKING FLUIDS - NH_3, H_2O, Hg, K, Na, Li
- GEOMETRY - FLAT, CYLINDRICAL, CONICAL

POWER PROCESSING AND TRANSMISSION
- TRANSMISSION LENGTHS - 25 TO 300M
- VOLTAGE LEVEL - 200 TO 10,000 VOLTS
- AC FREQUENCY RANGE - 100 Hz TO 20 kHz
- COLD PLATE TEMPERATURE - 60 TO 200°C

Rockwell International
Rocketdyne Division

The facing page lists the key ground rules and requirements for each task. The values were agreed to with NASA. The values represent the applicable range of interest and range of the current data base.

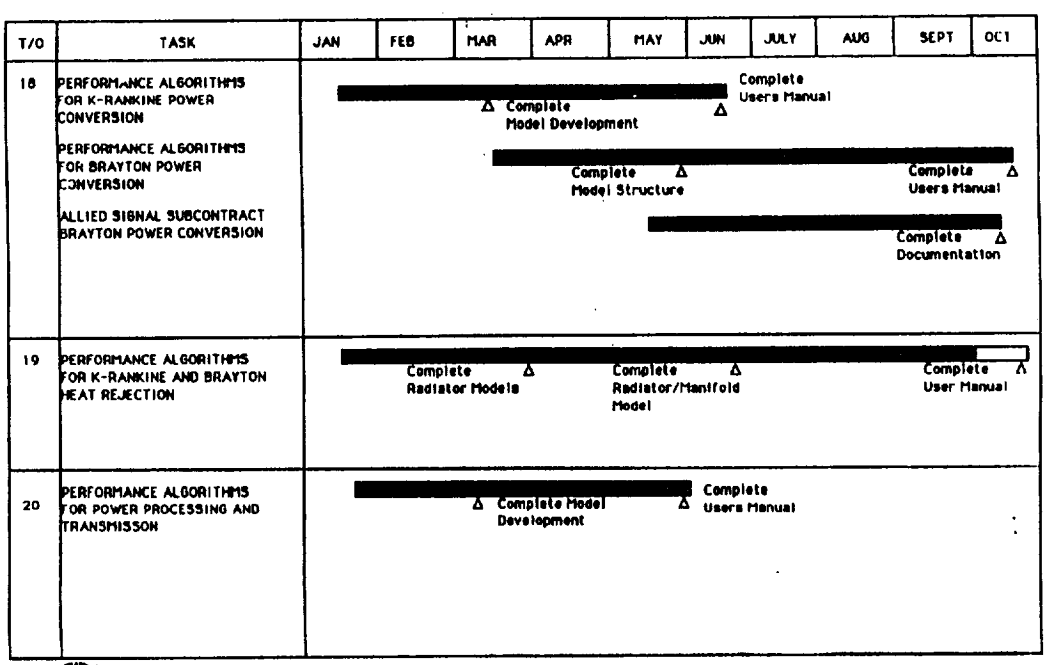
The models being developed are based on first principles. Where this is not possible such as heat transfer coefficients and aerodynamic efficiencies, algorithms are used to describe these parameters. Using first principals provides a great deal of flexibility for the user. The user, however, must be knowledgeable in the particular component being modeled. Default values are provided to aid the user in establishing realistic initial values.

MODULE ARCHITECTURE CHARACTERISTICS

- BASED ON FIRST PRINCIPLES WITH SOME EMPERICAL CORRELATIONS
- STEADY-STATE DESIGN CODE
- DEFAULT VALUES USED AS A STARTING POINT TO AID USER
- USER MUST HAVE SOME KNOWLEDGE OF BASIC PRINCIPLES

The schedule for developing the models is presented on the facing page. All activities have been completed with the exception of the Heat Rejection Task Order. The software for this Task Order has been completed and the users manual is in preparation. The task orders also includes user support to aid NASA in integration with the master module.

SCHEDULE AND MILESTONES FOR NEP SUBSYSTEM MODEL
DEVELOPMENT TASK ORDERS 18, 19, 20



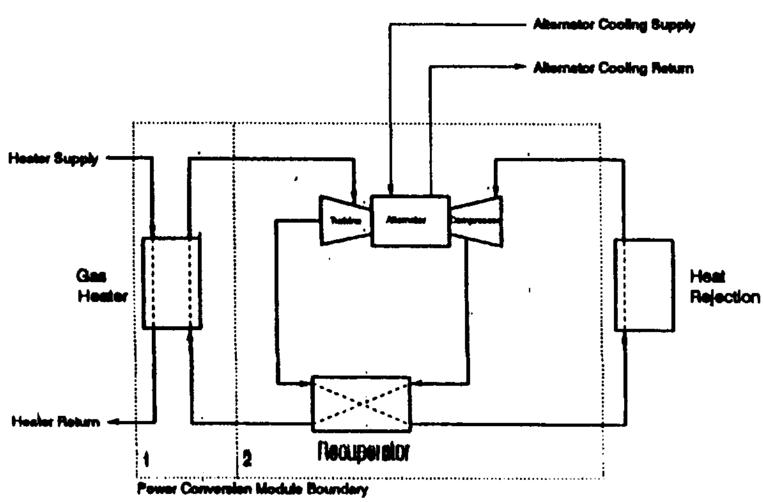
Rockwell International
Rocketdyne Division

Brayton Power Conversion Module Flow Diagram

The facing viewgraph shows a typical flow diagram for a closed Brayton cycle (CBC) system. The Power Conversion Module computer code provides for two heat source configurations; (1) liquid metal-to-gas primary heat exchanger, or (2) a gas cooled reactor configured into the CBC loop. The scope of the power conversion module for those two cases is indicated on the facing page.

The Brayton power conversion module provides for the cycle state point calculations, component performance projections, and component sizing. The components include the turbine, compressor, alternator, recuperator, and ducting. A primary heat exchanger performance and sizing routine is provided for the gas heater option.

Power Conversion Module Flow Diagram



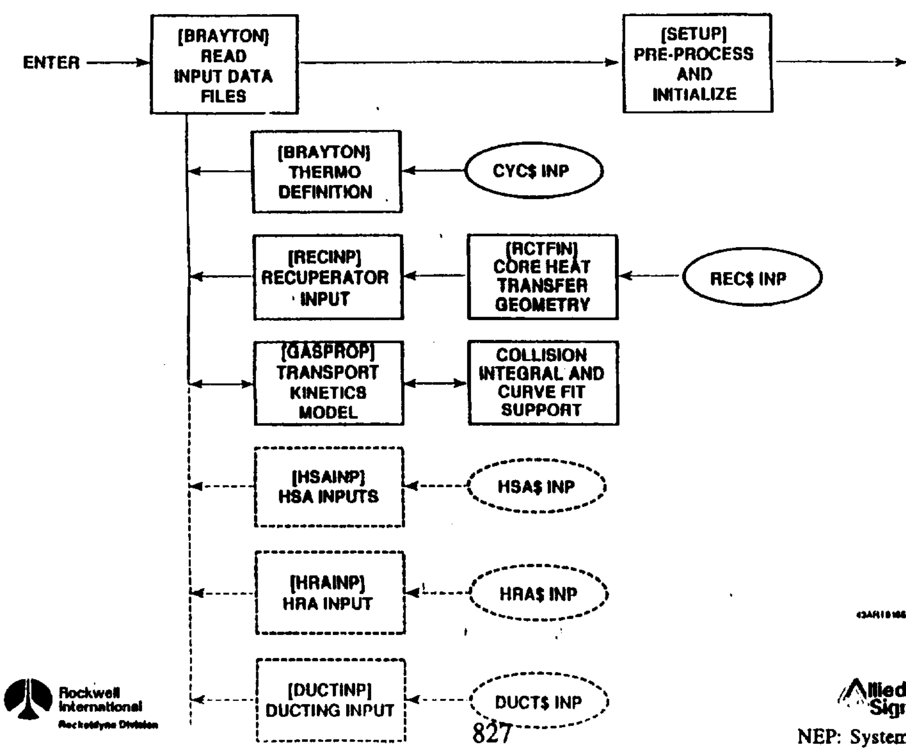
1. Full system module boundary
2. Gas reactor system option module boundary

Rockwell International

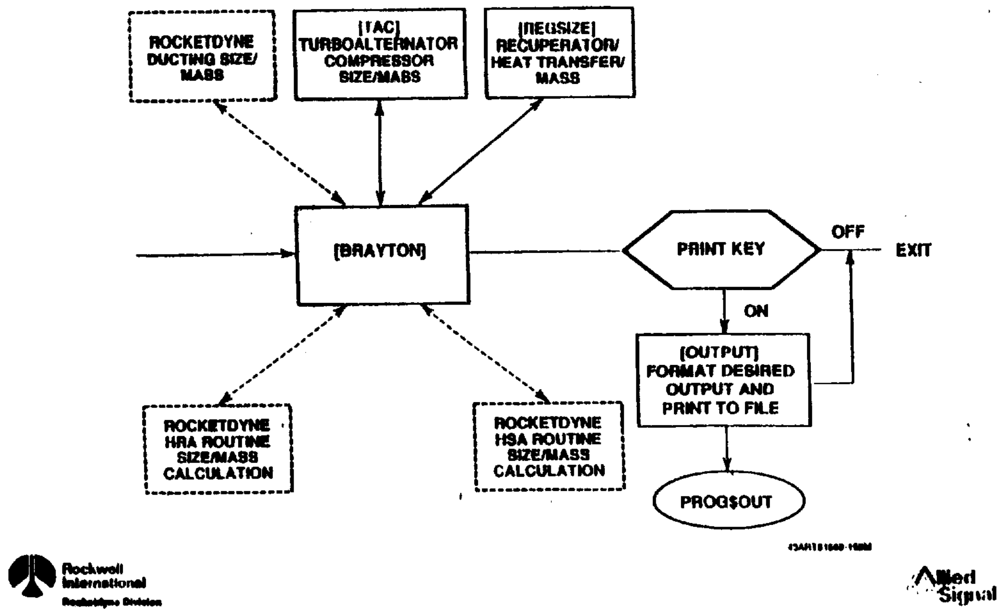
Power Conversion Module Computer Program Block Diagram

The next three viewgraphs give the computer program structure for the Brayton power conversion module. The first chart shows the input file structure for the program. Once the data files have been read and the appropriate preprocessing completed, the code moves on to the cycle state point definition routines including component performance computations. The second chart gives the layout of the subroutines used in the cycle statepoint definition portion of the code. Following the statepoint definition, the code moves into the detailed component sizing. The third chart gives the layout of the subroutines used in the component sizing portion of the code. Output options for the code are also provided.

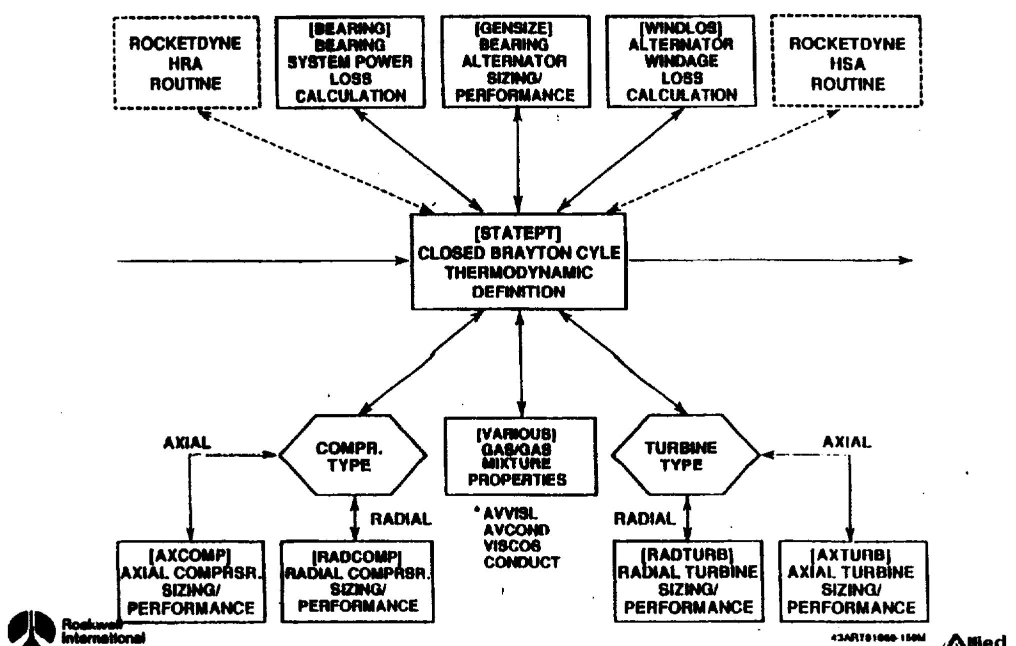
DATA INPUT/SETUP MODULE



POST PROCESSOR/OUTPUT MODULE



THERMODYNAMIC MODEL



The facing page is a table illustrating the input variables the heat rejection submodule receives and directs to the various routines, and the output variables generated by the routines that the heat rejection submodule directs to the master module. Since there are numerous variables, only a partial listing of some of the key variables where included in the table.

Brayton Power Conversion Module

Key Inputs

- Axial or radial
- Gross electrical power
- Turbine inlet temperature
- Pressure ratio
- Cycle beta
- Specify 2 of 3
  - RPM
  - Specific Speed
  - Compressor inlet temperature
- Recuperator effectiveness
- Pressure drop allocations
- Molecular weight options

- plus more than 30 others

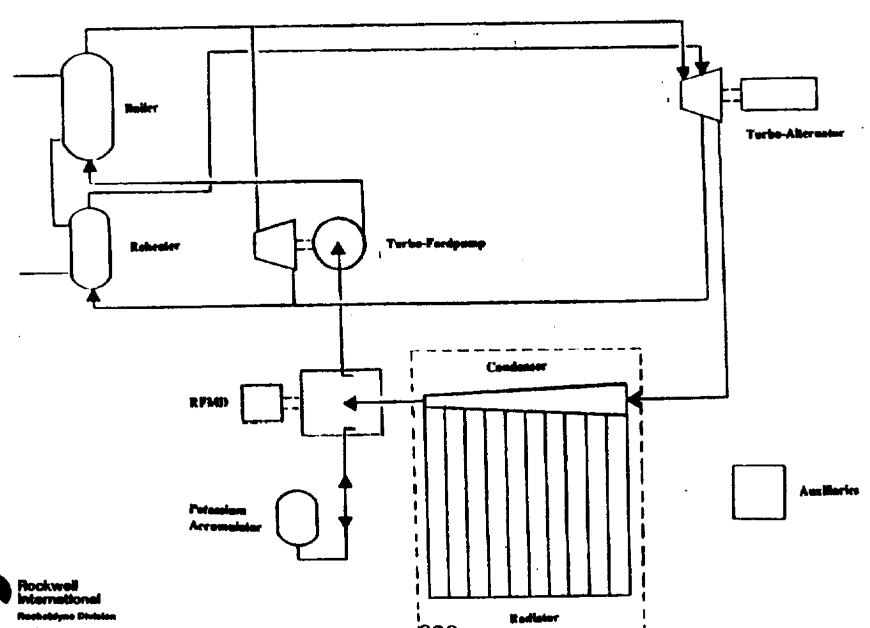
Key Outputs

- TAC mass
- Recuperator mass
- Turbine efficiency
- Compressor efficiency
- Alternator mass
- Cycle statepoints
  - Temperatures
  - Pressures
  - Flows
- 1 of 3
  - RPM
  - Specific speed
  - Compressor inlet pressure

- dozens of performance and geometry related parameters are available

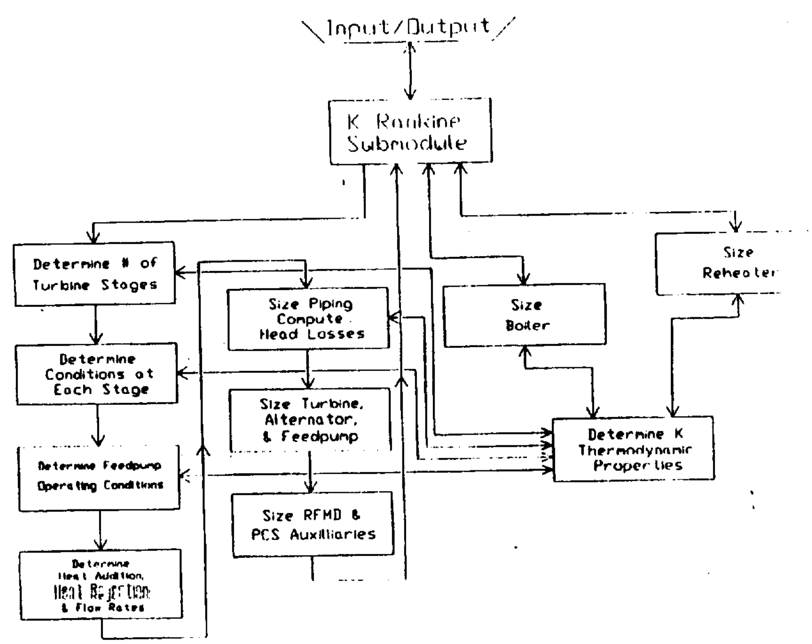
In the potassium-Rankine power conversion subsystem, shown on facing page, the principal flow of potassium vapor leaving the boiler is to the main turbine. A relatively small stream is diverted to the turbine of the turbo feed pump. The main turbine is divided into high-pressure stages and low-pressure stages. Upon exhausting the high-pressure stages, the wet potassium vapor is routed through a reheater to revaporize entrained moisture and re-superheat the vapor stream, upon which the vapor stream leaving the reheater is routed to the low-pressure turbine. Upon exhausting from the low-pressure turbine stages, the vapor is condensed in a shear flow controlled condenser. Latent heat of vaporization is rejected by the condenser to the heat rejection subsystem. Condensate leaving the condenser is directed to a Rotary Fluid Management Device (RFMD). The RFMD provides two phase fluid management and pressurizes the condensate to ensure that sufficient net positive suction head (NPSH) is provided to the main turbo-feedpump. The turbo-feedpump repressurizes the liquid potassium received from the RFMD and directs it to the boiler.

POTASSIUM-RANKINE POWER CONVERSION SYSTEM SCHEMATIC



The potassium-Rankine program structure and interfaces are illustrated on the facing page. The K-Rankine submodule is designed to interface with the master module by receiving input and directing output generated form the K-Rankine routines to the master module. Additionally, the K-Rankine submodule directs the flow of computations and data through the various K-Rankine routines.

NEP K-RANKINE TOP LEVEL FLOW DIAGRAM



The facing page is a table illustrating the input variables the K-Rankine submodule receives and directs to the various routines, and the output variables generated by the routines that the K-Rankine submodule directs to the master module. Since there are numerous variables, only a partial listing of some of the key variables where included in the table. The K-Rankine code requires in the neighborhood of 60 input variables and generates over 500 output variables.

K-RANKINE INPUT/OUTPUT VARIABLE

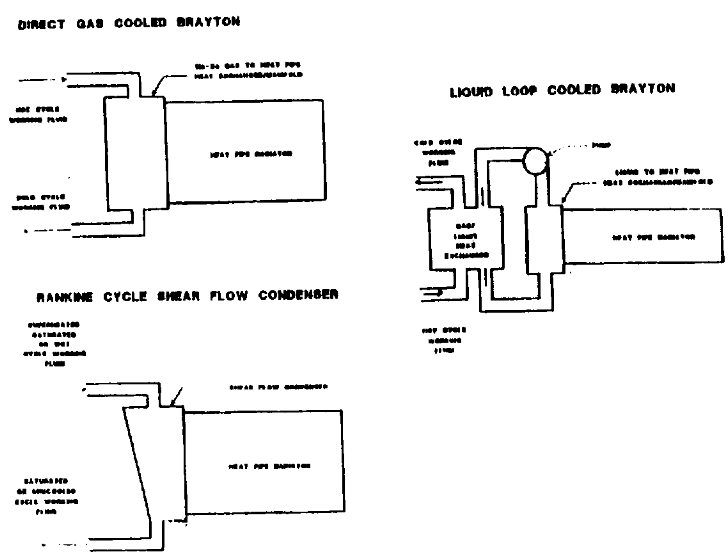
MAJOR INPUT VARIABLES	MAJOR OUTPUT VARIABLES
- Electric Power Out	- System Mass
- Turbine Inlet Temperature	- Heat Input Requirements
- System Life	- Heat Rejection Requirements
- Condenser Temperature	- Electrical Frequency
- Voltage	- + Over 500 Other Output Variables
- + 50 Other Input Variables	

HEAT REJECTION

The heat rejection subsystem design code provides the capability of analyzing three distinct configuration options; namely, direct gas cooled Braytons, liquid loop cooled Braytons and Rankine cycle shear flow condenser units. Algorithms to calculate the mass and performance expected for each component in each of the three subsystems are included. Normally, a relatively complete description of the dimensions and flows involved with the particular component is required to be supplied to the code. An option is offered that permits the code to run with relatively little information (namely; inlet and outlet conditions and system type). The output from this option can then be used as a baseline for other optimization studies.

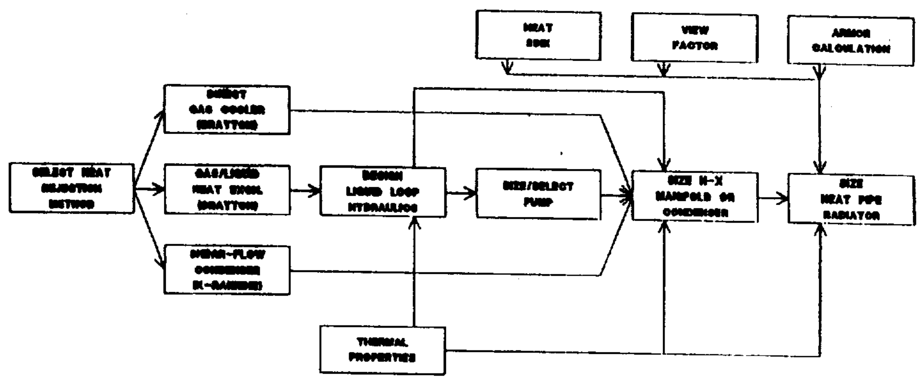
Note: Flow input to the Rankine condenser manifold must be either saturated or wet. The code cannot accommodate superheated vapor.

RADIATOR FLOW SCHEMATIC OPTIONS



Rockwell International
Rocketdyne Division

NEP HEAT REJECTION TOP LEVEL FLOW DIAGRAM



Rockwell International
Rocketdyne Division

The top level flow diagram for the heat rejection subsystem is shown. The driver code must, as a minimum, supply the subroutine with thermodynamic inlet and outlet conditions and with a heat rejection method selection. The code will then proceed to perform a detailed computation of the performance and mass of the system specified. The computation sequence for these estimates proceeds from first principles and follows the blocks as shown. The code contains all properties and orbit environmental information needed to analyze most operational situations.

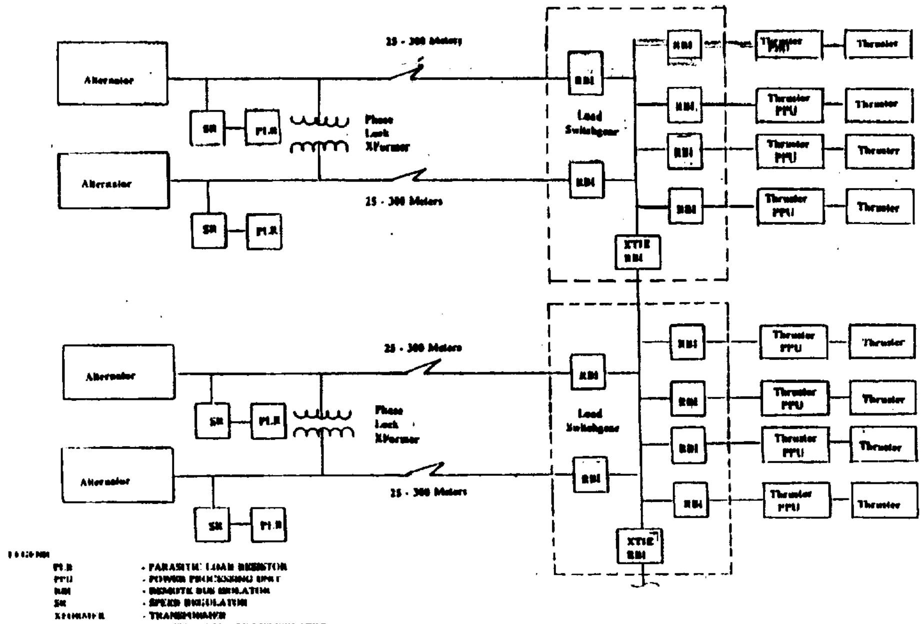
HEAT REJECTION INPUT/OUTPUT DESCRIPTION

KEY INPUTS	KEY OUTPUTS
- Inlet Flowrate	- Radiator Area
- Inlet Temperature	- Heat Rejection Subsystem Mass
- Inlet Pressure	- Component Masses
- Amount of Heat to be Rejected (Duty)	- Component Pressure Drops
	- Component Temperature Drops
- Detail Component Dimensions (Optional)	- Detail Component Dimensions, If Not Given

Rockwell International
Rocketdyne Division

The facing page is a table illustrating the input variables the heat rejection submodule receives and directs to the various routines, and the output variables generated by the routines that the heat rejection submodule directs to the master module. Since there are numerous variables, only a partial listing of some of the key variables where included in the table.

LOW FREQUENCY PMAD ARCHITECTURE



Rockwell International
Rocketdyne Division

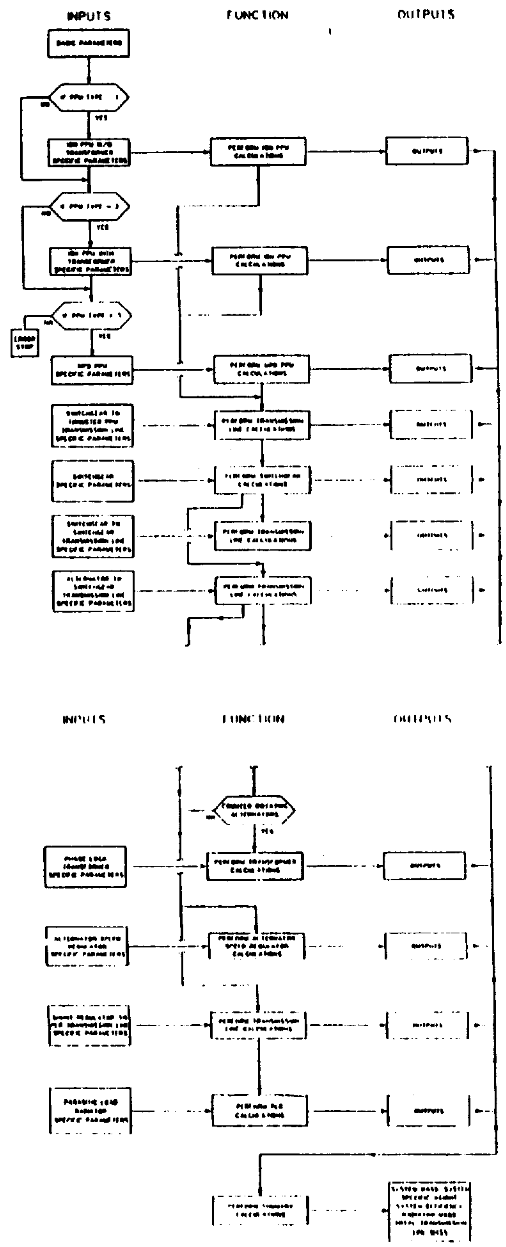
Low Frequency PMAD Architecture

The PMAD model is based on a low frequency PMAD architecture that transmits power to either ion or magnetoplasmadynamic (MPD) thrusters at the alternator voltage and frequency. It does not utilize a rectifier or inverter to change the alternator output power characteristics. This low frequency transmission approach was compared with dc and high frequency ac designs, and determined to have the lowest mass, highest efficiency, and on the basis of complexity judged to have the highest reliability and lowest development costs. Although its power quality is not as good as that provided by a high frequency system, it is adequate for both ion and MPD thruster applications.

This architecture has six main elements: thruster power processing units (PPUs), switchgear units, phase lock transformers, shunt regulators, parasitic load radiators, and transmission lines. The thruster PPUs convert the high voltage ac employed for power transmission into lower voltage dc feeds for the respective thruster elements. The switchgear units perform power switching operations and provide fault protection for the thruster PPUs. The phase lock transformer is only included if counter rotating alternators are employed. It synchronizes the alternator outputs and prevents a torque moment from being applied to the NEP vehicle due to unequal or unbalanced changes in alternator speed. The speed regulator controls the alternator and turbine speed by adjusting the connected load. The objective is to maintain the total connected load, thrusters and parasitic load, at a fairly constant level and prevent the reactor from experiencing power fluctuations. Finally, the transmission lines carry power from the alternators to the switchgear units and distribute it to thrusters.

TASK20VG OCT

NEP PMAD TOP LEVEL FLOW DIAGRAM



Rockwell International
Rocketdyne Division

NEP PMAD Top Level Flow Diagram

The model operator largely defines the PMAD architecture by selecting the number of operating and standby PMAD channels, and the number of alternators and thrusters per channel. Then, depending on whether Ion or MPD thrusters are being studied, the user selects the appropriate PPU type. The frequency used for power transmission is established by the alternator, and the thruster PPU input voltage selected by the user determines the transmission voltage. The final system level parameter selected ~~by the model operator is the power conditioning component coldplate temperature.~~ Many other component specific parameters can also be changed; however, the default values that are provided are appropriate for most applications. Based on the operator selected inputs, the PMAD model outputs such figures of merit as total PMAD system mass and specific weight, and the end-to-end PMAD system efficiency.

PMAD Model Input and Output Parameters

Key Inputs

Total Output Power Level

Alternator Frequency

Number of PMAD Channels

Number of Alternators per Channel

Number of Thrusters per Channel

Power Processing Unit Type

Component Coldplate Temperature

Numerous Other Inputs such as Transmission Voltage; Transmission Line Lengths; and Power Conditioning Component Configurations, Voltages, Filtering Levels, and Power Processing Element Efficiencies

Key Outputs

Total PMAD System Mass

PMAD System Specific Weight

PMAD System End-to-End Efficiency

Total PMAD Component Mass

Total Transmission Line Mass

Total Electronics Radiator Mass

Numerous Other Outputs such as Transmission Line Temperatures and Efficiencies; and Individual Power Conditioning Component Masses, Efficiencies, and Volumes

Rockwell International
Rocketdyne Division

The facing page is a table illustrating the input variables the PMAD submodule receives and directs to the various routines, and the output variables generated by the routines that the PMAD submodule directs to the master module. Since there are numerous variables, only a partial listing of some of the key variables where included in the table.