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PRELIMINARY DESIGN PROGRAM FOR ADVANCED PLANETARY SPACECRAFT

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PRELIMINARY DESIGN PROGRAM FOR ADVANCED PLANETARY SPACECRAFT

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ABSTRACT

A computer program is presented which employs analytical and empirical sizing techniques for combining spacecraft subsystem parametric information to rapidly evaluate the preliminary design concept of an advanced unmanned spacecraft suitable for planetary exploration. The sizing technique is limited to the orbiting and flyby spacecraft only. The simulation incorporates two program listings for two hypothetical modularized spacecraft compatible with the Saturn V launch vehicles and compiles the generating data of various design parameters of nine major subsystems at the subsystem level to be synthesized for parametric trade-off studies.

Numerical examples are provided for a solar-powered spacecraft designed to provide the capability of accomplishing Venus orbiter/lander missions and a radioisotope thermoelectric generator-powered counterpart designed for similar missions to Jupiter.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

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PRELIMINARY DESIGN PROGRAM FOR ADVANCED PLANETARY SPACECRAFT

By

J. T. Wheeler

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ADVANCED STUDIES OFFICE
AERO-ASTRODYNAMICS LABORATORY

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PRELIMINARY DESIGN PROGRAM FOR ADVANCED PLANETARY SPACECRAFT

I. INTRODUCTION

A computer program for use in evaluating, by means of analytical sizing technique, the preliminary design concept of an advanced unmanned spacecraft suitable for planetary exploration in the near future is presented. The computer simulation, written in FORTRAN II, uses analytical and empirical techniques for combining spacecraft subsystem parametric information to rapidly size the unmanned spacecraft system with respect to weight and power for such missions to the target planets from Mercury to Jupiter. Accordingly, the simulation incorporates two programs used in determining subsystem/system weights for two spacecraft configurations for missions to Venus and Jupiter, respectively. Additional programs to size the spacecraft for unmanned exploration of other target planets can be implemented in the digital computer.

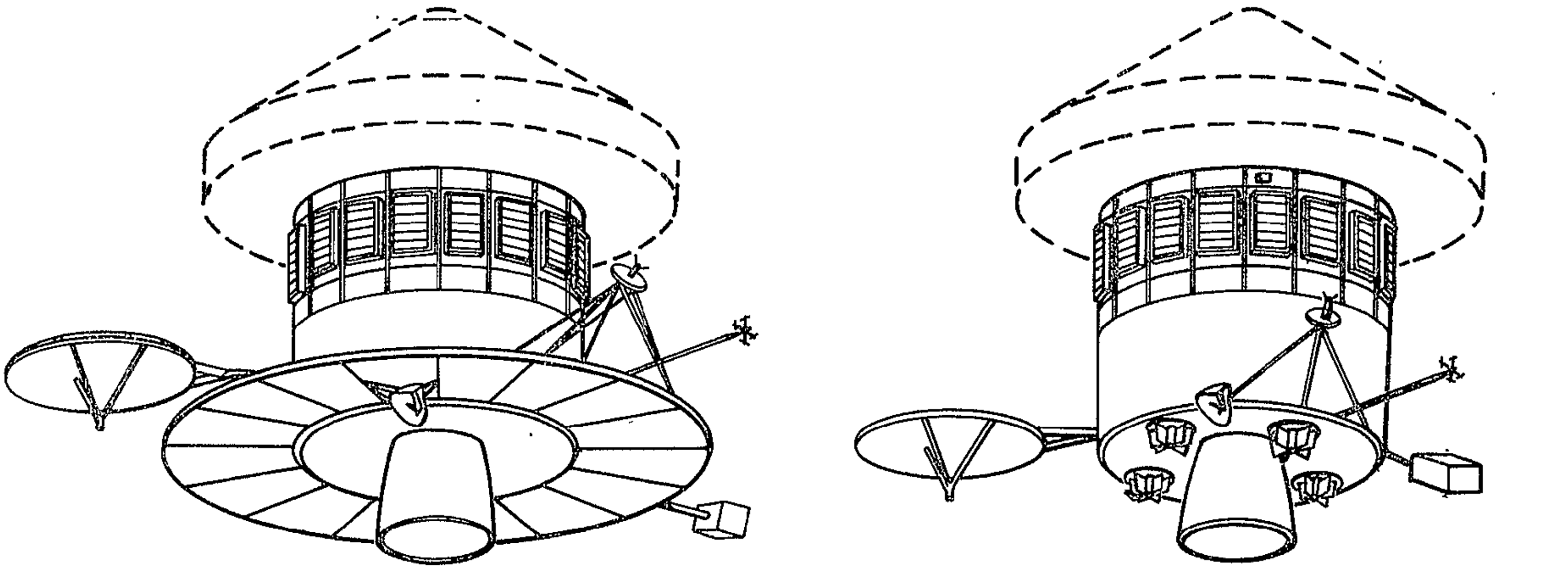
The sizing technique, limited to the orbiting and flyby spacecraft only, has been established from the analytical and historical data on existing and proposed programs of unmanned planetary spacecraft. Using available computerized options, the computer program compiles the state-of-the-art data of various design parameters at the subsystem level to be synthesized for parametric trade-off studies for this type of spacecraft concept, or an "optimum" weight breakdown of the spacecraft configuration, which indicates a summation of the subsystem weights to give the system weight. The program thus establishes relationships between spacecraft performance parameters and subsystem design characteristics of weight and power. Requirements have been established for each subsystem and system design parameter that influences weight and power, subject to science payload requirements.

The nine subsystems considered for the spacecraft are structure, propulsion, guidance, control and navigation, instrumentation (telecommunications), electric power, electric networks, temperature control, attitude control propulsion and science. Thus, the spacecraft design process is one of integrating the subsystems and subsystem functions into a total system concept of the orbiter/lander configuration for accomplishing a specified mission with a given science payload and, if applicable, an allotment of capsule (lander) to a particular planet. The selection of those science/capsule payloads reflects a capability of the program to optimize the design potential of a spacecraft configuration as a starting point within a constraint of the given launch vehicle shroud diameter by maximizing the subsystem weights. Results from further minor modifications in the program may readily demonstrate the adaptability of a specific spacecraft design to several different launch vehicles and planetary missions under application of mission/systems requirements and constraints. The design parameters (mission and system) critical to the spacecraft sizing that is considered in the analysis include post-injection velocity allocation (midcourse trajectory corrections, orbit insertion, gravity losses and orbit trim), spacecraft stage diameter or length, science payload, capsule weight allocation, engine-thrust level, engine-specific impulse, densities of selected propellants, and mission duration.

To illustrate the use of the program for one purpose of subsystem interrelation and design complexity inherent in a planetary vehicle, a preliminary design study has been made, using two alternate programs, of two hypothetical modularized spacecraft compatible with the Saturn V launch vehicles in accomplishing unmanned scientific missions to Venus and Jupiter. Two detailed conceptual spacecraft designs have been derived: a solar-powered version and a radioisotope thermoelectric generator-powered version (Figure 1). The solar-powered spacecraft is designed to provide the capability of accomplishing Venus orbiter/lander missions. Its electrical power is provided by 16 solar panels with 9.29 square meters of solar cell area, capable of generating some 900 watts of usable power at Venus. This configuration contains a liquid bipropellant system in two storage tanks. The counterpart version uses the electrical power of four RTG's with each rated at about 250 watts to accomplish Jupiter orbiter/lander missions. Four main propellant storage tanks are integrated in this version. Adaptation to either version appears possible with minor changes to other spacecraft equipment.

Scaling weight equations derived from analytical and empirical techniques have been computer-mechanized so that a wide range of variables for all subsystems could be examined in the form of weight breakdown, subject to the input parameters. In addition, the sizing technique is applied at the assembly level to improve accuracy. Table 1 shows the subsystem/assembly levels at which the technique is applied. The acceptance of any combination of main on-board engines and any spacecraft stage diameter constrained by the launch vehicle shroud diameter and the capability to design single- or multi-stage configurations consider some program objectives and the priority of each subsystem in terms of available weight and volume. The input parameters required for the application of the sizing technique reflect scientific objectives (science payload) and mission/system requirements (capsule data, launch vehicle, subsystem constraints, mission duration and velocity requirements). Spacecraft sizing results are sensitive to variations in most of the input parameters.

A computer program showing two listings for the solar-powered spacecraft and its RTG-powered counterpart is described. The program, originally reported in Reference 1, has been greatly modified to facilitate treatment of analytical and empirical techniques for relating spacecraft subsystem



SOLAR-POWERED SPACECRAFT   RTG-POWERED SPACECRAFT

FIG. 1. ISOMETRIC VIEW OF TWO SPACECRAFT CONFIGURATIONS

TABLE 1. UNMANNED SPACECRAFT BREAKDOWN STRUCTURE

Total System	Individual System	Subsystem	Assemblies
Spacecraft	Structure	Basic shell	Rings and frames
			Stringers, longerons & skins
		Systems support	(Beams)
		Micrometeoroid protection	
		Supports	(Antennas, scan platform and solar array) or (Antennas, and scan platform)
		Separation mechanism	
	Propulsion	Main engine	
		Fuel system	
		Oxidizer system	
		Supports	(Main engine and tanks)
		Telemetry sensors	
	Equipment and Instrumentation	Structure	
		Guidance, control and navigation	Sensors
			Computer/sequencer
			Control computer
			Servo actuators
			Articulation equipment
		Instrumentation	Radio
			Telemetry
			Data system
			Antennas
			Command
			Measurement
		Electric power	Solar array or Radioisotope thermoelectric generators
			Batteries
			Power control
		Electric networks	Networks
			Pyrotechnics
		Temperature control	
		Attitude control	Tanks
			Hardware
		Science	Instruments & scan platform

weights and electrical power requirements to mission and system parameters. An added feature imparts a sense switch procedure for two involved options, NCODE = 2 and NCODE = 3, in which a restraint is imposed upon main propellant tank radius. Numerical examples for two representative spacecraft designs are included to indicate, in part, the use of the program and the results obtainable. Studies of flight capsule (lander) sizing and performance and mission analysis are beyond the scope of the computer program.

II. SPACECRAFT OBJECTIVES AND DEFINITION

The objectives of the advanced unmanned planetary program currently being conceived are to provide a capability for scientific exploration of several planets within our solar system with instrumented, unmanned spacecraft designed to place meaningful experimental packages in orbits about the planets, to place experimental packages on the surfaces of the planets, to conduct observations of planetary phenomena with these packages for specified periods of time and to transmit the results of those observations to earth for retrieval, reduction and dissemination. The use of such spacecraft -- orbiters and landers -- to search out life on those planets would continue to extend the United States' capabilities in what would probably be the most challenging, open-ended arena for expansion of science and technology in the decade ahead.

The unmanned orbiting/landing spacecraft is defined as a concept that uses the spacecraft on-board propulsion and guidance systems for normal functions, such as midcourse corrections, planetary braking and orbit maneuvers, to inject scientific payloads to the planets. To illustrate the use of the spacecraft, the orbiter and lander would work as a team to verify individual conclusions. The orbiter's mission would include, for example, (1) measurements of gravitational field, magnetic field, cosmic and solar radiation, atmospheric composition changes; (2) observation of seasonal and diurnal variations, wave of darkening, circulation patterns and topography; (3) mapping of visible and infrared light; and (4) detection of storms and area weather. During the descent, the lander would perform experiments of atmospheric pressure, density, temperature profile, and composition and surface imaging. On the surface, the survivable lander would measure surface characteristics and changes, measure local meteorology, and search for biological activity. In addition, the lander would carry cameras which would provide coverage of the planet but less extensive because of the difficulty in returning images from the distance of the planet. The orbiter would assist in this mission by serving as a data-relay communications link.

For the missions to the selected planets, Venus and Jupiter, the preliminary spacecraft sizing study has been performed to parametrically determine the spacecraft weights, particularly at subsystem level, of advanced Voyager-type spacecraft. Subsystem weights are then summed up to give the system weight. Flight hardware consists of the single Saturn V launch vehicle designated to carry two identical planetary vehicles, each one being contained in a separate shroud section. The planetary vehicle consists of a flight spacecraft (orbiter) and a flight capsule (lander). The flight capsule comprises a capsule bus and a surface laboratory, and is joined to the flight spacecraft by means of mating flanges. The spacecraft fits within a cylindrical envelope in the launch vehicle; spacecraft support is provided by the shroud through an intermediate adapter.

The advanced planetary spacecraft, a simple modular design contrived to perform all necessary spacecraft mission functions, consists of an equipment module and a propulsion module. An encapsulated lander rests on the equipment module, while the propulsion module fastens to the planetary vehicle adapter that mounts to the Saturn V launch vehicle shroud. The adapter remains with the shroud after the planetary vehicle is injected into the transplanet trajectory. The equipment module contains all spacecraft electronic equipment (such as supporting electronics) contained in some 16 thermally controlled equipment bays, for a portion of various science instruments, telecommunications, guidance and control and electric power. Environmental control is provided by radiator plates and thermally controlled louvers. The main engine, which is used for all maneuvers of midcourse corrections, planetary orbit insertion and orbit trim, occupies the central core of the propulsion module. This lower cylindrical housing also contains both the propellant and the pressurant storage and feed systems. For the RTG-powered configuration, four radioisotope thermoelectric generators surround the nozzle end of the main engine. A monopropellant propulsion system, normally used for midcourse corrections or insertion into a degraded orbit, is not reflected in either one of the two representative spacecraft.

The base of the spacecraft is a round frame which also serves as the mounting structure for the hinges of the solar array foldout assemblies for the solar-powered spacecraft. Other major spacecraft equipments mounted to the propulsion module are several communication antennas, a cold-gas nitrogen system for attitude control mounted on the edge of the solar-array structure for pitch, roll and yaw control, and a planet-scan platform mounted near the periphery of the module for science viewing of the planet. A 7.5-foot parabolic high-gain antenna gimbaled on two axes is used for high-data-rate communication to earth. A backup medium gain antenna is also installed in the event of failure of the high-gain antenna. It is mounted to be earth-pointing at the time of planet encounter. Low-gain antennas provide communication capability during both near-earth and maneuver operations. A Sun-Canopus reference system is typically used for spacecraft three-axis attitude control. The central or roll axis is sun-pointing and accounts for two axes of control. Rotation about the roll axis, to permit Canopus acquisition, accounts for the third control axis. During maneuvers, gyro inertial control is used.

III. SUBSYSTEMS

Functional requirements and implementations of the specific spacecraft subsystems are discussed in some detail. More elaborate information on any subsystem may be found in existing literature. The analytical/empirical relationships for the subsystems and assemblies have been developed and are provided in the program listings. Since the component weights are often subject to change, the coefficients of the scaling equations should be periodically updated. No generalization can be made with respect to the critical parameter(s) for spacecraft sizing. Since each mission has inherent characteristics that affect its sensitivity to the individual input parameters, each spacecraft must be sized for each given mission to establish the impact of the input parameters.

A. Structure

1. Basic Shell

The spacecraft structure provides for the overall mounting of equipment and serves as the load-carrying medium between the flight capsule and the launch vehicle shroud. It is desirable for the spacecraft design to have a good modularity, contain larger propellant tanks, and be able to carry the structural loads of a larger capsule. The structure should be designed for such possible growth in capsule weight, but should retain the virtues of the design pushed towards minimum weight. The spacecraft structural arrangement is designed in two sections: the equipment and the propulsion modules.

The equipment module is a semi-monocoque cylinder with the equipment bays. Primary loads are carried by 16 equally spaced stringers which are increased in depth as they pass between the equipment bays to serve as a mounting structure for the equipment tray fittings and thermal radiator plates. The stringers are attached to the interface rings with bath-tub fittings. Equipment bay support rings serve as load transfer members, stabilizing rings and access panel mounting frames. Structural access panels provided above and below the equipment bays in the circular portion of the structure extend from the equipment support rings to the flight capsule interface ring and the propulsion module interface ring. The electronic equipment is located in 15 of the 16 structurally integrated bays with the equipment internally mounted on the stringers. The thermal radiating panel is used for the primary shear structure through the equipment bays. Panel stabilization is obtained by the attached electronic module trays.

The propulsion module is a semi-monocoque ring-stiffened aluminum shell. It joins together, by means of a frame-stringer splice, either the radioisotope-generator submodule or the solar array submodule. Also connected to the propulsion module is a system of 16 equally spaced tabular members extending radially outward and downward at an angle from the equipment/propulsion module interface. These tubes, together with the basic shell and either the RTG system or solar array structure, form a truss-like support structure for transmitting planetary vehicle inertial loads to the booster shroud during powered flight.

The main propulsion engine is supported longitudinally and laterally at the fore end by a thrust-cone/truss structure and laterally by truss members at the aft engine skirt. The thrust-cone/truss structure is a sheetstringer cone which attaches to the engine case forward interface at 64 places. The loads are fed into 16 truss members which attach to the equipment/propulsion-module interface ring at mid-joint point. The thrust-cone structure uses a ring to react the kick loads and ensure the engine case a uniformly distributed load. The eight truss members at the aft skirt transfer the load tangentially to the engine case. This is accomplished through the use of an interface ring to react the radial component of the load. The members are attached using spherical ball rod end fittings which allow for misalignment at installation and engine case expansion at firing. The propulsion module also houses and supports two or four bipropellant tanks, helium pressurization spheres and all associated plumbing and hardware.

The structural members of the basic shell are stringers, fittings, rings, longerons, frames, plates, stiffeners, panel skins, truss, ribs and attachments for both modules of equipment and propulsion. Some structural members are reflected in the components of rings, frames, stringers, longerons and skins; therefore, the weights are calculated by the following scaling equations:

For the four-propellant-tank configuration:

$$RI = 0.0413640\ D(W_p)^{0.5}\ G$$

$$FR = 0.00928041\ D(W_p)^{0.5}\ G$$

$$STRI = 0.23904\ D(HMX + 1.016)G$$

$$XLON = 0.58706\ D(HMX + 1.016)G.$$

For the two-propellant-tank configuration:

$$RI = 0.0413640\ D(W_p)^{0.5}\ G$$

$$FR = 0.00928041\ D(W_p)^{0.5}\ G$$

$$STRI = 0.31638\ D(HMX + 1.016)G$$

$$XLON = 0.66791\ D(HMX + 1.016)G$$

$$SKI = 2.42559\ D(HMX + 1.016)G,$$

where

RI = weight of rings (kgm)

FR = weight of frames (kgm)

STRI = weight of stringers (kgm)

XLON = weight of longerons (kgm)

SKI = weight of skins (kgm)

D = diameter of spacecraft stage (m)

W_p = weight of bipropellants in the tanks (kgm)

$G = \sqrt{G_1^2 + G_2^2}$ = acceleration parameter = (g)

HMX = length of propulsion module section (m).

2. Systems Supports (Beams)

The propulsion module structure is supported by the beams formed through the juncture of the support struts, the array radials and the inner shell longerons. The weight for the beams is calculated by

$$BEAM\ (kgm) = 0.03844742\ D(W_p)^{0.5}\ G.$$

3. <u>Micrometeoroid Protection</u>

The basic method of providing protection against meteoroid penetration is to provide armor-type shielding. The hypervelocity impact prediction equation used to calculate the maximum thickness of a target is given by

$$t_T = E\ [illegible]^{2/3}\ \rho_P^{1/3}\ m_P^{1/3}\ \ln\left[1 + \frac{\rho_P^{2/3}\ \rho_T^{1/3}\ V^2}{FH_T}\right]$$

where

E and F = constants

ρ_T = target density (g/m^3)

ρ_P = particle density (g/m^3)

m_P = mass of particle (m)

V = velocity relative to the target (m/s)

H_T = Brinell hardness of target (g/m^2).

The analysis defines a meteoroid flux for a given portion of space, i.e., the expected number of meteoroids of mass m or greater passing through a unit area of the particular region of space in unit time. This flux Ø is expressed as

$$\text{Ø} = \alpha m^{-\beta} = \frac{\text{number of particles of mass m or greater}}{m^2\ \text{sec}}$$

where

α and β = constants.

If the flux is multiplied by the spacecraft exposed area and the spacecraft flight time in the particular region, the number of expected impacts, I, on the spacecraft of particles having mass m or greater is

$$I = \text{Ø}AT,$$

where

A = spacecraft exposed area (m^2)

T = staytime (sec).

The expected number of penetrations N of spacecraft exposed area, A, during time, T, is determined by

$$N = \alpha AT \left[\frac{t_T \rho_T^{2/3}}{E \rho_P^{1/3} \ln \left[1 + \dfrac{\rho_P^{2/3} \rho_T^{1/3} V^2}{FH_T} \right]} \right]^{-3\beta}$$

The parameter N is used as a basic measure of the meteoroid hazard to spacecraft.

The typical structural design philosophy considers the use of existing structure, augmented as necessary by a bumper to form a split-skin design. A separate split-skin assembly, which also supports the thermal insulation blanket, encloses the aft end of the spacecraft. Protection is afforded to the upper portion of the main engine by the equipment modules and a split skin formed by the outer panels of the spacecraft and the support cone for the engine. Protection from frontal impact is provided by the biological barrier. The aft bumper consists of an aluminum target sheet and an aluminum outer sheet separated by polystyrene foam. The pressure vessels and main engine are protected from radial impact by a split-skin design that uses the shear panels as the main target wall. The outer wall is the aluminum sheet stiffened by circumferential beading. The electrical components in the equipment module are protected by magnesium alloy. This protection consists of the outer thermal panel and the equipment tray.

In the program, the equation for the weight of micrometeoroid protection shielding appears as

$$XMP(kgm) = 22.0905\ D(HMX + 1.016).$$

4. Supports (Antennas, Planetary Scan Platform With or Without Solar Array)

The weight of supports includes the external structure which supports the high-gain antenna, auxiliary antennas, the planetary scan platform, solar panels and other equipment items.

5. Separation Mechanism

Separation mechanisms are used to release and separate spacecraft from the launch vehicle and to perform the functions of deployment, articulation and actuation of the high-gain antenna and the planetary-scan platform, as well as deployment of all medium-gain and low-gain antennas, the auxiliary solar panels, and the gimbal actuators for thrust vector control.

B. Propulsion

1. Engine

The computer program accepts any candidate spacecraft propulsion subsystem engine which can occupy the central core of the spacecraft, provided it is designed to furnish all thrust forces for all maneuvers of midcourse corrections, arrival-time biasing, orbit insertion and orbit trim. The propulsion subsystem uses a liquid bipropellant concept in the program. The pressure-fed engine should have multiple restart capability, should produce some variable thrust, and should be operable on any storable propellant combination. The backup engines, which could impart some velocity increment for midcourse corrections and orbit trims, are not considered in the program. A number of main engines in the propulsion module is dictated during the computer simulation by either the minimum thrust-to-weight ratio or the maximum propellant-burn time, whichever is critical. Should one engine ever be added, attributable to the burn time constraint, the program prints out a statement to the effect. Otherwise, the minimum T/W ratio may be assumed to influence the number of the engines in the module. The program assumes four engines as a maximum number and prints out "stage impractical" should the fifth engine be added.

2. Oxidizer and Fuel Systems

To be able to perform all missions, the propulsion subsystem should have a propellant capacity that can accommodate the most severe mission requirements with a spacecraft that takes advantage of the maximum growth potential. The propulsion subsystem functionally is a regulated gas (helium), pressure-fed, liquid bipropellant system with a main gimbaled engine. Propellants are contained in either two or four spherical tanks fabricated of 6Al-4V titanium alloy unless a diameter of either or both tanks interferes in such a way that the in-between section will be cylindrical with the hemispherical bulkheads. The tanks contain elastomeric bladders. Values are provided to regulate gas and liquid flows and to isolate the system as required. Liquid check valves and trimming orifices are incorporated in outlet lines to prevent propellant migration and to minimize unsymmetrical propellant depletion. To size the propulsion module, the propellant consumption depends upon the required velocity increment for the mission and the net injection weight of the spacecraft. Unless the propellant weight required in the stage is small enough to allow spherical tank design, the radii of the propellant tanks are determined by the clearance equations:

$$R1 = \frac{[RN \times (RN - R2 - 0.254) + 0.3175]}{(RN + R2)}$$

or

$$R2 = \frac{[RN \times (RN - R1 - 0.254) + 0.3175]}{(RN + R1)} ,$$

where

R1 = radius of oxidizer tank (m)

R2 = radius of fuel tank (m)

RN = 1/2 stage diameter (m),

[NOTE: The above equations maintain a clearance of 0.1270 meter between the tanks and the shroud.]

and

$$R1 \text{ (or } R2) \leq CK,$$

where

CK = maximum radius determined by diameter of stage and clearance.

The length of the propulsion module section is always equal to 0.1016 m unless the section length is controlled by an input of minimum section length or the mixture ratio. The densities of oxidizer and fuel and the mixture ratio dictate the length of the cylindrical section of the propellant tanks.

Tank weights are calculated by dividing each tank into three sections (two sections if the tank is a sphere): upper bulkhead, cylinder and lower bulkhead. A tank wall thickness is then calculated for each section, according to the maximum ullage pressure and allowable strength of the material. The tank weight is taken as a sum of the section's surface area-thickness product times the density of the tank material (6Al - 4V titanium). A minimum thickness of 0.00254 meter is assumed. The weight for total fuel or oxidizer system is the tank weight multiplied by a factor of 2.8 for the four-propellant tank configuration and by a factor of 1.4 for the two-propellant-tank version.

3. Supports (Engine and Tanks)

The engine support structure for a multiple engine stage is independent of the stage diameter since the engines will be hung on the shroud around the perimeter of the stage. The weight of such supports is determined by total thrust from a number of engines.

The weight of the propellant tank supports is varying directly with the propellant loading and the acceleration parameter and is determined by

$$\text{SUPT (kgm)} = 0.000611\ (W_p)(G).$$

4. Pressurization System

The pressurization system for the propulsion subsystem is a pre-pressurized, gas-pressure-regulated device employing helium as the pressurant to control the gas pressure in the gas space of the propellant tanks. The system maintains the gas space, called ullage, at a pre-selected pressure history bounded by propellant and tank structural requirements. During operation of the system, helium passes through a pressure regulator and displaces propellant from the propellant tank by the deformation of some rubber bladder.

Pressurant requirements are calculated, according to the equation:

$$W_{press} = \frac{P_T V_T}{R\ T_i} \left[\frac{k}{I - \frac{P_i}{P_f}} \right]$$

where

W_{press} = weight of pressurant gas (kgm)

P_T = helium tank working pressure (N/m^2)

V_T = helium tank volume (m^3)

R = pressurant gas constant (m kgf/kgm °K)

T_i = initial temperature (°K)

k = ratio of specific heats of pressurant gas (-)

P_i = initial storage pressure of pressurant (N/m^2)

P_f = final storage pressure of pressurant (N/m^2).

The k term includes some percentage of leakage factor and some percent increase to account for actual variations from the isothermal process. The tank weight is determined by

$$W_{press\ tank} = W_{press}\left[1.5(R)\ (T_{max})(\rho/\sigma)_{mat}(SF)\right]$$

where

$W_{press\ tank}$ = weight of pressurant gas tank (kgm)

T_{max} = maximum anticipated temperature (°K)

ρ_{mat} = density of tank material (kgm/m^3)

σ_{mat} = ultimate tensile strength of material (kgf/m^2)

(SF) = design safety factor (-).

For the four-propellant tank configuration, the equations used in the program are

$$W_{press} = 6.10472293 \times 10^{-6}(UP)(V1 + V2)$$

$$W_{press\ tank} = 7.959931242\ W_{press}$$

and, for the two-propellant tank configuration,

$$W_{press} = 3.052361465 \times 10^{-6}(UP)(V1 + V2)$$

$$W_{press\ tank} = 7.959931242\ W_{press}$$

where

UP = ullage pressure (N/m^2)

V1 = total volume of oxidizer tanks (m^3)

V2 = total volume of fuel tanks (m^3).

The total weight of the pressurization system is given by

$$W_{helium} = W_{press} + W_{press\ tank} + W_{press\ tank\ supports} + W_{press\ tank\ plumbing}.$$

5. Telemetry Sensors

The telemetry sensors are used primarily to verify propulsion system performance and to diagnose malfunctions or failures should they occur. A history of events, pressures, temperatures and valve positions is necessary for in-cruise and post-maneuver evaluation of system status or operations. These analyses will provide a basis for improving spacecraft performance on subsequent maneuvers or launch operations. The items include pressure transducers, temperature sensors, cable and miscellaneous bracketry.

C. Equipment and Instrumentation

1. Structure

The equipment module structure houses and supports the electronic equipment, including the functions of the flight capsule load transfer, thermal control and environmental protection for the propulsion system, and electronic equipment. The structure consists of two support rings, longeron caps and longeron webs, excluding beaded skin, and is calculated by

$$EM\ (kgm) = 2.441184\ (D)(G).$$

2. Guidance, Control and Navigation

The guidance, control and navigation system comprises the following subsystems: sensors (part of attitude control), computer/sequencer, control computer (part of attitude control), servo actuators and high-gain antenna actuation. The system provides three-axis attitude stabilization to the spacecraft during all mission phases of cruise, maneuver, guidance correction and orbital.

The attitude control subsystem acquires and stabilizes the spacecraft to the external attitude references from any initial attitude and rates up to a specified number of degrees per second. It then maintains the spacecraft attitude relative to these references to less than some degree during the heliocentric and planet orbital phases. It also maneuvers the spacecraft, by sequential rotations, to any arbitrary spatial attitude necessary to perform velocity change or capsule separation maneuvers. The attitude control subsystem includes the sensors (for pitch, yaw and roll), the attitude control propulsion subsystem, and the control power.

The optical sensor designs consist of (1) the Canopus sensor for sensing the position of the star Canopus and providing error signals for roll control (2) the limb and terminator crossing detectors for providing output signals indicative of the crossing of the planet limb and terminator for the purpose of sequencing the scientific experiments, (3) the fine sun sensor for providing two-axis output signals of the proper polarity and magnitude to enable pointing of the negative roll axis of the spacecraft to the sun, (4) the switching sensor, combined with the fine sun sensor, for generating a signal to transfer attitude control of the spacecraft from the coarse sensor to the fine sensor after it is illuminated, and (5) the coarse sun sensor for providing analog signals that locate the sun over a 4π-steradian field of view.

The computer and sequence subsystem provides discrete commands and serial data for the control of spacecraft operations and scientific instruments throughout the planetary mission. It contains a cycled, special-purpose digital computer that stores the mission sequence of commands in a magnetic core memory. It can be updated by ground command to provide flexibility to handle anomalies or to change mission plans. The computer and sequencer contains the oscillator/register (master clock) for controlling all timed events, which include some functions such as limb sensing, incremental velocity accumulation, planetary science sequencing, maneuver attitude verification, antenna control, earth-occultation sensing, maneuver turns, start and stop propulsion engine, time basing and power interruption. This subsystem consists of the master sequencer, the time-to-go and ΔV registers, the gimbal sequencer, the planetary scan platform control logic, and the telemetry registers.

The control computer subsystem consists of three single-degree-of-freedom rate-integrating gyroscopes which provide angular rate or position signals in the spacecraft pitch, roll and yaw axes, a single force balance linear accelerometer for measurement of incremental acceleration along the thrust axis, and electronic circuitry which processes output signals from the sensors and the gyroscopes for rate nulling, sun acquisition, Canopus acquisition, cruise mode, maneuvers, inertial attitude hold and thrust vector control.

Servo actuators (thrust vector control actuators) provide linear force output for gimbaling the main engine during midcourse trajectory corrections, orbit insertion, and orbit trim maneuvers through commands received from the guidance, control and navigation subsystem.

The articulation equipment is used for deployment, articulation, and actuation of the high gain antenna and the planetary scan platform. These mechanisms rotate the high-gain antenna from the stowed to the deployed position and point the antenna toward earth during the cruise and planetary orbital phases of the unmanned mission. They also have the planetary scan platform articulated about three orthogonal axes after deployment, with two axes used to erect a perpendicular to the orbit plane and a third axis used to track the planet in the orbit plane.

3. Instrumentation

The radio subsystem, operating at S-band, is a major element capable of providing a highly reliable spacecraft command reception of the uplink data and command information from the Deep Space Instrumentation Facility (DSIF), converting scientific and engineering data into formats suitable for transmission to the DSIF, transmitting scientific and engineering data at transmission rates and signal levels sufficient for proper detection and discrimination by the DSIF during all phases of the mission, and providing turn-around ranging when required. The subsystem comprises amplifiers, transponders, subcarrier modulators, analog and digital multiplexers, analog-to-digital converters, formatting and error-correction coding circuitry, hybrid couplers, and transfer switches.

The telemetry subsystem provides a capability of acquiring, conditioning and formatting engineering, capsule, and science data from all spacecraft subsystems and generating, modulating, and mixing subcarriers for transmission of these data to earth via the radio subsystem. The subsystem design incorporates time and frequency multiplexing, biphase modulation, biorthogonal blocking encoding of science data and synchronization techniques. The subsystem typically consists of analog-to-digital converters, analog and digital multiplexers, a.c./d.c. power supplies, signal conditioners, clock countdown circuits, programmers, biphase modulators, summing circuits, buffers, synchronization generators, and biorthogonal block encoders.

The data (storage) system records in a digital form spacecraft engineering and cruise science data and high rate planetary science data acquired from the science subsystem and the flight capsule data received via the relay link for delayed playback and transmission at communication link compatible rates. The amount of necessary storage is dependent upon the particular mission. The subsystem is composed of some 6-8 magnetic tape recorders/reproducers and their associated control and power supply electronics.

The antenna subsystem provides at least five antennas to accomplish mission requirements. A 7.5-foot diameter parabolic high gain antenna provides a capability for transmitting the required science data rates when the spacecraft is operating in the stabilized mode. Medium gain antenna, which is neither steered nor deployed, functions as a backup to the high-gain antenna and would support the required science data rates for a number of days in planetary orbit. During maneuvers, communications are established through the low gain (maneuver) antenna. During early phases of the mission, normal communications are through another low-gain antenna (broad coverage) which has the fixed omnidirectional toroidal pattern. This antenna provides the greatest angular coverage and is used as the command antenna during emergency conditions. Fixed low-gain relay antenna is provided for the relay link from the capsule from separation through the post-landing period. In addition to the S-band antennas, the subsystem consists of VHF antennas, coaxial switches, diplexer, structures and transmission lines associated with each antenna.

The command subsystem receives the composite output of the S-band radio subsystem, extracts the command and synchronization information, decodes the command words and routes them to the spacecraft subsystems and the capsule through isolated switches. The subsystem contains bit synchronizers, detector selectors, input/output decoders, program control, demodulators and power supply.

The measurement subsystem accepts the output from the selected measuring points, either from transducers or discrete events, and conditions the signals, if necessary, for input to the telemetry subsystem. Transducers are used for the measurements of temperature, pressure, strain and displacement.

4. Electric Power

Spacecraft configuration and mission requirements dictate the basic electric power subsystem design. Average coast transit phases to the selected target planets, Venus and Jupiter, and planetary time power requirements establish an exigency for photovoltaic energy sources and radioisotope thermoelectric generators (RTG's) for electric power generation. Batteries are used as a secondary power source to provide the necessary transient peak requirements.

The functional requirements for the electric power subsystem are (1) to provide and distribute electrical power on the flight spacecraft and to the flight capsule until separation, (2) to provide a secondary electrical power in the form of storage battery power and provide power from solar array or RTG's for recharge, and (3) to provide power control for regulation of solar energy, RTG's and battery power. In addition, the subsystem normally has battery chargers, AC to DC converters, DC to AC inverters, reference frequency sources, transducer power supplies and required control and protective circuitry.

From a power requirement standpoint, photovoltaic energy sources have been the most commonly used type of spacecraft electrical power generation. During the coast phases of transit to the Venus planet, the solar cells collect radiant solar energy and convert it into electrical energy when the spacecraft is sun-oriented and the solar array is illuminated. This electrical energy is supplied in adequate quantity and quality to the spacecraft loads and is, in part, stored for use during planetary vehicle maneuvers when the solar energy is not available. Power is supplied from a set of storage batteries when the spacecraft is occulted from the sun.

As a solar-powered spacecraft moves toward the sun, its power output increases. The solar energy available at Venus would be about 2700 thermal watts per square meter compared to 1400 at the Earth's mean distance. In the vicinity of Venus, the increased solar flux raises the steady-state solar array temperature above that on a Mars mission. The albedo causes a still further transient rise of the array temperature shortly after periapsis passage of the aphrodiocentric orbit. As a result of the higher solar intensity, solar array area requirements thus could be reduced below the requirements for the Mars mission. In addition, this intensity creates potential problems in selecting array area material. An array output in terms of watts depends upon a total projected solar array area (fixed and deployable).

Electrical power for the Jupiter mission must be provided by some nuclear source since solar thermal energy intensity in the Jovian vicinity is quite low due to its great distance from the sun. This low level and the length of the mission negate any practical consideration of using any form of solar energy collection system currently envisioned. The power requirements for the Jupiter mission are more severe than those for the Venus mission. The photovoltaic system capacity installed for the Mars mission would be about 2.3 times that required at the Earth, and the area required at Jupiter would be 27 times that required at the Earth. Therefore, since an external energy source is not required, the radioisotope thermoelectric generators are chosen from the stable of alternative energy sources, including several nuclear electric power system concepts, to provide power for the Jupiter mission application and to potentially overcome the limitations of the photovoltaic systems.

The basic elements of an RTG consist of an isotope fuel heat source, a thermoelectric converter (thermopile), which transforms a percentage of the thermal energy to electrical energy and a radiator which rejects the unused thermal energy. The RTG is characterized by power densities, hot and cold junction temperatures, and the application of thermocouples. The relatively constant output of the RTG's over the mission time, along with the substantial reduction in battery capacity, could result in reduced power conditioning complexity.

The energy storage medium used in the program is the nickel-cadmium battery. The battery requirements depend upon power peaks and solar occultation for the Venus mission; for the Jupiter mission, the amount of battery capacity is greatly reduced since the RTG's operate independently of solar occultation. The batteries are used principally for high-peak momentary loads, but may also be used on a duty-cycle basis in the event of failure of one or more RTG's.

The power control unit regulates solar array, radioisotope thermoelectric generators and battery power within the power system. Along with the inverter, converter, and shunt element assembly, the unit consists of the boost regulator, the redundant sequential shunt regulator, the synchronizer, power switching logic, battery charge control logic, command capability and telemetry monitors.

5. Electric Networks

The networks' objective for the electrical interconnections is to provide for the reliable transfer of electrical energy between the various elements of the flight spacecraft and the launch vehicle and capsule throughout ground test, and launch and spacecraft flight operations. The networks for the spacecraft consist of two main ring harness assemblies of many individual cables, some separate system interconnecting cables not part of the main harness, individual bay harnesses for each of the fifteen electronic assemblies, and in-flight disconnecting cables to the launch vehicle and flight capsule, and do not contain the harnesses for the pyrotechnic subsystem. The harnesses, in general, are composed of one or more cables of insulated and twisted wires, either shielded or unshielded, bundled together and terminated at the ends by connectors.

The pyrotechnic subsystem consists of the spacecraft electro-explosive devices and the networks required for controlling, initiating and accomplishing nonrepetitive events by explosive actuation. It performs the planetary vehicle functions of separation from the launch vehicle, control of the propulsion subsystem during midcourse corrections and orbit insertion, and control of deployment devices for antennas and magnetometers. The items are composed of parallel redundant separation switches, a pyrotechnic controller, electro-explosive devices, pin pullers, igniters, valves, harnesses, electrical connections, and firing circuits.

D. Temperature Control

Spacecraft temperature control is implemented through thermostatically controlled heaters, thermal louvers, surface coatings and multilayer thermal insulation. All spacecraft equipments are maintained within specified temperature limits by heat dissipated by the electronics. In the equipment bays, the thermal louvers are regulated to be fully open at a radiation plate temperature of approximately 70°F and to close at a temperature of approximately 40°F. The temperature of external equipment is controlled by the use of surface coatings or by electrical heating. The heaters are also used for contingency heating of certain select equipments. The subsystem covers internal electronic equipment, guidance, control and navigation equipment bays, the propulsion subsystem, and external equipment

E. Attitude Control Propulsion

The primary functional requirement of the attitude control propulsion subsystem (or reaction control subsystem) is, as a mass expulsion system, to provide control torques to the spacecraft in response to processed information from the attitude control system. To achieve three-axis stabilization, the subsystem must be capable of imparting a control torque about either of the three spacecraft-centered axes. This torque is accomplished by the simultaneous expulsion of mass from two opposing thruster assemblies. Simultaneous operation of two opposing assemblies is required to assure a pure moment about any one axis, and two assembly pairs are required for each axis to provide control capability for performing the functions of pitch, roll or yaw. The subsystem also provides torques for roll control during operation of the main engine.

The selected propellant, gaseous nitrogen, is stored in four spherical tanks fabricated from 6Al-4V titanium alloy. The other equipment, or fixed hardware components, is composed of filters, regulators, valves, nozzles, temperature sensors, pressure transducers, heaters, tubing and fittings.

The total weight of propellant, tanks and fixed hardware for the attitude control propulsion subsystem without mounting structure or micrometeoroid shield is represented by the following equation:

$$ACS = W_{TAN_{N2}} + HDW_{ACS}.$$

The weight of nitrogen propellant required is given by

$$W_{N2} = 2(I_t/I_{sp}) \left[\frac{1 + \delta_p}{1 - (P_f/P_i)(T_i/T_f)}\right],$$

where

W_{N2} = weight of nitrogen propellant required (kgm)

I_t = total impulse required (kgf. sec)

I_{sp} = specific impulse (kgf. sec/kgm)

δ_p = contingency factor for I_{sp} degradation (-)

P_i = initial propellant tank pressure (kfg/m^2)

P_f = final propellant tank pressure (kgf/m^2)

T_i = initial propellant temperature (°K)

T_f = final propellant temperature (°K).

For durations as long as 1500 days, some operational redundancy is necessary in order to increase the probability of mission success. Therefore, the term "2" is added to the W_{N2} equation on an assumption that twice the nominal supply of propellant will be carried.

The weight of a spherical propellant tank with a wall thickness that is small compared to the tank radius is given by the following equation:

$$W_{TAN_{N2}} = 1.5(W_{N2})(R)(T_{max})(\rho/\sigma)_{mat}(SF),$$

where

$W_{TAN_{N2}}$ = weight of nitrogen propellant tank (kgm)

R = nitrogen gas constant (m . kgf/kgm °K)

T_{max} = maximum anticipated temperature (°K)

ρ_{mat} = density of tank material (kgm/m^3)

σ_{mat} = ultimate tensile strength of material (kgf/m^2)

(SF) = design safety factor (-).

Thus,

$$W_{N2} = 0.04135338\ I_t$$

$$W_{TAN_{N2}} = 1.32\ W_{N2}$$

$$HDW_{ACS} = 34.$$

F. Science

The flight spacecraft is designed to accommodate and provide support for a science payload that is capable of accomplishing the specified science mission. Although there is no such science subsystem, integration of the scientific experiments requires consideration of scientific tasks, equipment, and spacecraft subsystem interfaces. The experiments may be contained in the planetary-scan platform or mounted on the equipment module or on booms deployed from that module, depending on provision of flexibility in orientation.

A spectrum of possible scientific experiments for any spacecraft mission is so wide that it is not intended to recommend any particular experiment in order to derive estimates of the engineering requirements and constraints that may be imposed by the science payload on other spacecraft subsystems. For a typical spacecraft, boom-mounted experiments may include photo-imaging, infrared radiometer, broadband infrared spectrometer, high resolution infrared spectrometer, ultraviolet spectrometer, gamma ray, polarimeter and meteoroid flash director; and body-mounted experiments may comprise celestial X-ray, micrometeor impact detectors, solar X-rays, cosmic ray, solar occultation, solar plasma and atmospheric mass spectrometer.

For the computer program, input may be generalized by specifying an approximate realistic value of science payload (instruments and scan platform) motivated by the degree of confidence, or, alternatively, parametric curves for some spacecraft subsystems may be generated internally by specifying various acceptable input values of science payload.

G. Residuals

The residuals consist of propellants (unusable propellant, random outage and fuel bias), pressurants (storage bottles and propellant tanks) and attitude control system fluids. The equations used in the program are as follows:

$$\mathrm{WPFIX} = 0.0048 W_p + 0.04953(\mathrm{P1X} + \mathrm{P2X})$$

$$\mathrm{PRESS} = 6.10472293 \times 10^{-6}(\mathrm{UP})(\mathrm{V1} + \mathrm{V2})$$

$$\mathrm{ACSF} = 0.0832\ \mathrm{ACS},$$

where

WPFIX = weight of unusable propellants (kgm)

W_p = weight of propellant loading (kgm)

P1X = density of oxidizer (gm/cm^3)

P2X = density of fuel (gm/cm^3)

PRESS = weight of pressurant gas (kgm)

ACSF = weight of fluid in attitude control propulsion subsystem (kgm).

IV. NUMERICAL APPLICATION

Two numerical examples considered here for two hypothetical configurations carrying two and four propellant tanks, respectively, illustrate the impact of a number of propellant tanks and the electric power. For use in the programs (Tables 2 and 2a), the input parameters for the Venus and Jupiter missions are as follows:

Flight capsule weight = 2267.960 kgm.

Science payload = 204.117 kgm.

Adapter weight = 113.3981 kgm.

Electric power:
- Venus mission: No RTG system
- Jupiter mission: RTG system = 226.7962 kgm.

Propulsion subsystem:
- ΔV = 2050 m/s
- Thrust = 46706.3270 N
- I_{sp} = 305 sec
- Engine weight = 185.973 kgm
- MR = 1.6
- Oxidizer density = 1.440 gm/cm^3
- Fuel density = 0.872 gm/cm^3
- Ullage pressure = 1620267.942 N/m^2.

Maximum stage diameter = 3.556 m.

Minimum stage length for propulsion module = 1.27 m.

Maximum radius for propellant tanks = 0.6731 m.

Mission duration = 1000 days.

Acceleration:
- 5 g's longitudinally
- 2 g's laterally.

Tables 4a and 4b show the weight statements for the Jupiter spacecraft and 5a and 5b for the Venus counterpart.

Table 2:' Program Listing for Four-Propellant-Tank Spacecraft Design

```
ΔJOB.
ΔASSIGN S=MTO,SI=CR,BC=MT1,LO=LP.
ΔREWIND MT1.
ΔFORTRAN 90,LO.
C     R-AERO-X SPACECRAFT PRELIMINARY DESIGN PROGRAM
      COMMON STR,BS,RIFR,STLP,BSMISC,BEAM,XMP,SUFF,SM,PROPUN,ENGX,FS,
     10S,SUPET,HEL,TS,EGUT,EMTSC,SEN,COSE,CONTCO,ACT,ART,XINST,RAD,TEL,
     2DATAS,ANTE,COM,SURE,EP,RTG,BAT,PWRC,EN,XNETW,PYR,TCS,ACS,WTANN2,
     3HDWACS,SCIEN,CONTIG,TDS,RESID,WPFIX,PRESS,ACSF,TIS,WPUT,WF,WO,WN2,
     4TSAL,CAPS,TPVAL,ADAP,TPVA
1     FORMAT(7F14.4)
2     FORMAT(20H MAXIMUM BURN TIME =,F8.1,14H SEC, EXCEEDED)
3     FORMAT(F5.0,F10.4,F8.4,F11.2,F10.1,F7.1,F9.4,F10.4,F10.5,F9.5,F8.4
     1,F7.4,F6.3,F8.1//)
4     FORMAT(2X,$ OXIDIZER $,2X,$ FUEL $,2V,$ MIXTURE $,25X,$ MINIMUM $,
     113X,$ ULLAGE $,21X,$ ENGINE $,/,3X,$ DENSITY $,1X,$ DENSITY $,1X,$
     2 RATIO $,1X,$ CAPSULE $,2X,$ DV1 $,2X,$ DV2 $,1X,$ T/W RATIO $,1X,
     3$ TIME $,4Y,$ PRESSURE $,3X,$ THRUST $,3X,$ ISP $,3X,$ WT. $,1X,$
     4 MCODE $,/,1X,$ [GM/CU.CM] [GM/CU.CM] $,10X,$ [KG] $,2X,$ [M/S]   [M
     5/S] $,11X,$ (DAYS] $,3X,$ [N/SQ.M] $,4X,$ [N] $,5X,$ [S] $,2X,$ [K
     6G] $,//)
5     FORMAT(2F10.3,F9.2,F10.2,F8.1,F7.1,F9.3,F10.1,F14.3,F12.4,F7.1,F9.
     13,I5///)
7     FORMAT(37X,$ TOTAL              OXIDIZER     FUEL    OXIDIZER    FUEL $/2
     1X,$ NO.     STAGE    STAGE  PROPELLANT     INERT      DELTA        TANK
     2TANK       TANK       TANK                                 BURN $/$ ENGINES
     3 DIA    LENGTH      WEIGHT      WEIGHT       V       RADIUS       RADIUS     VOL
     4UME    VOLUME       XL1         XL2      T/W      TIME $,/,10X,$ (M] $,3X,$ (M]
     5 $,4X,$ [KG] $,4X,$ [KG] $,2X,$ [M/S] $,2X,$ [M] $,5X,$ [M] $,3X,$
     6 [CU.M] $,1X,$ [CU.M] $,3X,$ [M] $,2X,$ [M] $,9X,$ [S] $,///)
8     FORMAT(2F10.1,4I5)
9     FORMAT(18H STAGE IMPRACTICAL)
118   FORMAT(F6.0,F12.1,4F10.1,F12.1,2F11.1)
119   FORMAT(93H    NO.       STAGE          STAGE      DELTA               PROPEL
     1LANT                    STAGE     STARTING/94H  ENGINES    DIAMETER     LE
     2NGTH          V         CAPSULE      WEIGHT        RESIDUALS    DRY WT.     GROSS
     3WT.//)
414   FORMAT(1X,$ BASIC $,1X,$ XMETEOROID $,2X,$ FUEL $,2X,$ OXIDIZER $,
     13X,$ TANK $,3X,$ ENGINE $,1X,$ PRESSURIZATION $,/,
     21X,$ SHELL $,1X,$ PROTECTION $,1X,$ SYSTEM $,2X,$ SYSTEM $,2X,
     3$ SUPPORTS  SUPPORTS $,4X,$ SYSTEM $,4X,$ ACS $,1X,
     4 $ CONTINGENCY  RESIDUALS $,1X,$ FUEL $,1X,$ OXIDIZER $,/,2X,$ [KG
     5] $,4X,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,7X
     6,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,6X,$ [KG] $,3X,$ [KG] $,3X,$ [KG
     7] $,//)
415   FORMAT(F8.3,2F11.3,2F10.3,F9.3,F13.3,F11.3,F10.3,F12.3,F10.3,F9.3/
     1/)
900   FORMAT(1H1,40X,53HPRELIMINARY DESIGN DATA FOR SPACECRAFT
     1     //25X,22HOUTPUT FORMAT  NCODE =,I2,F10.1,15H G LONGITUDINAL,F
     210.1,10H G LATERAL//)
10    READ 1,HM,P1,P2,XMR,C,CAPS,DV1
      READ 1,DV2,XTW,T,XISP,ENG,UP,TIME
      READ 1,G1,G2,RTG,SCIEN,ADAP,FMAX,OMAX
      READ 8,XSTR,BTM,I,NCODE,MCODE,K
```

```
      DV3 = DV1
      PRINT 900,NCODE,G1,G2
      PRINT 4
      PRINT 5,P1,P2,XMR,CAPS,DV1,DV2,XTW,TIME,UP,T,XISP,ENG,MCODE
      IF[NCODE-4] 134,120,608
  608 IF[NCODE-6] 120,134,134
  120 PRINT 119
      GO TO 122
  134 PRINT 7
  122 X = 2.
      G=SQRT[G1**2+G2**2]
      P1X = P1*1000
      P2X = P2*1000
      PI=3.1415926536
      IF [SENSE SWITCH 3] 308,309
  308 K3 = 1
      GO TO 307
  309 K3 = 2
  307 GO TO [310,311],K3
  310 R1 = DMAX
      R2 = FMAX
      WPU = 453.59237
      DWPU = 453.59237
      GO TO 84
  311 IF[FMAX] 510,510,511
  510 FMAX=25.4
  511 IF[DMAX] 512,512,550
  512 DMAX=25.4
  550 VR = P1X/[XMR*P2X]
      IF[NCODE-2] 107,108,74
   74 IF[NCODE-4] 108,110,600
  600 IF[NCODE-6] 113,601,601
  601 H = HM
      DH = 1.27
      DV3 = DV1-1.0
  602 D = [H-0.1016]*2.+0.381
      R1 = [H-0.1016]/2.
      V1 = 4./3.*PI*R1**3
      V2 = VR*V1
      R2 = [0.23873242*V2]**.333
      IF[R1-R2] 610,611,611
  610 R2 = R1
      V2 = V1
      V1 = V2/VR
      R1 = [0.23873242*V1]**.333
  611 P = 2.
      C1 = 1.
      C2 = 1.
      XL1 = 0.0
      XL2 = 0.0
      SAOSPH=6.283184*R1**2
      SAFSPH=6.283184*R2**2
      SAOCYL=0.0
      SAFCYL=0.0
      GO TO 91
```

```
110   CAPS = 0.0
      DCAPS = 453.59237
      H = HM
      GO TO 106
113   D = 2.54
      DD = 0.254
      H = HM
      CAPS = C.0
      DCAPS = 453.59237
      GO TO 84
107   H = 1.C16
      GO TO 106
108   H = 0.254
106   DH = 0.254
84    GO TO [312,313],K3
 312  CALL 3FFLD  [R1,R2,WPU,DWPU,H,C1,C2,XL1,XL2,V1,V2,XMR,P1X,P2X]
      P = 2.
      GO TO 318
313   C1 = 1.
      C2 = 1.
      XL1 = 0.C
      XL2 = C.0
      RN = D/2.
      CK = [D-0.381]/4.
      IF[[H-C.1016]-2.*CK] 24,24,210
24    R1 = [H-0.1016]/2.
      V1 = 4.18879*R1**3
      V2 = V5*V1
      R2 = [0.23873242*V2]**.333
      IF[R1-R2] 28,29,29
28    R2 = [H-0.1016]/2.
      V2 = 4.18879*R2**3
      V1 = V2/VR
      R1 = [0.23873242*V1]**.333
29    SAOSPH=6.283184*R1**2
      SAFSPH=6.283184*R2**2
      SAOCYL=0.0
      SAFCYL=0.0
      P = 1.0
      RX = [RN*[RN-R1-0.254]+0.3175]/[RN+R1]
      IF[R2-RX] 517,517,210
210   IF[OMAX-25.4] 518,25,518
517   IF[R2-FMAX] 91,91,518
   518 R1=OMAX
      R2=FMAX
      VA=1.33333*PI*R1**3
      VB=[H-C.1016-2.*R1]*R1**2*PI
      V1=VA+VB
      XL1=H-0.1016-2.*R1
      V2=VR*V1
      VA=1.33333*PI*R2**3
      VB=V2-VA
      XL2=VB/[PI*R2**2]
      P=2.
      HX=XL2+0.1016+2.*R2
```

```
         IF(HX-H) 516,91,91
     516 XL2=H-0.1016-2.*R2
         VB=XL2*PI*R2**2
         V2=VA+V3
         V1=V2/VR
         VA=1.333333*PI*R1**3
         V3=V1-VA
         XL1=VB/(PI*R1**2)
         GO TO 91
  25     R1 = 0.0254
         DR1 = 0.254
         P = 2.0
  20     R2 = (RN*(RN-R1-0.254)+0.3175)/(RN+R1)
         V1 = 4.18879*R1**3+PI*R1**2*(H-2.*R1-0.1016)
         V2 = 4.18879*R2**3+PI*R2**2*(H-2.*R2-0.1016)
         VRX = V2/V1
         IF (ABS(VRX-VR)-.001) 40,40,30
  30     IF(VRX-VR) 43,43,42
  42     R1 = R1 + DR1
         GO TO 20
  43     R1 = R1-DR1
         DR1 = 0.1*DR1
         GO TO 20
      40 IF(R1-CK) 60,60,50
      50 R1 = CK
         C2 = 0.0
         R2 = (RN*(RN-R1-0.254)+0.3175)/(RN+R1)
         V1 = 4.18879*R1**3+PI*R1**2*(H-2.*R1-0.1016)
         V2 = VR*V1
         XL2 = (V2-4.18879*R2**3)/(PI*R2**2)
         IF(XL2) 76,76,91
  76     R2 = (0.23873242*V2)**.333
         XL2= 0.0
         GO TO 91
  60     IF (R2-CK)91,91,81
  81     R2 = CK
         C1= 0.0
         R1 = (RN*(RN-R2-0.254)+0.3175)/(RN+R2)
         V2 = 4.18879*R2**3+PI*R2**2*(H-2.*R2-0.1016)
         V1 = V2/VR
         XL1 = (V1-4.18879*R1**3)/(PI*R1**2)
         IF(XL1) 75,75,91
  75     R1 = (0.23873242*V1)**.333
         XL1= 0.0
  91     WPU = 2.*(P1X*V1+P2X*V2)/1.05
  318    IF(H-HM) 109,111,111
  109    HMX = HM
         GO TO 112
  111    HMX = H
     112 RI = .0413640*D*WPU**.5*G
         FR = .0092841*D*WPU**.5*G
         RIFR = RI + FR
         STRI = .23904*D*(HMX+1.016)*G
         XLON = .58706*D*(HMX+1.016)*G
         STLO = STRI + XLON
```

```
      BSMISC = 17.145791586
      BEAM = .03844742*D*WPU**.5*G
      IF(XSTR)525,525,526
  525 SUPT=.000736*WPU*G
      GO TO 527
  526 SUPT=WPU*G*.000611
527   IF(P-1.) 33,33,32
32    SAOSPH=6.283184*R1**2
      SAOCYL=(H-2*R1-0.1016)*6.283184*R1*C1+6.283184*R1*XL1
      SAFSPH=6.283184*R2**2
      SAFCYL=(H-2*R2-0.1016)*6.283184*R2*C2+6.283184*R2*XL2
33    TKOBOT=UP*R1/1082476880.4
      TKOCYL=UP*R1/541238440.2
      TKOTOP=UP*R1/1082476880.4
      TKFBOT=UP*R2/1082476880.4
      TKFCYL=UP*R2/541238440.2
      TKFTOP=UP*R2/1082476880.4
      IF(TKOBOT-0.00254) 400,401,401
400   TKOBOT=0.00254
401   IF(TKOCYL-0.00254) 402,403,403
402   TKOCYL=0.00254
403   IF(TKOTOP-0.00254) 404,405,405
404   TKOTOP=0.00254
405   IF(TKFBOT-0.00254) 406,407,407
406   TKFBOT=0.00254
407   IF(TKFCYL-0.00254) 408,409,409
408   TKFCYL=0.00254
409   IF(TKFTOP-0.00254) 410,411,411
410   TKFTOP=0.00254
411   WTANO=4428.7848*(SAOSPH*(TKOBOT+TKOTOP)+SAOCYL*TKOCYL)
      WTANF=4428.7848*(SAFSPH*(TKFBOT+TKFTOP)+SAFCYL*TKFCYL)
      OS = 2.8*WTANO
      FS = 2.8*WTANF
      PRESS = UP*(V1+V2)*6.104722293E-06
      WPGT = 7.959931242*PRESS
      WPGTSUP = .012 * WPGT
      WPGTPLUM = .085*WPGT
      FEL = WPGT + WPGTSUP + WPGTPLUM
      IF(XSTR)523,523,524
  524 SUPE = .0002794*T
      GO TO 61
  523 SUPE = .0021378*ENG*D*G
      SUPE1 = .000220805*T*D
      IF (SUPE-SUPE1) 13,61,61
13    SUPE=SUPE1
61    V1=V1
      V2=V2
      XMP = 22.0905*D*(HMX+1.016)
      EM = 2.441184*D*G
      ACSF = .0832 * ACS
      WPFIX = .0048*WPU+.04953*(P1X+P2X)
      RESID = WPFIX + PRESS + ACSF
      IF(I-2) 80,212,96
   80 WSS = .0007555*(6.604-D)*WPU*G
      GO TO 19
```

```
96    TCS=TCS+2.*[2.*SAOSPH+SAOCYL+2.*SAFSPH+SAFCYL]*0.0065
      IF[I-4] 212,80,80
212   WSS = 0.0
19    DENG = ENG
      DT = T
      ENGX = ENG
      TX = T
      IF[X-2.] 94,94,303
303   X = X-1.0
92    ENGX    = X*DENG
      SUPE = 8.21E-03*DENG*G
      SUPE1 = .000846364*DT
      IF [SUPE-SUPE1] 15,16,16
15    SUPE=SUPE1
16    SUPE=X*SUPE
      TX    = X*DT
      X = X+1.
      IF[X-6.] 94,221,221
  221 PRINT 9
      GO TO 83
94    SUPT=.000611*WPU*G
      IF [ NCODE-2]  135,135,135
135   TIMEN2 = TIME * 86164.09
      IT = TIMEN2*2.6587303632E-05
      WN2 = IT * .04135338
      WTANN2 = 1.32 * WN2
      HDWACS = 15.42214058
      ACS=WTANN2+HDWACS
  500 BS=RIFR+STLO+BSMISC
      SUPF = 34.200864698
      SM = 12.972741782
      STR=WSS+BS+BEAM+XMP+SUPF+SM
      SUPET = SUPE + SUPT
      TS = 16.646839979
      PROPU=ENGX+FS+DS+HEL+SUPET+TS
      SEN = 7.172150976*D**.5
      COSE = 8.111361222*D**.5
      CONTCO = 12.722029707*D**.5
      ACT = 8.566735888*D**.5
      ART = 11.583593044*D**.5
      GC=SEN+COSE+CONTCO+ACT+ART
      RAD = 55.79186151
      TEL = 5.54987831*D**.5
      DATAS = 15.42214058
      ANTE = 34.708087757*D**.5
      COM = 6.375245312*D**.5
      SURE = 15.87573295
      XINST=RAD+TEL+DATAS+ANTE+COM+SURE
      BAT = 2.26796185
      PWRC = 74.38914868
      EP=RTG+BAT+PWRC
      XNETW = 61.190970626*D**.5
      PYR = 7.636063916*D**.5
      EN=XNETW+PYR
      TCS=.055*[STR+EM+GC+XINST+EP+EN+ACS+SCIEN]
```

```
      EQUI=EM+GC+XINST+EP+EN+TCS+ACS+SCIEN
      CONTIG = .05 * [STR + PROPU + EQUI]
      TDS=STR+PROPU+EQUI+CONTIG
      TIS=RESID+TDS
      WF=WPU/[1.+XMR]
      WO=WPU-WF
      WPUT=WF+WO+WN2
      TSAL=TIS+WFUT
      TPVAL=TSAL+CAPS
      TPVA=TPVAL+ADAP
      WBO = TIS + CAPS
      WBF = TPVAL - CAPS-WN2
      DV=9.80665*XISP*ALOG[[WBO+WPU]/WBO]
      TW = TX  /[WPU+W30]
      IF[NCODE-2] 202,203,203
  202 IF[TW-XTW] 92,93,93
  203 IF[TW-XTW] 92,98,98
   98 IF[ABS[DV-DV1]-.01] 93,93,124
  124 IF[DV1-DV] 82,82,85
   85 IF[NCODE-4] 121,121,603
  603 IF[NCODE-6] 123,604,604
  604 H = H+DH
      GO TO 602
  123 CAPS = CAPS-DCAPS
      DCAPS = 0.5*DCAPS
      GO TO 84
  121 GO TO [314,315],K3
  314 WPU = WPU+DWPU
      GO TO 84
  315 H = H+DH
      GO TO 84
   92 IF[NCODE-4] 125,125,605
  605 IF[NCODE-6] 126,606,606
  606 H = H-DH
      DH = 0.5*DH
      GO TO 602
  126 CAPS = CAPS+DCAPS
      GO TO 84
  125 GO TO [316,317],K3
  316 WPU = WPU-DWPU
      DWPU = DWPU*.5
      GO TO 84
  317 H = H-DH
      DH =  0.1*DH
      GO TO 84
   93 X = X-1.
      BURN = 9.80665*WPU*XISP/TX
      IF[BURN-BTM] 300,300,301
  301 PRINT 2,BTM
      X = X+1.
      DH = 0.254
      GO TO 92
  300 IF[NCODE-4] 114,115,607
  607 IF[NCODE-6] 115,609,609
  609 HMX = H
```

```
      GO TO 53
  115 TPVL=TIS+CAPS+WPUT
      PRINT 118,X,D,H,DV,CAPS,WPUT,RESID,TIS,TPVL
      IF(NCODE-4) 116,116,117
  116 CAPS = CAPS+DCAPS
      X = X + 1.0
      IF(TPVL-DV2) 106,106,83
  117 D = D+DD
      DCAPS = 453.59237
      X = X + 1.0
      IF(D-6.858) 84,83,83
  114 IF(XL1) 53,53,52
   52 PRINT 3,X,D,HMX,WPUT,TIS,DV,R1,R2,V1,V2,XL1,XL2,TW,BURN
      GO TO 54
   53 PRINT 3,X,D,HMX,WPUT,TIS,DV,R1,R2,V1,V2,XL1,XL2,TW,BURN
   54 IF(NCODE-2) 413,412,412
  412 PRINT 414
      PRINT 415,BS,XMP,FS,OS,SUPT,SUPE,HEL,ACS,CONTIG,RESID,WF,WO
  413 IF(NCODE-2) 204,83,205
  206 H = H+0.254
      X = X+1.
      GO TO 106
  204 IF(H-12.7) 206,83,83
  205 IF(DV1-  DV3) 83,99,83
   99 DV1 = DV2
      CAPS=WBO-TIS
      X = 2.0
      GO TO 134
   83 IF(MCODE)530,530,531
  531 N=X
      CALL HELP
  530 IF(K)10,10,70
   70 CALL EXIT
      END
```

COMMON ALLOCATION

77776	STR	77774	BS	77772	RIFR	77770	STLO
77766	BSMISC	77764	BEAM	77762	XMP	77760	SUPF
77756	SM	77754	PROPU	77753	N	77751	ENGX
77747	FS	77745	OS	77743	SUPET	77741	HEL
77737	TS	77735	EQUI	77733	EM	77731	GC
77727	SEN	77725	COSE	77723	CONTCC	77721	ACT
77717	ART	77715	XINST	77713	RAD	77711	TEL
77707	DATAS	77705	ANTE	77703	COM	77701	SURE
77677	EP	77675	RTG	77673	BAT	77671	PWRC
77667	EN	77665	XNETW	77663	PYR	77661	TCS
77657	ACS	77655	WTANN2	77653	HDWACS	77651	SCIEN
77647	CONTIG	77645	TDS	77643	RESID	77641	WPFIX
77637	PRESS	77635	ACSF	77633	TIS	77631	WPUT
77627	WF	77625	WO	77623	WN2	77621	TSAL
77617	CAPS	77615	TPVAL	77613	ADAP	77611	TPVA

PROGRAM ALLOCATION

00020	I	00021	NCODE	00022	MCODE	00023	K
00024	K3	00025	IT	00026	HM	00030	P1
00032	P2	00034	XMR	00036	D	00040	DV1
00042	DV2	00044	XTW	00046	T	00050	XISP
00052	ENG	00054	UP	00056	TIME	00060	G1
00062	G2	00064	FMAX	00066	OMAX	00070	XSTR
00072	BTM	00074	DV3	00076	X	00100	G
00102	P1X	00104	P2X	00106	PI	00110	R1
00112	R2	00114	WFU	00116	DWPU	00120	VR
00122	H	00124	DH	00126	V1	00130	V2
00132	P	00134	C1	00136	C2	00140	XL1
00142	XL2	00144	SAOSPH	00146	SAFSPH	00150	SAOCYL
00152	SAFCYL	00154	DCAPS	00156	DD	00160	RN
00162	CK	00164	RX	00166	VA	00170	VB
00172	HX	00174	DR1	00176	VRX	00200	HMX
00202	RI	00204	FR	00206	STRI	00210	XLON
00212	SUPT	00214	TKOBOT	00216	TKOCYL	00220	TKOTOP
00222	TKFBOT	00224	TKFCYL	00226	TKFTOP	00230	WTANO
00232	WTANF	00234	WPGT	00236	WPGTSUP	00240	WPGTPLUM
00242	SUPE	00244	SUPE1	00246	WSS	00250	DENG
00252	DT	00254	TX	00256	TIMEN2	00260	WBO
00262	WBF	00264	DV	00266	TW	00270	BURN
00272	TPVL						

SUBPROGRAMS REQUIRED

SQRT OFFLD ABS ALOG HELP EXIT

THE END

```
      SUBROUTINE HELP
C     SUBROUTINE HELP WHEN CALLED WILL PRINT OUT A R-AERO-X TYPE WEIGHT
C     STATEMENT FOR THE VEHICLE
C     HELP IS BEST USED WITH NCODE = 2, WHEN USED WITH OTHER CODES THE
C     OUTPUT IS APT TO BE EXCESSIVELY LONG AND CONFUSING
      COMMON STR,SS,RIFR,STLP,BSMISC,BEAM,WMP,SUFF,SM,PROPUL,N,ENGX,FS,
     1OS,SUPFT,HEL,TS,EQUI,EM,GC,SEN,COSE,CONTCO,ACT,ART,XINST,RAD,TEL,
     2DATAS,ANTE,COM,SURE,EP,RTG,BAT,PWRC,EN,XNETW,PYR,TCS,ACS,WTANK2,
     3HDWACS,SCIEN,CONTIG,TDS,RESID,WPFIX,PRESS,ACSF,TIS,WPUT,WF,WO,WN2,
     4TSAL,CAPS,TPVAL,ADAP,TPVA
 1000 FORMAT(1H1,34X,$ WEIGHT SUMMARY $,/)
 1001 FORMAT(14X,$ ITEM $,45X,$ WEIGHT (KILOGRAMS)$,//)
 1002 FORMAT(5X,$ STRUCTURE $,49X,F14.4)
 1003 FORMAT(7X,$ BASIC SHELL $,38X,F12.4)
 1004 FORMAT(9X,$ RINGS AND FRAMES $,28X,F10.4)
 1005 FORMAT(9X,$ STRINGERS AND LONGERONS $,21X,F10.4)
 1006 FORMAT(9X,$ MISCELLANEOUS $,31X,F10.4)
 1007 FORMAT(7X,$ SYSTEM SUPPORTS (BEAMS) $,26X,F12.4)
 1008 FORMAT(7X,$ MICROMETEOROID PROTECTION $,24X,F12.4)
 1009 FORMAT(7X,$ SUPPORTS (ANTENNA AND SCAN PLATFORM)$,14X,F12.4)
 1010 FORMAT(7X,$ SEPARATION MECHANISM $,29X,F12.4)
 1011 FORMAT(5X,$ PROPULSION $,48X,F14.4)
 1012 FORMAT(7X,$ ENGINE (MAIN) ($,I2,$) $,29X,F14.4)
 1013 FORMAT(7X,$ FUEL SYSTEM (2) $,34X,F12.4)
 1014 FORMAT(7X,$ OXIDIZER SYSTEM (2) $,30X,F12.4)
 1015 FORMAT(7X,$ SUPPORTS (MAIN ENGINE AND TANKS) $,17X,F12.4)
 1016 FORMAT(7X,$ PRESSURIZATION SYSTEM $,28X,F12.4)
 1017 FORMAT(7X,$ TELEMETRY SENSORS $,32X,F12.4)
 1018 FORMAT(5X,$ EQUIPMENT AND INSTRUMENTATION $,29X,F14.4)
 1019 FORMAT(7X,$ STRUCTURE $,40X,F12.4)
 1020 FORMAT(7X,$ GUIDANCE, CONTROL AND NAVIGATION $,17X,F12.4)
 1021 FORMAT(9X,$ SENSORS $,37X,F10.4)
 1022 FORMAT(9X,$ COMPUTER/SEQUENCER $,26X,F10.4)
 1023 FORMAT(9X,$ CONTROL COMPUTER $,28X,F10.4)
 1024 FORMAT(9X,$ SERVO ACTUATORS $,29X,F10.4)
 1025 FORMAT(9X,$ ARTICULATION EQP. $,27X,F10.4)
 1026 FORMAT(7X,$ INSTRUMENTATION $,34X,F12.4)
 1027 FORMAT(9X,$ RADIO $,39X,F10.4)
 1028 FORMAT(9X,$ TELEMETRY $,35X,F10.4)
 1029 FORMAT(9X,$ DATA SYSTEM $,33X,F10.4)
 1030 FORMAT(9X,$ ANTENNAS $,36X,F10.4)
 1031 FORMAT(9X,$ COMMAND $,37X,F10.4)
 1032 FORMAT(9X,$ MEASUREMENT $,33X,F10.4)
 1033 FORMAT(7X,$ ELECTRIC POWER $,35X,F12.4)
 1034 FORMAT(9X,$ RTG SYSTEM $,34X,F10.4)
 1035 FORMAT(9X,$ BATTERIES $,35X,F10.4)
 1036 FORMAT(9X,$ POWER CONTROL $,31X,F10.4)
 1037 FORMAT(7X,$ ELECTRIC NETWORKS $,32X,F12.4)
 1038 FORMAT(9X,$ NETWORKS $,36X,F10.4)
 1039 FORMAT(9X,$ PYROTECHNICS $,32X,F10.4)
 1040 FORMAT(7X,$ TEMPERATURE CONTROL SYSTEM $,23X,F12.4)
 1041 FORMAT(7X,$ ATTITUDE CONTROL SYSTEM $,26X,F12.4)
 1042 FORMAT(9X,$ TANKS $,39X,F10.4)
 1043 FORMAT(9X,$ HARDWARE $,36X,F10.4)
```

```
*  1044  FORMAT(7X,$ SCIENCE (INSTRUMENTS AND SCAN PLATFORM) $,10X,F12.4)
*  1045  FORMAT(5X,$ CONTINGENCY $,47X,F14.4/69X,$------------$)
*  1046  FORMAT(10X,$ TOTAL DRY SPACECRAFT $,32X,F15.4)
*  1047  FORMAT(5X,$ RESIDUALS $,49X,F14.4)
*  1048  FORMAT(7X,$ PROPELLANTS $,38X,F12.4)
*  1049  FORMAT(7X,$ PRESSURANTS $,38X,F12.4)
*  1050  FORMAT(7X,$ ATTITUDE CONTROL SYSTEM FLUIDS $,19X,F12.4/69X,$------
*       1-----$,/)
*  1051  FORMAT(10X,$ TOTAL INERT SPACECRAFT $,30X,F15.4)
*  1052  FORMAT(5X,$ USABLE PROPELLANT $,40X,F15.4)
*  1053  FORMAT(7X,$ FUEL $,45X,F12.4)
*  1054  FORMAT(7X,$ OXIDIZER $,41X,F12.4)
*  1055  FORMAT(7X,$ NITROGEN $,41X,F12.4/69X,$------------$)
*  1056  FORMAT(10X,$ TOTAL SPACECRAFT AT LAUNCH $,26X,F15.4)
*  1057  FORMAT(5X,$ CAPSULE $,50X,F15.4/69X,$------------$)
*  1058  FORMAT(10X,$ TOTAL PLANETARY VEHICLE AT LAUNCH $,19X,F15.4)
*  1059  FORMAT(5X,$ ADAPTER $,51X,F14.4/69X,$------------$)
*  1060  FORMAT(10X,$ TOTAL PLANETARY VEHICLE + ADAPTER $,19X,F15.4//)
*        PRINT 1000
*        PRINT 1001
*        PRINT 1002,STR
*        PRINT 1003,BS
*        PRINT 1004,RIFR
*        PRINT 1005,STLD
*        PRINT 1006,BSMISC
*        PRINT 1007,BEAM
*        PRINT 1008,XMP
*        PRINT 1009,SUPF
*        PRINT 1010,SM
*        PRINT 1011,PROPJ
*        PRINT 1012,N,ENGX
*        PRINT 1013,FS
*        PRINT 1014,OS
*        PRINT 1015,SUPET
*        PRINT 1016,HEL
*        PRINT 1017,TS
*        PRINT 1018,EQUI
*        PRINT 1019,EM
*        PRINT 1020,GC
*        PRINT 1021,SEN
*        PRINT 1022,COSE
*        PRINT 1023,CONTCO
*        PRINT 1024,ACT
*        PRINT 1025,ART
*        PRINT 1026,XINST
*        PRINT 1027,RAD
*        PRINT 1028,TEL
*        PRINT 1029,DATAS
*        PRINT 1030,ANTE
*        PRINT 1031,COM
*        PRINT 1032,SURE
*        PRINT 1033,EP
*        PRINT 1034,RTG
*        PRINT 1035,BAT
*        PRINT 1036,PWRC
```

```
      PRINT 1037,EN
      PRINT 1038,XNETW
      PRINT 1039,PYR
      PRINT 1040,TCS
      PRINT 1041,ACS
      PRINT 1042,WTANN2
      PRINT 1043,HOWACS
      PRINT 1044,SCIEN
      PRINT 1045,CONTIG
      PRINT 1046,TCS
      PRINT 1047,RESID
      PRINT 1048,WPFIX
      PRINT 1049,PRESS
      PRINT 1050,ACSF
      PRINT 1051,TIS
      PRINT 1052,WPUT
      PRINT 1053,WF
      PRINT 1054,WO
      PRINT 1055,WN2
      PRINT 1056,TSAL
      PRINT 1057,CAPS
      PRINT 1058,TPVAL
      PRINT 1059,ADAP
      PRINT 1060,TPVA
      RETURN
      END
```

COMMON ALLOCATION

77776 STR	77774 BS	77772 RIFR	77770 STLO
77766 BSMISC	77764 BEAM	77762 XMP	77760 SUPF
77756 SM	77754 PROPU	77753 N	77751 ENGX
77747 FS	77745 OS	77743 SUPET	77741 HEL
77737 TS	77735 EQUI	77733 EM	77731 GC
77727 SEN	77725 COSE	77723 CONTCO	77721 ACT
77717 ART.	77715 XINST	77713 RAD	77711 TEL
77707 DATAS	77705 ANTE	77703 COM	77701 SURE
77677 EP	77675 RTG	77673 BAT	77671 PWRC
77667 EN	77665 XNETW	77663 PYR	77661 TCS
77657 ACS	77655 WTANN2	77653 HOWACS	77651 SCIEN
77647 CONTIG	77645 TOS	77643 RESID	77641 WPFIX
77637 PRESS	77635 ACSF	77633 TIS	77631 WPUT
77627 WF	77625 WO	77623 WN2	77621 TSAL
77617 CAPS	77615 TPVAL	77613 ADAP	77611 TPVA

PROGRAM ALLOCATION

00000 HELP

THE END

```
      SUBROUTINE OFFLD [R1,R2,WPU,CWPU,H,C1,C2,XL1,XL2,V1,V2,XMR,P1X,P2X
     1]
      IF[R1-R2]2,2,1
    1 H = 2.*R1+0.1016
      GO TO 3
    2 H = 2.*R2+0.1016
    3 V1 = 4.18879*R1**3
      V2 = 4.18879*R2**3
      WP = 2.*[V1*P1X+V2*P2X]/1.05
      IF[WP-WPU]4,13,13
    4 VF = WPU/[[XMR+1.]*P2X]/2.
      V0 = WPU*XMR/[[XMR+1.]*P1X]/2.
      EX1 = V0-V1
      EX2 = VF-V2
      XL1 = EX1/[3.14159*R1**2]
      XL2 = EX2/[3.14159*R2**2]
      C1 = 0.0
      C2 = 0.0
      IF[XL1]7,7,6
    6 IF[XL2]8,8,9
    7 XL1 = 0.0
      C1 = 0.0
      V0 = V1
      GO TO 6
    8 XL2 = 0.0
      C2 = 0.0
      VF = V2
    9 IF[XL1-XL2]11,11,10
   10 H = 2.*R1+XL1+0.1016
      GO TO 12
   11 H = 2.*R2+XL2+0.1016
   12 V1 = V0
      V2 = VF
      GO TO 14
   13 XL1 = 0.0
      XL2 = 0.0
      C1 =0.0
      C2 = 0.0
   14 RETURN
      END
```

PROGRAM ALLOCATION

00036 OFFLD	DUMMY R1	DUMMY R2	DUMMY H
DUMMY V1	DUMMY V2	00040 WP	DUMMY P1X
DUMMY P2X	DUMMY WPU	00042 VF	DUMMY XMR
00044 V0	00046 EX1	00050 EX2	DUMMY XL1
DUMMY XL2	DUMMY C1	DUMMY C2	

THE END

```
ΔASSIGN BI=MT1.
ΔREWIND MT1.
ΔFORTLOAD =BIU.
```

Table 2A: Program Listing for Two-Propellant-Tank Spacecraft Design

```
ΔJOB.
ΔASSIGN S=MTO,SI=CR,BP=MT1,LO=LP.
ΔREWIND MT1.
ΔFORTRAN 50,LO.
      C    R-AERO-X SPACECRAFT PRELIMINARY DESIGN PROGRAM
           COMMON STR,BS,RIFR,STLS,BSMISC,BEAM,WMP,SUFF,SM,PROPUN,ENGX,FS,
          1OS,SUPST,HEL,TS,EQUI,EM,GC,SEN,COSE,CONTCO,ACT,ART,XINST,RAC,TEL,
          2DATAS,ANTE,COM,SURE,EP,SOLAR,BAT,PARC,EN,XNETW,PYR,TCS,ACS,WTANN2,
          3HDWACS,SCIEN,CONTIG,TDS,RESID,WPFIX,PRESS,ACSF,TIS,WPUT,WF,WO,WN2,
          4TSAL,CAPS,TPVAL,ADAP,TPVA
      1    FORMAT(7F14.4)
      2    FORMAT(20H MAXIMUM BURN TIME =,F2.1,14H SEC, EXCEEDED)
      3    FORMAT(F5.0,F10.4,F8.4,F11.2,F10.1,F7.1,F9.4,F10.4,F10.5,F9.5,F8.4
          1,F7.4,F6.3,F8.1//)
      4    FORMAT(2X,$ OXIDIZER $,2X,$ FUEL $,2X,$ MIXTURE $,25X,$ MINIMUM $,
          113X,$ ULLAGE $,21X,$ ENGINE $,/,3X,$ DENSITY $,1X,$ DENSITY $,1X,$
          2 RATIO $,1X,$ CAPSULE $,2X,$ DV1 $,2X,$ DV2 $,1X,$ T/W RATIO $,1X,
          3$ TIME $,4X,$ PRESSURE $,3X,$ THRUST $,3X,$ ISP $,3X,$ WT. $,1X,$
          4 MCODE $,/,1X,$ [GM/CU.CM][GM/CU.CM] $,10X,$ [KG] $,2X,$ [M/S]  [M
          5/S] $,11X,$ [DAYS] $,3X,$ [N/SQ.M] $,4X,$ [N] $,5X,$ [S] $,2X,$ [K
          6G] $,//)
      5    FORMAT(2F10.3,F9.2,F10.2,F8.1,F7.1,F9.3,F10.1,F14.3,F12.4,F7.1,F9.
          13,I5///)
      7    FORMAT(37X,$ TOTAL               OXIDIZER    FUEL   OXIDIZER   FUEL $/2
          1X,$ NO.     STAGE   STAGE  PROPELLANT   INERT   DELTA    TANK
          2TANK      TANK      TANK                                BURN $/$ ENGINES
          3 DIA   LENGTH    WEIGHT    WEIGHT      V     RADIUS    RADIUS   VOL
          4UME   VOLUME       XL1      XL2     T/W      TIME $,/,10X,$ [M] $,3X,$ [M]
          5 $,4X,$ [KG] $,4X,$ [KG] $,2X,$ [M/S] $,2X,$ [P] $,5X,$ [M] $,3X,$
          6 [CU.M] $,1X,$ [CU.M] $,3X,$ [M] $,2X,$ [M] $,9X,$ [S] $,///)
      8    FORMAT(2F10.1,4I5)
      9    FORMAT(18H STAGE IMPRACTICAL)
      118  FORMAT(F6.0,F12.1,4F10.1,F12.1,2F11.1)
      119  FORMAT(93H     NO.       STAGE        STAGE      DELTA            PROPEL
          1LANT                STAGE     STARTING/94H ENGINES   DIAMETER    LE
          2NGTH         V       CAPSULE      WEIGHT      RESIDUALS   DRY WT.   GROSS
          3WT.//)
      414  FORMAT(1X,$ BASIC $,1X,$ XMETEOROID $,2X,$ FUEL $,2X,$ OXIDIZER $,
          13X,$ TANK $,3X,$ ENGINE $,1X,$ PRESSURIZATION $,/,
          21X,$ SHELL $,1X,$ PROTECTION $,1X,$ SYSTEM $,2X,$ SYSTEM $,2X,
          3$ SUPPORTS  SUPPORTS $,4X,$ SYSTEM $,4X,$ ACS $,1X,
          4 $ CONTINGENCY  RESIDUALS $,1X,$ FUEL $,1X,$ OXIDIZER $,/,2X,$ [KG
          5] $,4X,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,7X
          6,$ [KG] $,5X,$ [KG] $,4X,$ [KG] $,6X,$ [KG] $,3X,$ [KG] $,3X,$ [KG
          7] $,//)
      415  FORMAT(F8.3,2F11.3,2F10.3,F9.3,F13.3,F11.3,F10.3,F12.3,F10.3,F9.3/
          1/)
      900  FORMAT(1H1,40X,53HPRELIMINARY DESIGN DATA FOR SPACECRAFT
          1      //25X,22HOUTPUT FORMAT  NCODE =,I2,F10.1,15H G LONGITUDINAL,F
          210.1,10H G LATERAL//)
       10  READ 1,HM,P1,P2,XMR,D,CAPS,DV1
           READ 1,DV2,XTW,T,XISP,ENG,UP,TIME
           READ 1,G1,G2,RTG,SCIEN,ADAP,FMAX,OMAX
           READ 8,XSTR,BTM,I,NCODE,MCODE,K
```

```
      DV3 = DV1
      PRINT 900,NCODE,G1,G2
      PRINT 4
      PRINT 5,P1,P2,XMR,CAPS,DV1,DV2,XTW,TIME,UP,T,XISP,ENG,MCODE
      IF(NCODE-4) 134,120,608
 608  IF(NCODE-6) 120,134,134
  120 PRINT 119
      GO TO 122
  134 PRINT 7
 122  X = 2.
      G=SQRT(G1**2+G2**2)
      P1X = P1*1000
      P2X = P2*1000
      PI=3.1415926536
      IF (SENSE SWITCH 3) 308,309
 308  K3 = 1
      GO TO 307
 309  K3 = 2
 307  GO TO (310,311),K3
  310 R1 = DMAX
      R2 = FMAX
      WPU = 453.59237
      DWPU = 453.59237
      GO TO 84
 311  IF(FMAX) 510,510,511
  510 FMAX=25.4
 511  IF(DMAX) 512,512,550
  512 DMAX=25.4
 550  VR = P1X/(XMR*P2X)
      IF(NCODE-2) 107,108,74
 74   IF(NCODE-4) 108,110,600
 600  IF(NCODE-6) 113,601,601
 601  H = HM
      DH = 1.27
      DV3 = DV1-1.0
 602  D = (H-0.1016)*2.+0.381
      R1 = (H-0.1016)/2.
      V1 = 4./3.*PI*R1**3
      V2 = VR*V1
      R2 = (0.23873242*V2)**.333
      IF(R1-R2) 610,611,611
 610  R2 = R1
      V2 = V1
      V1 = V2/VR
      R1 = (0.23873242*V1)**.333
 611  P = 2.
      C1 = 1.
      C2 = 1.
      XL1 = 0.0
      XL2 = 0.0
      SAOSPH=6.283184*R1**2
      SAFSPH=6.283184*R2**2
      SAOCYL=0.0
      SAFCYL=0.0
      GO TO 91
```

```
 110  CAPS = 0.0
      CCAPS = 453.59237
      H = HM
      GO TO 106
 113  D = 2.54
      DD = 0.254
      H = HM
      CAPS = 0.0
      CCAPS = 453.59237
      GO TO 24
 107  H = 1.016
      GO TO 106
 108  H = 0.254
 106  DH = 0.254
 24   GO TO [312,313],K3
  312 CALL OFFLD  [R1,R2,XPU,DXPU,H,C1,C2,XL1,XL2,V1,V2,XMR,P1X,P2X]
      F = 2.
      GO TO 318
 313  C1 = 1.
      C2 = 1.
      XL1 = 0.0
      XL2 = 0.0
      RN = D/2.
      CK = [D-0.381]/4.
      IF[[H-0.1016]-2.*CK] 24,24,210
 24   R1 = [H-0.1016]/2.
      V1 = 4.18879*R1**3
      V2 = VR*V1
      R2 = [0.23873242*V2]**.333
      IF[R1-R2] 28,29,29
 28   R2 = [H-0.1016]/2.
      V2 = 4.18879*R2**3
      V1 = V2/VR
      R1 = [0.23873242*V1]**.333
 29.  SAOSPH=6.283184*R1**2
      SAFSPH=6.283184*R2**2
      SAOCYL=0.0
      SAFCYL=0.0
      P = 1.0
      RX = [RN*[RN-R1-0.254]+0.3175]/[RN+R1]
      IF[R2-RX] 517,517,210
 210  IF[OMAX-25.4] 518,25,518
 517  IF[R2-FMAX] 91,91,518
   518 R1=OMAX
      R2=FMAX
      VA=1.33333*PI*R1**3
      VB=[H-0.1016-2.*R1]*R1**2*PI
      V1=VA+VB
      XL1=H-0.1016-2.*R1
      V2=VR*V1
      VA=1.33333*PI*R2**3
      VB=V2-VA
      XL2=VB/[PI*R2**2]
      P=2.
      HX=XL2+0.1016+2.*R2
```

```
      IF[HX-H] 516,91,91
  516 XL2=H-0.1016-2.*R2
      VB=XL2*PI*R2**2
      V2=VA+VB
      V1=V2/VR
      VA=1.333333*PI*R1**3
      VB=V1-VA
      XL1=VB/[PI*R1**2]
      GO TO 91
 25   R1 = 0.0254
      DR1 = 0.254
      P = 2.0
 20   R2 = [RN*[RN-R1-0.254]+0.3175]/[RN+R1]
      V1 = 4.18879*R1**3+PI*R1**2*[H-2.*R1-0.1016]
      V2 = 4.18879*R2**3+PI*R2**2*[H-2.*R2-0.1016]
      VRX = V2/V1
      IF [ABS[VRX-VR]-.001] 40,40,30
 30   IF[VRX-VR] 43,43,42
 42   R1 = R1 + DR1
      GO TO 20
 43   R1 = R1-DR1
      DR1 = 0.1*DR1
      GO TO 20
   40 IF[R1-CK] 60,60,50
   50 R1 = CK
      C2 = 0.0
      R2 = [RN*[RN-R1-0.254]+0.3175]/[RN+R1]
      V1 = 4.18879*R1**3+PI*R1**2*[H-2.*R1-0.1016]
      V2 = VR*V1
      XL2 = [V2-4.18879*R2**3]/[PI*R2**2]
      IF[XL2] 76,76,91
 76   R2 = [0.23273242*V2]**.333
      XL2= 0.0
      GO TO 91
 60   IF [R2-CK]91,91,81
 81   R2 = CK
      C1= 0.0
      R1 = [RN*[RN-R2-0.254]+0.3175]/[RN+R2]
      V2 = 4.18879*R2**3+PI*R2**2*[H-2.*R2-0.1016]
      V1 = V2/VR
      XL1 = [V1-4.18879*R1**3]/[PI*R1**2]
      IF[XL1] 75,75,91
 75   R1 = [0.23873242*V1]**.333
      XL1= 0.0
 91   WPU = [P1X*V1+P2X*V2]/1.05
 318  IF[H-HP] 109,111,111
 109  HMX = HM
      GO TO 112
 111  HMX = H
  112 RI = .0413640*D*WPU**.5*G
      FR = .00928041*D*WPU**.5*G
      RIFR = RI + FR
      STRI = .31638*D*[HMX+1.016]*G
      XLON = .66791*D*[HMX+1.016]*G
      SKI = 2.42559*D*[HMX+1.016]*G
```

```
      STLO = STRI + XLGN + SKI
      BSMISC = 15.875733C
      BEAM = .03844742*D*WPU**.5*G
      IF(XSTR)525,525,526
  525 SUPT=.000736*WPU*G
      GO TO 527
  526 SUPT=WPU*G*.000611
527   IF(P-1.) 33,33,32
32    SAOSPH=6.283184*R1**2
      SAOCYL=(H-2*R1-0.1016)*6.283184*R1*C1+6.283184*R1*XL1
      SAFSPH=6.283184*R2**2
      SAFCYL=(H-2*R2-0.1016)*6.283184*R2*C2+6.283184*R2*XL2
33    TKOBOT=UP*R1/1082476880.4
      TKOCYL=UP*R1/541238440.2
      TKOTOP=UP*R1/1082476880.4
      TKFBOT=UP*R2/1082476880.4
      TKFCYL=UP*R2/541238440.2
      TKFTOP=UP*R2/1082476880.4
      IF(TKOBOT-0.00254) 400,401,401
400   TKOBOT=0.00254
401   IF(TKOCYL-0.00254) 402,403,403
402   TKOCYL=0.00254
403   IF(TKOTOP-0.00254) 404,405,405
404   TKOTOP=0.00254
405   IF(TKFBOT-0.00254) 406,407,407
406   TKFBOT=0.00254
407   IF(TKFCYL-0.00254) 408,409,409
408   TKFCYL=0.00254
409   IF(TKFTOP-0.00254) 410,411,411
410   TKFTOP=0.00254
411   WTANO=4428.7848*(SAOSPH*(TKOBOT+TKOTOP)+SAOCYL*TKOCYL)
      WTANF=4428.7848*(SAFSPH*(TKFBOT+TKFTOP)+SAFCYL*TKFCYL)
      OS = 1.4*WTANO
      FS = 1.4*WTANF
      PRESS = UP*(V1+V2)*6.10472293E-06/2.
      WPGT = 7.959931242*PRESS
      WPGTSUP = .012 * WPGT
      WPGTPLUM = .085*WPGT
      HEL = WPGT + WPGTSUP + WPGTPLUM
      IF(XSTR)523,523,524
  524 SUPE = .0002794*T
      GO TO 61
  523 SUPE = .0021378*ENG*D*G
      SUPE1 = .000220805*T*D
      IF (SUPE-SUPE1) 13,61,61
13    SUPE=SUPE1
61    V1=V1
      V2=V2
      XMP=0
      EM = 2.441184*D*G
      ACSF = .0832 * ACS
      WPFIX = .0048*WPU+.04953*(P1X+P2X)
      RESID = WPFIX + PRESS + ACSF
      IF(I-2) 80,212,96
   80 WSS = .0007555*(6.604-D)*WPU*G
```

```
      GO TO 19
 96   TCS=TCS+2.*(2.*SADSPH+SADCYL+2.*SAFSPH+SAFCYL)*0.0065
      IF(I-4) 212,90,90
 212  ASS = 0.0
 19   DENG = ENG
      DT = T
      ENGX = ENG
      TX = T
      IF(X-2.) 94,94,303
 303  X = X-1.0
 92   ENGX    = X*DENG
      SUPE = 3.21E-03*DENG*G
      SUPE1 = .000246364*DT
      IF (SUPE-SUPE1) 15,16,16
 15   SUPE=SUPE1
 16   SUPE=X*SUPE
      TX    = X*DT
      X = X+1.
      IF(X-6.) 94,221,221
  221 PRINT 3
      GO TO 83
 94   SUPT=.000611*APU*G
      IF ( NCODE-2)  135,135,135
 135  TIMEN2 = TIME * 86164.09
      IT = TIMEN2*2.6587303632E-05
      AN2 = IT * .04135338
      WTANN2 = 1.32 * AN2
      HDWACS = 15.42214058
      ACS=WTANN2+HDWACS
  500 BS=RIFR+STLD+BSMISC
      SUPF = 52.3445595
      SM = 12.972741782
      STR=ASS+BS+BEAM+XMP+SUPF+SM
      SUPET = SUPE + SUPT
      TS = 16.646839979
      PROPU=ENGX+FS+DS+HEL+SUPET+TS
      SEN = 6.815294572*D**.5
      COSE = 8.084313328*D**.5
      CONTCD = 12.575099592*D**.5
      ACT = 8.563735838*D**.5
      ART = 11.583593044*D**.5
      GC=SEN+COSE+CONTCD+ACT+ART
      RAD = 29.0299117
      TEL = 5.54987831*D**.5
      DATAS = 11.3398092
      ANTE = 27.76647021*D**.5
      COM = 6.375245312*D**.5
      SURE = 15.87573295
      XINST=RAD+TEL+DATAS+ANTE+COM+SURE
      SOLAR = 80.7394419
      BAT = 159.6645142
      PWRC = 71.2140021
      EP=SOLAR+BAT+PWRC
      XNETW = 58.097946599*D**.5
      PYR = 7.636063916*D**.5
```

```
      EN=XNETW+PYR
      TCS = .060*(STR+EM+GC+XINST+EP+EN+ACS+SCIEN)
      EQUI=EM+GC+XINST+EP+EN+TCS+ACS+SCIEN
      CONTIG = .05 * (STR + PROPU + EQUI)
      TDS=STR+PROPU+EQUI+CONTIG
      TIS=RESID+TDS
      WF=WPU/(1.+XMR)
      WO=WPU-WF
      WPUT=WF+WO+W2
      TSAL=TIS+WPUT
      TPVAL=TSAL+CAPS
      TPVA=TPVAL+ACAP
      WBO = TIS + CAPS
      WBF = TPVAL - CAPS-W2
      DV=9.80665*XISP*ALOG((WBO+WPU)/WBO)
      TW = TX  /(WPU+WBO)
      IF(NCODE-2) 202,203,203
  202 IF(TW-XTW) 92,93,93
  203 IF(TW-YTW) 92,98,98
   98 IF(ABS(DV-DV1)-.01) 93,93,124
  124 IF(DV1-DV) 82,82,85
   85 IF(NCODE-4) 121,121,603
  603 IF(NCODE-6) 123,604,604
  604 H = H+DH
      GO TO 602
  123 CAPS = CAPS-DCAPS
      DCAPS = 0.5*DCAPS
      GO TO 84
  121 GO TO (314,315),K3
  314 WPU = WPU+DWPU
      GO TO 84
  315 H = H+DH
      GO TO 84
   82 IF(NCODE-4) 125,125,605
  605 IF(NCODE-6) 126,606,606
  606 H = H-DH
      DH = 0.5*DH
      GO TO 602
  126 CAPS = CAPS+DCAPS
      GO TO 84
  125 GO TO (316,317),K3
  316 WPU = WPU-DWPU
      DWPU = DWPU*.5
      GO TO 84
  317 H = H-DH
      DH =  0.1*DH
      GO TO 84
   93 X = X-1.
      BURN = 9.80665*WPU*XISP/TX
      IF(BURN-BTM) 300,300,301
  301 PRINT 2,BTM
      X = X+1.
      DH = 0.254
      GO TO 92
  300 IF(NCODE-4) 114,115,607
```

```
607   IF(NCODE-6) 115,609,609
609   HMX = P
      GO TO 53
  115 TPVL=TIS+CAPS+WPUT
      PRINT 118,X,D,H,DV,CAPS,WPUT,RESID,TIS,TPVL
      IF(NCODE-4) 116,116,117
116   CAPS = CAPS+DCAPS
      X = X + 1.0
      IF(TPVL-DV2) 106,106,83
117   D = D+DD
      DCAPS = 453.59237
      X = X + 1.0
      IF(D-6.858) 84,83,83
114   IF(XL1) 53,53,52
   52 PRINT 3,X,D,HMX,WPUT,TIS,DV,R1,R2,V1,V2,XL1,XL2,TW,BURN
      GO TO 54
   53 PRINT 3,X,D,HMX,WPUT,TIS,DV,R1,R2,V1,V2,XL1,XL2,TW,BURN
54    IF(NCODE-2) 413,412,412
  412 PRINT 414
      PRINT 415,BS,XMP,FS,OS,SUPT,SUPE,HEL,ACS,CONTIG,RESID,WF,WO
413   IF(NCODE-2) 204,83,205
206   H = H+0.254
      X = X+1.
      GO TO 106
204   IF(H-12.7) 206,83,83
205   IF(DV1- DV3) 83,99,83
99    DV1 = DV2
      CAPS=WBC-TIS
      X = 2.0
      GO TO 134
83    IF(MCODE)530,530,531
  531 N=X
      CALL HELP
530   IF(K)10,10,70
   70 CALL EXIT
      END
```

COMMON ALLOCATION

77776 STR	77774 BS	77772 RIFR	77770 STLO
77766 BSMISC	77764 BEAM	77762 XMP	77760 SUPF
77756 SM	77754 PROPU	77753 N	77751 ENGX
77747 FS	77745 OS	77743 SUPET	77741 HEL
77737 TS	77735 EQUI	77733 EM	77731 GC
77727 SEN	77725 COSE	77723 CONTCO	77721 ACT
77717 ART	77715 XINST	77713 RAD	77711 TEL
77707 DATAS	77705 ANTE	77703 COM	77701 SURE
77677 EP	77675 SOLAR	77673 BAT	77671 PWRC
77667 EN	77665 XNETW	77663 PYR	77661 TCS
77657 ACS.	77655 WTANN2	77653 HDWACS	77651 SCIEN
77647 CONTIG	77645 TOS	77643 RESID	77641 WPFIX
77637 PRESS	77635 ACSF	77633 TIS	77631 WPUT
77627 WF	77625 WO	77623 WN2	77621 TSAL
77617 CAPS	77615 TPVAL	77613 ADAP	77611 TPVA

PROGRAM ALLOCATION

00020 I	00021 NCODE	00022 MCODE	00023 K
00024 K3	00025 IT	00026 HM	00030 P1
00032 P2	00034 XMR	00036 D	00040 DV1
00042 DV2	00044 XTW	00046 T	00050 XISP
00052 ENG	00054 UP	00056 TIME	00060 G1
00062 G2	00064 RTG	00066 FMAX	00070 OMAX
00072 XSTR	00074 BTM	00076 DV3	00100 X
00102 G	00104 P1X	00106 P2X	00110 PI
00112 R1	00114 R2	00116 WPU	00120 DWPU
00122 VR	00124 H	00126 DH	00130 V1
00132 V2	00134 P	00136 C1	00140 C2
00142 XL1	00144 XL2	00146 SAOSPH	00150 SAFSPH
00152 SAOCYL	00154 SAFCYL	00156 DCAPS	00160 DD
00162 RN	00164 CK	00166 RX	00170 VA
00172 V3	00174 HX	00176 DR1	00200 VRX
00202 HMX	00204 RI	00206 FR	00210 STRI
00212 XLON	00214 SKI	00216 SUPT	00220 TKOBOT
00222 TKOCYL	00224 TKOTOP	00226 TKFBOT	00230 TKFCYL
00232 TKFTOP	00234 WTANO	00236 WTANF	00240 WPGT
00242 WPGTSUP	00244 WPGTPLUM	00246 SUPE	00250 SUPE1
00252 WSS	00254 DENG	00256 DT	00260 TX
00262 TIMEN2	00264 WBC	00266 WBF	00270 DV
00272 TW	00274 BURN	00276 TPVL	

SUBPROGRAMS REQUIRED

SQRT OFFLD ABS ALOG HELP EXIT

THE END

```
      SUBROUTINE HELP
C     SUBROUTINE HELP WHEN CALLED WILL PRINT OUT A R-AERO-X TYPE WEIGHT
C     STATEMENT FOR THE VEHICLE
C     HELP IS BEST USED WITH NCODE = 2, WHEN USED WITH OTHER CODES THE
C     OUTPUT IS APT TO BE EXCESSIVELY LONG AND CONFUSING
      COMMON STR,BS,RIFR,STLO,BSMISC,BEAM,MMP,SUPF,SM,PROPULN,ENGX,FS,
     1OS,SUPPT,PEL,TS,EQUI,EM,GC,SEN,COSE,CONTCO,ACT,ART,XINST,RAD,TEL,
     2DATAS,ANTE,COM,SURE,EP,SOLAR,BAT,PWRC,EN,XNETW,PYR,TCS,ACS,WTANK2,
     3HDWACS,SCIEN,CONTIG,TDS,RESID,WPFIX,PRESS,ACSF,TIS,WPUT,WF,WO,WN2,
     4TSAL,CAPS,TPVAL,ADAP,TPVA
 1000 FORMAT(1H1,34X,$ WEIGHT SUMMARY $,/)
 1001 FORMAT(14X,$ ITEM $,45X,$ WEIGHT (KILOGRAMS)$,//)
 1002 FORMAT(5X,$ STRUCTURE $,49X,F14.4)
 1003 FORMAT(7X,$ BASIC SHELL $,38X,F12.4)
 1004 FORMAT(9X,$ RINGS AND FRAMES $,28X,F10.4)
 1005 FORMAT(9X,$ STRINGERS, LONGERONS AND SKINS $,14X,F10.4)
 1006 FORMAT(9X,$ MISCELLANEOUS $,31X,F10.4)
 1007 FORMAT(7X,$ SYSTEM SUPPORTS (BEAMS) $,26X,F12.4)
 1008 FORMAT(7X,$ MICROMETEOROID PROTECTION $,24X,F12.4)
 1009 FORMAT(7X,$ SUPPORTS (ANT.,SCAN PLAT.,AND SOLAR ARR.)$,9X,F12.4)
 1010 FORMAT(7X,$ SEPARATION MECHANISM $,28X,F12.4)
 1011 FORMAT(5X,$ PROPULSION $,48X,F14.4)
 1012 FORMAT(7X,$ ENGINE (MAIN) ($,I2,$) $,29X,F14.4)
 1013 FORMAT(7X,$ FUEL SYSTEM (1) $,34X,F12.4)
 1014 FORMAT(7X,$ OXIDIZER SYSTEM (1) $,30X,F12.4)
 1015 FORMAT(7X,$ SUPPORTS (MAIN ENGINE AND TANKS) $,17X,F12.4)
 1016 FORMAT(7X,$ PRESSURIZATION SYSTEM $,28X,F12.4)
 1017 FORMAT(7X,$ TELEMETRY SENSORS $,32X,F12.4)
 1018 FORMAT(5X,$ EQUIPMENT AND INSTRUMENTATION $,29X,F14.4)
 1019 FORMAT(7X,$ STRUCTURE $,40X,F12.4)
 1020 FORMAT(7X,$ GUIDANCE, CONTROL AND NAVIGATION $,17X,F12.4)
 1021 FORMAT(9X,$ SENSORS $,37X,F10.4)
 1022 FORMAT(9X,$ COMPUTER/SEQUENCER $,26X,F10.4)
 1023 FORMAT(9X,$ CONTROL COMPUTER $,28X,F10.4)
 1024 FORMAT(9X,$ SERVO ACTUATORS $,29X,F10.4)
 1025 FORMAT(9X,$ ARTICULATION EQP. $,27X,F10.4)
 1026 FORMAT(7X,$ INSTRUMENTATION $,34X,F12.4)
 1027 FORMAT(9X,$ RADIO $,39X,F10.4)
 1028 FORMAT(9X,$ TELEMETRY $,35X,F10.4)
 1029 FORMAT(9X,$ DATA SYSTEM $,33X,F10.4)
 1030 FORMAT(9X,$ ANTENNAS $,36X,F10.4)
 1031 FORMAT(9X,$ COMMAND $,37X,F10.4)
 1032 FORMAT(9X,$ MEASUREMENT $,33X,F10.4)
 1033 FORMAT(7X,$ ELECTRIC POWER $,35X,F12.4)
 1034 FORMAT(9X,$ SOLAR ARRAY $,33X,F10.4)
 1035 FORMAT(9X,$ BATTERIES $,35X,F10.4)
 1036 FORMAT(9X,$ POWER CONTROL $,31X,F10.4)
 1037 FORMAT(7X,$ ELECTRIC NETWORKS $,32X,F12.4)
 1038 FORMAT(9X,$ NETWORKS $,36X,F10.4)
 1039 FORMAT(9X,$ PYROTECHNICS $,32X,F10.4)
 1040 FORMAT(7X,$ TEMPERATURE CONTROL SYSTEM $,23X,F12.4)
 1041 FORMAT(7X,$ ATTITUDE CONTROL SYSTEM $,26X,F12.4)
 1042 FORMAT(9X,$ TANKS $,39X,F10.4)
 1043 FORMAT(9X,$ HARDWARE $,36X,F10.4)
```

```
1044  FORMAT(7X,$ SCIENCE (INSTRUMENTS AND SCAN PLATFORM) $,10X,F12.4)
1045  FORMAT(5X,$ CONTINGENCY $,47X,F14.4/69X,$------------$)
1046  FORMAT(10X,$ TOTAL DRY SPACECRAFT $,32X,F15.4)
1047  FORMAT(5X,$ RESIDUALS $,49X,F14.4)
1048  FORMAT(7X,$ PROPELLANTS $,38X,F12.4)
1049  FORMAT(7X,$ PRESSURANTS $,33X,F12.4)
1050  FORMAT(7X,$ ATTITUDE CONTROL SYSTEM FLUIDS $,19X,F12.4/69X,$------
     1------$,/)
1051  FORMAT(10X,$ TOTAL INERT SPACECRAFT $,30X,F15.4)
1052  FORMAT(5X,$ USABLE PROPELLANT $,40X,F15.4)
1053  FORMAT(7X,$ FUEL $,45X,F12.4)
1054  FORMAT(7X,$ OXIDIZER $,41X,F12.4)
1055  FORMAT(7X,$ NITROGEN $,41X,F12.4/69X,$------------$)
1056  FORMAT(10X,$ TOTAL SPACECRAFT AT LAUNCH $,26X,F15.4)
1057  FORMAT(5X,$ CAPSULE $,50X,F15.4/69X,$------------$)
1058  FORMAT(10X,$ TOTAL PLANETARY VEHICLE AT LAUNCH $,19X,F15.4)
1059  FORMAT(5X,$ ADAPTER $,51X,F14.4/69X,$------------$)
1060  FORMAT(10X,$ TOTAL PLANETARY VEHICLE + ADAPTER $,19X,F15.4//)
      PRINT 1000
      PRINT 1001
      PRINT 1002,STR
      PRINT 1003,BS
      PRINT 1004,RIFP
      PRINT 1005,STLS
      PRINT 1006,BSMISC
      PRINT 1007,BEAM
      PRINT 1008,XMP
      PRINT 1009,SUPF
      PRINT 1010,SM
      PRINT 1011,PROPU
      PRINT 1012,N,ENGX
      PRINT 1013,FS
      PRINT 1014,OS
      PRINT 1015,SUPET
      PRINT 1016,HEL
      PRINT 1017,TS
      PRINT 1018,EQUI
      PRINT 1019,EM
      PRINT 1020,GC
      PRINT 1021,SEN
      PRINT 1022,COSE
      PRINT 1023,CONTCO
      PRINT 1024,ACT
      PRINT 1025,ART
      PRINT 1026,XINST
      PRINT 1027,RAD
      PRINT 1028,TEL
      PRINT 1029,DATAS
      PRINT 1030,ANTE
      PRINT 1031,COM
      PRINT 1032,SURE
      PRINT 1033,EP
      PRINT 1034,SOLAR
      PRINT 1035,BAT
      PRINT 1036,PKRC
```

```
      PRINT 1037,EN
      PRINT 1038,XNETW
      PRINT 1039,PYR
      PRINT 1040,TCS
      PRINT 1041,ACS
      PRINT 1042,WTANN2
      PRINT 1043,HDWACS
      PRINT 1044,SCIEN
      PRINT 1045,CONTIG
      PRINT 1046,TDS
      PRINT 1047,RESID
      PRINT 1048,WPFIX
      PRINT 1049,PRESS
      PRINT 1050,ACSF
      PRINT 1051,TIS
      PRINT 1052,WPUT
      PRINT 1053,WF
      PRINT 1054,WD
      PRINT 1055,WN2
      PRINT 1056,TSAL
      PRINT 1057,CAPS
      PRINT 1058,TPVAL
      PRINT 1059,ADAP
      PRINT 1060,TPVA
      RETURN
      END

COMMON ALLOCATION

  77776 STR       77774 BS        77772 RIFR      77770 STLO
  77766 BSPISC    77764 BEAP      77762 XMP       77760 SUPF
  77756 SM        77754 PROPU     77753 N         77751 ENGX
  77747 FS        77745 OS        77743 SUPET     77741 HEL
  77737 TS        77735 EQUI      77733 EM        77731 GC
  77727 SEN       77725 CPSE      77723 CONTCO    77721 ACT
  77717 ART       77715 XINST     77713 RAD       77711 TEL
  77707 DATAS     77705 ANTE      77703 COM       77701 SURE
  77677 EP        77675 SOLAR     77673 BAT       77671 PWRC
  77667 EN        77665 XNETW     77663 PYR       77661 TCS
  77657 ACS       77655 WTANN2    77653 HDWACS    77651 SCIEN
  77647 CONTIG    77645 TDS       77643 RESID     77641 WPFIX
  77637 PRESS     77635 ACSF      77633 TIS       77631 WPUT
  77627 WF        77625 WD        77623 WN2       77621 TSAL
  77617 CAPS      77615 TPVAL     77613 ADAP      77611 TPVA

PROGRAM ALLOCATION

  00000 HELP
THE END
```

```
      SUBROUTINE OFFLD [R1,R2,WPU,DWPU,H,C1,C2,XL1,XL2,V1,V2,XMR,P1X,P2X
     1]
      IF[R1-R2]2,2,1
 1    H = 2.*R1+0.1016
      GO TO 3
 2    H = 2.*R2+0.1016
 3    V1 = 4.18879*R1**3
      V2 = 4.18879*R2**3
      WP = [V1*P1X+V2*P2X]/1.05
      IF[WP-WPU]4,13,13
 4    VF = WPU/[[XMR+1.]*P2X]
      VO = WPU*XMR/[[XMR+1.]*P1X]
      EX1 = VO-V1
      EX2 = VF-V2
      XL1 = EX1/[3.14159*R1**2]
      XL2 = EX2/[3.14159*R2**2]
      C1 = 0.0
      C2 = 0.0
      IF[XL1]7,7,6
 6    IF[XL2]8,8,9
 7    XL1 = 0.0
      C1 = 0.0
      VO = V1
      GO TO 6
 8    XL2 = 0.0
      C2 = 0.0
      VF = V2
 9    IF[XL1-XL2]11,11,10
 10   H = 2.*R1+XL1+0.1016
      GO TO 12
 11   H = 2.*R2+XL2+0.1016
 12   V1 = VO
      V2 = VF
      GO TO 14
 13   XL1 = 0.0
      XL2 = 0.0
      C1 =0.0
      C2 = 0.0
 14   RETURN
      END
```

PROGRAM ALLOCATION

00036 OFFLD	DUMMY R1	DUMMY R2	DUMMY H
DUMMY V1	DUMMY V2	00040 WP	DUMMY P1X
DUMMY P2X	DUMMY WPU	00042 VF	DUMMY XMR
00044 VO	00046 EX1	00050 EX2	DUMMY XL1
DUMMY XL2	DUMMY C1	DUMMY C2	

THE END

```
△ASSIGN BI=MT1.
△REWIND MT1.
△FØRTLØAD =BIU.
```

TABLE 3: PROGRAM INPUT

CARD NO. 1

Symbol	Format	Units	Explanation
HM	F14.4	gm/cu.cm	Minimum length allowable for the stage of propulsion module
P1	F14.4	gm/cu.cm	Density of the oxidizer
P2	F14.4	gm/cu.cm	Density of the fuel
XMR	F14.4	-	Mixture ratio (kg oxidizer/kg fuel)
D	F14.4	m	Stage diameter
CAPS	F14.4	kg	Capsule weight
DV1	F14.4	m/s	Total velocity increment

CARD NO. 2

Symbol	Format	Units	Explanation
DV2	F14.4	m/s or kg	For NCODE = 2, input = 0.
XTW	F14.4	-	Minimum thrust-to-weight ratio
T	F14.4	N	Main engine thrust
XISP	F14.4	s	Main engine specific impulse
ENG	F14.4	kg	Main engine dry weight
UP	F14.4	N/sq. m	Propellant tank ullage pressure
TIME	F14.4	days	Mission duration

CARD NO. 3

Symbol	Format	Units	Explanation
G1	F14.4	g	Axial acceleration
G2	F14.4	g	Lateral acceleration

2

TABLE 3 (Cont.)

Symbol	Format	Units	Explanation
		CARD NO. 3 (Cont.)	
RTG	F14.4	kg	Weight of total system of radio-isotope thermoelectric generators
SCIEN	F14.4	kg	Science payload
ADAP	F14.4	kg	Adapter weight
FMAX	F14.4	m	*Maximum allowable radius for fuel tank
QMAX	F14.4	m	*Maximum allowable radius for oxidizer tank

* If constant tank radius, input required valves in FMAX and QMAX, use sense switch #3 option subroutine with lever down.

If not constant tank radius, input either zero or nonzero values in FMAX and QMAX, with up lever of sense switch #3 option subroutine and program will assume its own limits.

Symbol	Format	Units	Explanation
		CARD NO. 4	
XSTR	F10.1	-	Use XSTR = 1
BTM	F10.1	s	Maximum allowable engine burn time
I	I5	-	I = 1 : Stage is storable with the shroud I = 2 : Stage is storable without the shroud I = 3 : Stage is cryogenic with the shroud I = 4 : Stage is cryogenic without the shroud
NCODE	I5		NCODE = 1 : Program will design a series of stages with a constant capsule weight and a stage length increment from HM to 12.70m by 0.254m lengths.

TABLE 3 (Cont.)

Symbol	Format	Units	Explanation
			CARD NO. 4 (Cont.)
			NCODE = 2 : Program will design one stage to acheive DV1
			NCODE = 3 : Program will design a two-stage vehicle--the first stage to achieve DV2 and the second stage to achieve DV1
			NCODE = 4 : Program will design a number of stages to a constant velocity increment and increment capsule weight in 453.59237 kilogram steps
			NCODE = 5 : Program will vary stage's capsule weight and increment stage diameter, keeping velocity increment and stage length constant. D varies from D to 6.604m by 0.254m steps
			NCODE = 6 : Program will vary both diameter and length to find the base-line for a given capsule weight and velocity increment
NCODE	I5		A key code used to call subroutine HELP which prints out weight statement; use 1 if desired; 0 if not
K	I5		Exit code (0 except on last data card, then 1)

TABLE 4a. PROGRAM OUTPUT FOR FOUR-PROPELLANT-TANK SPACECRAFT DESIGN

(NCODE = 2)

PRELIMINARY DESIGN DATA FOR SPACECRAFT

OUTPUT FORMAT NCODE = 2 5.0 G LONGITUDINAL 2.0 G LATERAL

OXIDIZER DENSITY [GM/CU.CM]	FUEL DENSITY [GM/CU.CM]	MIXTURE RATIO	CAPSULE [KG]	DV1 [M/S]	DV2 [M/S]	MINIMUM T/W RATIO	TIME [DAYS]	ULLAGE PRESSURE [N/SQ.M]	THRUST [N]	ISP [S]	ENGINE WT. [KG]	MCODE
1.440	.872	1.60	2267.96	2050.0	.0	.000	1000.0	1620267.942	4670[illegible].3270	305.0	185.973	1

NO. ENGINES	STAGE DIA. [M]	STAGE LENGTH [M]	PROPELLANT WEIGHT [KG]	TOTAL INERT WEIGHT [KG]	DELTA V [M/S]	OXIDIZER TANK RADIUS [M]	FUEL TANK RADIUS [M]	OXIDIZER TANK VOLUME [CU.M]	FUEL TANK VOLUME [CU.M]	XL1 [M]	XL2 [M]	T/W	BURN TIME [S]
1.	3.5560	1.4473	4981.23	2695.3	2050.0	.6731	.6731	1.27740	1.27740	.0000	.0000	4.742	312.9

BASIC SHELL [KG]	XMETEOROID PROTECTION [KG]	FUEL SYSTEM [KG]	OXIDIZER SYSTEM [KG]	TANK SUPPORTS [KG]	ENGINE SUPPORTS [KG]	PRESSURIZATION SYSTEM [KG]	ACS [KG]	CONTINGENCY [KG]	RESIDUALS [KG]	FUEL [KG]	OXIDIZER [KG]
123.916	193.541	179.327	179.327	16.078	13.050	220.661	140.425	120.019	174.922	1879.434	3007.094

TABLE 4b. PROGRAM OUTPUT FOR FOUR-PROPELLANT-TANK SPACECRAFT DESIGN

(NCODE = 2 and MCODE = 1)

WEIGHT SUMMARY

ITEM	WEIGHT (KILOGRAMS)		
STRUCTURE			416.0975
BASIC SHELL		123.9161	
RINGS AND FRAMES	67.7942		
STRINGERS AND LONGERONS	38.9761		
MISCELLANEOUS	17.1458		
SYSTEM SUPPORTS (BEAMS)		51.4669	
MICROMETEOROID PROTECTION		193.5409	
SUPPORTS (ANTENNA AND SCAN PLATFORM)		34.2009	
SEPARATION MECHANISM		12.9727	
PROPULSION			811.0627
ENGINE (MAIN) (1)		185.9729	
FUEL SYSTEM (2)		179.3263	
OXIDIZER SYSTEM (2)		179.3265	
SUPPORTS (MAIN ENGINE AND TANKS)		29.1281	
PRESSURIZATION SYSTEM		220.6613	
TELEMETRY SENSORS		16.6462	
EQUIPMENT AND INSTRUMENTATION			1173.2251
STRUCTURE		46.7478	
GUIDANCE, CONTROL AND NAVIGATION		90.8093	
SENSORS	13.5248		
COMPUTER/SEQUENCER	15.2959		
CONTROL COMPUTER	23.9904		
SERVO ACTUATORS	16.1546		
ARTICULATION EQP.	21.8436		
INSTRUMENTATION		175.0277	
RADIO	55.7919		
TELEMETRY	10.4656		
DATA SYSTEM	15.4221		
ANTENNAS	65.4503		
COMMAND	12.0220		
MEASUREMENT	15.8757		
ELECTRIC POWER		303.4533	
RTG SYSTEM	226.7962		
BATTERIES	2.2680		
POWER CONTROL	74.3891		
ELECTRIC NETWORKS		129.7896	
NETWORKS	115.3900		
PYROTECHNICS	14.3996		
TEMPERATURE CONTROL SYSTEM		82.8557	
ATTITUDE CONTROL SYSTEM		140.4251	
TANKS	125.0030		
HARDWARE	15.4221		
SCIENCE (INSTRUMENTS AND SCAN PLATFORM)		204.1166	
CONTINGENCY			120.0193

TOTAL DRY SPACECRAFT			2520.4046
RESIDUALS			174.9223
PROPELLANTS		137.9687	
PRESSURANTS		25.2703	
ATTITUDE CONTROL SYSTEM FLUIDS		11.6834	

TOTAL INERT SPACECRAFT			2695.3269
USABLE PROPELLANT			4981.2268
FUEL		1879.4337	
OXIDIZER		3007.0939	
NITROGEN		94.6992	

TOTAL SPACECRAFT AT LAUNCH			7676.5538
CAPSULE			2267.9619

TOTAL PLANETARY VEHICLE AT LAUNCH			9944.5157
ADAPTER			113.3981

TOTAL PLANETARY VEHICLE + ADAPTER			10057.9138

TABLE 5a. PROGRAM OUTPUT FOR TWO-PROPELLANT-TANK SPACECRAFT DESIGN

(NCODE = 2)

PRELIMINARY DESIGN DATA FOR SPACECRAFT

OUTPUT FORMAT NCODE = 2 5.0 G LONGITUDINAL 2.0 G LATERAL

OXIDIZER DENSITY [GM/CU.CM]	FUEL DENSITY [GM/CU.CM]	MIXTURE RATIO	CAPSULE [KG]	DV1 [M/S]	DV2 [M/S]	MINIMUM T/W RATIO	TIME [DAYS]	ULLAGE PRESSURE [N/SQ.M]	THRUST [N]	ISP [S]	ENGINE WT. [KG]	MCODE
1.440	.872	1.60	2267.96	2050.0	.0	.000	1000.0	1620267.942	46706.3270	305.0	185.973	1

NO. ENGINES	STAGE DIA [M]	STAGE LENGTH [M]	PROPELLANT WEIGHT [KG]	TOTAL INERT WEIGHT [KG]	DELTA V [M/S]	OXIDIZER TANK RADIUS [M]	FUEL TANK RADIUS [M]	OXIDIZER TANK VOLUME [CU.M]	FUEL TANK VOLUME [CU.M]	XL1 [M]	XL2 [M]	T/W	BURN TIME [S]
1.	3.5560	1.9930	4750.11	2460.6	2050.0	.6731	.6731	1.98949	2.05338	.5003	.5452	4.977	298.1

BASIC SHELL [KG]	XMETEOROID PROTECTION [KG]	FUEL SYSTEM [KG]	OXIDIZER SYSTEM [KG]	TANK SUPPORTS [KG]	ENGINE SUPPORTS [KG]	PRESSURIZATION SYSTEM [KG]	ACS [KG]	CONTINGENCY [KG]	RESIDUALS [KG]	FUEL [KG]	OXIDIZER [KG]
278.528	.000	125.975	122.986	15.318	13.050	174.594	140.425	109.145	168.537	1790.543	2864.869

TABLE 5b. PROGRAM OUTPUT FOR TWO-PROPELLANT-TANK SPACECRAFT DESIGN

(NCODE = 2 and MCODE = 1)

WEIGHT SUMMARY

ITEM	WEIGHT (KILOGRAMS)		
STRUCTURE			394.0799
BASIC SHELL		278.5275	
RINGS AND FRAMES	66.1716		
STRINGERS, LONGERONS AND SKINS	196.4802		
MISCELLANEOUS	15.8757		
SYSTEM SUPPORTS (BEAMS)		50.2351	
MICROMETEOROID PROTECTION		.0000	
SUPPORTS (ANT.,SCAN PLAT.,AND SOLAR ARR.)		52.3446	
SEPARATION MECHANISM		12.9727	
PROPULSION			654.5414
ENGINE (MAIN) (1)		185.9729	
FUEL SYSTEM (1)		125.9749	
OXIDIZER SYSTEM (1)		122.9855	
SUPPORTS (MAIN ENGINE AND TANKS)		28.3676	
PRESSURIZATION SYSTEM		174.5936	
TELEMETRY SENSORS		16.6468	
EQUIPMENT AND INSTRUMENTATION			1134.2768
STRUCTURE		46.7478	
GUIDANCE, CONTROL AND NAVIGATION		89.8082	
SENSORS	12.8518		
COMPUTER/SEQUENCER	15.2449		
CONTROL COMPUTER	23.7133		
SERVO ACTUATORS	16.1546		
ARTICULATION EQP.	21.8436		
INSTRUMENTATION		131.0933	
RADIO	29.0299		
TELEMETRY	10.4656		
DATA SYSTEM	11.3398		
ANTENNAS	52.3602		
COMMAND	12.0220		
MEASUREMENT	15.8757		
ELECTRIC POWER		311.6180	
SOLAR ARRAY	80.7394		
BATTERIES	159.6645		
POWER CONTROL	71.2140		
ELECTRIC NETWORKS		123.9570	
NETWORKS	109.5574		
PYROTECHNICS	14.3996		
TEMPERATURE CONTROL SYSTEM		86.5108	
ATTITUDE CONTROL SYSTEM		140.4251	
TANKS	125.0030		
HARDWARE	15.4221		
SCIENCE (INSTRUMENTS AND SCAN PLATFORM)		204.1166	
CONTINGENCY			109.1449

TOTAL DRY SPACECRAFT			2292.0430
RESIDUALS			168.5373
PROPELLANTS		136.8593	
PRESSURANTS		19.9946	
ATTITUDE CONTROL SYSTEM FLUIDS		11.6834	

TOTAL INERT SPACECRAFT			2460.5803
USABLE PROPELLANT			4750.1118
FUEL		1790.5433	
OXIDIZER		2864.8692	
NITROGEN		94.6992	

TOTAL SPACECRAFT AT LAUNCH			7210.6921
CAPSULE			2267.9619

TOTAL PLANETARY VEHICLE AT LAUNCH			9478.6540
ADAPTER			113.3981

TOTAL PLANETARY VEHICLE + ADAPTER			9592.0521

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PLANETARY DESIGN PROGRAM FOR ADVANCED PLANETARY SPACECRAFT

by J. T. Wheeler

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This document has also been reviewed and approved for technical accuracy.

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