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Nuclear Engine System Simulation (NESS): Version 2.0

Program User's Guide

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FOREWORD

This Program User's Guide discusses the Nuclear Thermal Propulsion (NTP) engine system design features and capabilities modeled in the Nuclear Engine System Simulation (NESS): Version 2.0 program (referred to as NESS throughout the remainder of this document), as well as its operation. NESS has been upgraded to include many new modeling capabilities not available in the original version delivered to the NASA Lewis Research Center in December 1991, see Ref. 1-0. NESS's new features include:

- An improved input format
- An advanced solid-core NERVA-type reactor system model (ENABLER II)
- A bleed-cycle engine system option
- An axial-turbopump design option
- An automated pump-out turbopump assembly sizing option
- An off-design gas generator engine cycle design option
- Updated hydrogen properties
- An improved output format
- Personal computer operation capability

Sample design cases are presented in this user's guide that demonstrate many of the new features associated with this upgraded version of NESS, as well as design modeling features associated with the original version of NESS, discussed in Ref. 1-0.

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1.0 INTRODUCTION

An accurate, standalone, preliminary Nuclear Thermal Propulsion (NTP) engine system design analysis tool is required to support current and future Space Exploration Initiative (SEI) propulsion and vehicle design studies. Currently available NTP engine design models are those developed during the NERVA program in the 1960s and early 1970s and are highly unique to that design (see Ref. 1-1) or are modifications of current liquid propulsion system design models. To date, NTP engine-based liquid design models lack integrated design of key NTP engine design features, such as in the areas of reactor, shielding, multipropellant capability, and multiredundant pump feed fuel systems. Additionally, since the SEI effort is in the initial development stage, a robust, verified NTP analysis design tool could be of great use to the community.

This effort developed an accurate, versatile NTP engine system design analysis program (tool), known as the Nuclear Engine System Simulation (NESS) program, to support ongoing and future engine system and stage design study efforts. In this effort, Science Applications International Corporation's (SAIC) NTP version of the Expanded Liquid Engine Simulation (ELES) program was modified extensively to include Westinghouse Electric Corporation's near-term and next generation solid-core reactor design models, ENABLER I and ENABLER II reactor designs, respectively. The ELES program has extensive capability to conduct preliminary system design analysis of liquid rocket systems and vehicles. The program is modular in nature and is versatile in terms of modeling state-of-the-art component and system options as discussed in Refs. 1-2 and 1-3. The Westinghouse reactor design model, which were integrated in the NESS program, are based on the near-term and upgraded version of the solid-core ENABLER NTP reactor design concept, see Ref. 1-4.

This program is now capable of accurately modeling (characterizing) a complete near-term or next generation solid-core NTP engine system in great detail, for a number of design options, in an efficient manner. The following discussion summarizes the overall analysis methodology, key assumptions, and capabilities associated with the NESS, presents example problems, and compares the results to a related NTP engine system design.

2.0 ENGINE SYSTEM MODEL

This section discusses the overall NTP engine system design and performance prediction methodology and the unique model input options associated with NESS. To better understand the operation of NESS, it is important that the operator be familiar with the ELES program which is discussed in detail in Refs. 1-2 and 2-1.

2.1 Overall Analysis Method

The NESS flow logic is essentially the same as the ELES logic detailed in the ELES Programmer's Manual, Ref. 1-3. A simple summary of the analysis procedure is shown in Figure 2-1, and a detailed flow chart is given in Figure 2-2. Many portions of the code are iterated two or more times to improve accuracy. The key inputs include the thrust level, FVAC, reactor type, IREACTR, and engine cycle type, KCYCLE=1 for gas generator (GG), =3 for expander, or =7 for bleed cycle. Also important are the chamber pressure and temperature, PC and TCHAMBER, respectively, flow paths (bypass fractions NFF and BYPTUR), nozzle configuration, NOZTYP and KOOLNZ, turbopump type, IPTYPE, reactor scaling factor, FALPHA, and the number of propellant feed legs, NTPA.

Once an input file has been formulated and read in by NESS, the first step is to initialize propellant properties from the libraries of propellant data stored in the code. These properties will be recalculated at many different code locations and for many different conditions throughout code execution. The ideal performance is initially estimated based on known chamber pressure and temperature, and nozzle area ratio; the boundary layer and divergence efficiencies are calculated at this time and an estimated delivered specific impulse (Isp) is found. This estimate is used to calculate a reactor flowrate. The nozzle heat load is estimated as 1% of total reactor power, and this heat load, Isp, and flowrate are passed to the reactor design portion of the code, ENABLER, for calculation of reactor fuel and overall operating characteristics. The generic NESS ENABLER reactor design module can be configured to represent either an ENABLER I or ENABLER II NTP reactor design, see Section 3.0.

The reactor inlet pressure and temperature are now used to calculate the cycle pressure schedule. During the pressure calculations, the nozzle barrier cooling requirement is also calculated along with the regen cooling requirements. Now that all engine efficiencies are known, the actual delivered Isp and flowrate are calculated. The actual nozzle heat load is compared with the original estimate and if they are not within 10%, the code loops back to the reactor design portion of the code and repeats all steps up to the point this comparison is made. If the nozzle heat loads are reasonably matched but the reactor design has only been performed once, the code loops back to the reactor design with the newly calculated Isp and flowrate to improve accuracy.

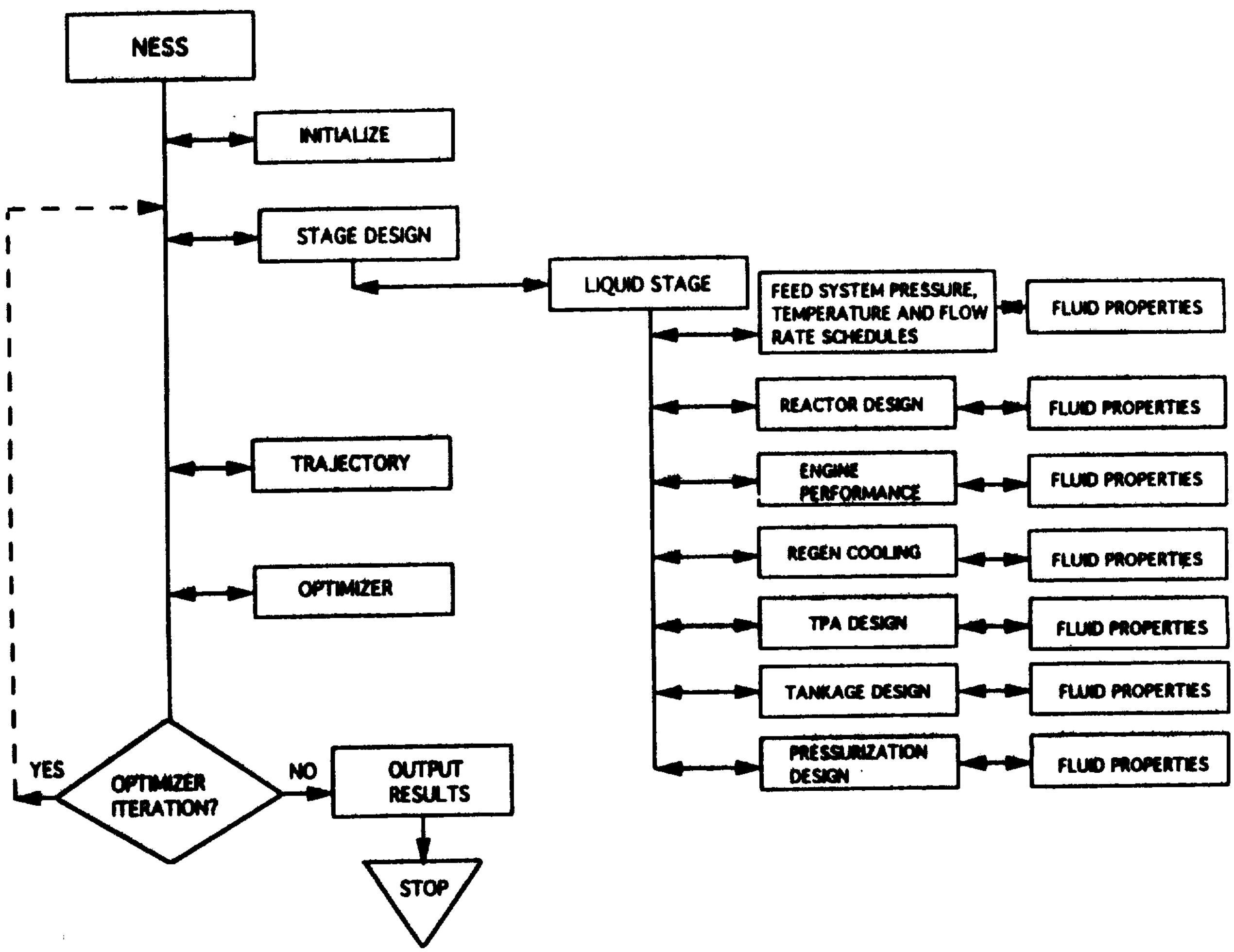

Figure 2-1. NESS Program Overview

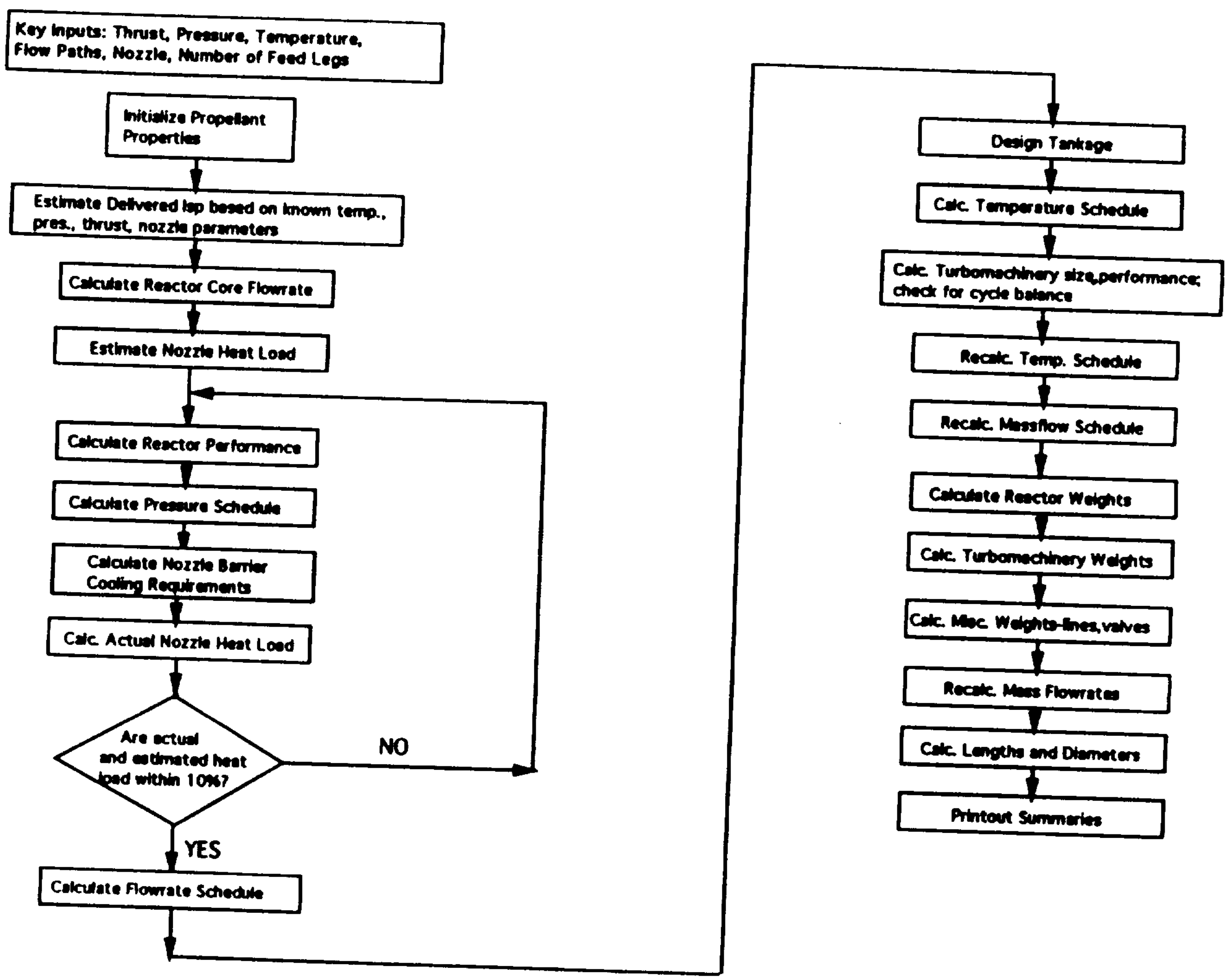

Figure 2-2. NESS Program Flow Logic

After the reactor design, performance, and pressure schedule have been completed satisfactorily, the code now calculates all cycle flowrates. Tankage volumes, pressures, temperatures, and pressurization requirements are calculated next. The temperature schedule is determined, and the turbomachinery can now be analyzed. The turbopump assembly (TPA) portion of the code calculates the size and performance of the pumps and turbines, and checks for cycle balance by comparing pump required horsepower to the turbine delivered horsepower; if not balanced, a new turbine pressure ratio is calculated and the TPA design process is repeated.

Once the TPA design has been completed, the flowrate and temperature schedules are recalculated to improve accuracy. Next, component weight calculations for the reactor, turbomachinery, nozzle, and all miscellaneous parts (lines, valves, etc) are performed. Mass flowrates are calculated one more time, overall engine dimensions are found, and finally, output summaries are printed out. When the pump-out (double run) option is selected (see Section 2.3.1), the entire design process is completed for an engine at reduced thrust level and then a second iteration of the entire design at full thrust level is performed beginning with the reactor module using some of the values calculated in the first pass (TPA parameters and some weights).

Flow path schematics of the representative NTP expander, gas generator, and bleed engine cycle systems are shown in Figure 2-3. The representative NTP engine systems shown in Figure 2-3, incorporate dual propellant feed systems in all cases, and boost pumps for the expander and bleed cycles only. The representative GG system does not include boost pumps.

2.2 Major Code Components

Table 2-1 lists the major code modules along with key flags and input variables. Each of these modules is discussed in further detail in the sections following, including both overall discussion of the module and how to determine the inputs required.

2.2.1 Engine Performance

Engine performance calculations begin with an ideal one-dimensional equilibrium (ODE) performance value that is later degraded with loss multipliers. The ideal values for specific impulse (Isp) and C star (C*) are calculated by the ODE module of the Two-Dimensional Kinetic Reference Program (TDK), Ref. 2-1, as a function of chamber pressure, temperature, and nozzle area ratio. Tables of hydrogen performance data are stored in the subroutine HYDROGEN along with the curve-fit equations used to calculate ideal C*, which is a function of temperature and pressure

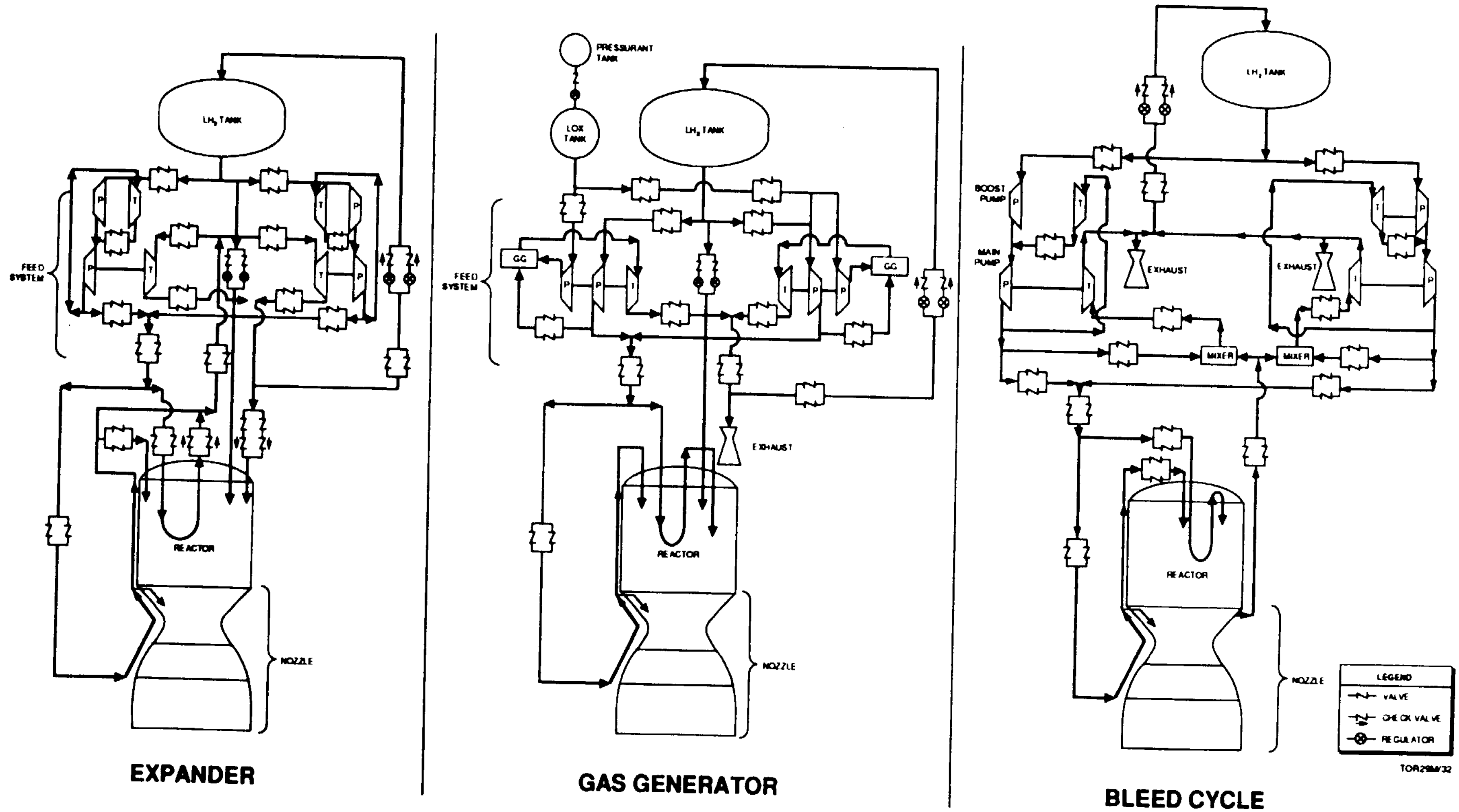

Figure 2-3. Representative NTP Expander, Gas Generator, and Bleed Engine System Cycle Flow Paths

Table 2-1. Key NESS Input Flags and Variables

Module	Variable	Value	Result
General Input:			
Cycle Type	KCYCLE	= 1	Gas Generator Cycle
		= 3	Expander Cycle
		= 7	Bleed Cycle
Thrust Level	FVAC	--	Set thrust level
Chamber Pressure	PC	--	Set pressure
Chamber Temperature	TCHAMBER	--	Set temperature
Reactor Type	IREACTR	= 1	Use ENABLER I
		= 2	Use ENABLER II
Choose double-run?	IDBLRUN	0,1	If =1, double-run used
Iterate pump design?	ITRATE	0,1	If=1, iterate pump design
Bleed cycle solver	ISOLVE	= 0	Input bleed flow fractions
		= 1	Input turbine inlet temp.
Input burn time?	IUSRBRN	0,1	If =1, input burn time
User-defined TPA?	ISTSET	0,1	If =1, input TPA values
Nozzle:			
Exit area ratio	EPS	--	Set exit area ratio
Use extension?	KEXNOZ	0,1	If =1, use extension
Use 3-portion nozzle?	NOZTYP	0,1	If =1, use 3-portion nozzle
Attach area ratio 1	EPSATT	--	Set ext. attach area ratio
Attach area ratio 2	EPSAT2	--	Set 2nd ext attach area ratio
Nozzle cooling	KOOLNZ	= 2	Regen cooling of nozzle ext.
		= 3	Trans-regen cooling
		= 4	Radiation cooling
		= 5	Film cooling (GG cycle only)
Regen Cooling:			
Turbine Bypass Ratio	BYPTUR	--	Set turbine bypass flow
		= 1.0	Tie tube flow drives turbine
Barrier Temp. Fraction	DIFTBF	--	Set barrier temperature
Reactor:			
Reactor flow paths	CONFIG	= 1	Original flow paths
		= 2	Tie tube flow drives turbine
Fuel Type	FTYPE	= 1	Graphite fuel
		= 2	Composite fuel
		= 3	Carbide fuel
Support Pattern	SPAT	= 2:1	Set support pattern
		= 3:1	
		= 6:1	
Nozzle Flow Percent	NFF	--	Set nozzle/tie tube flows
Fuel Scaling Factor	FALPHA	--	Set fuel scaling factor
Tankage:			
Tank Type	NCTNK	= 0	Tandem tankage
		= 1	Non-conventional tankage
Pressurization Method	KGASFL	= 0	Cold helium or solid GG
		= 1	Autogenous
Turbopump Assembly:			
Pump Configuration	JCNFIG	= 1	Gearbox
		= 2	Single shaft TPA
		= 3	Twin TPA in series
		= 4	Twin TPA in parallel
		= 5	Multiple feed leg TPA
Turbopump Type	IPTYPE	= 0	Centrifugal Pumps
		= 1	Axial Pumps
Use Boost Pumps?	JBPFL	0,1	If =1, use fuel boost pump
Number of Feed Legs	NTPA	--	Set number of TPA feed legs

only. An ideal Isp at desired conditions is interpolated from these tables. To run the code with a propellant other than hydrogen, ODE (or a similar code) must be run to generate the tables of Isp data and the C* equations. This data would be put into a new subroutine that is called by the rest of the code when appropriate.

The loss multipliers used to degrade the ideal performance are calculated using standard JANNAF procedures, Ref. 2-2, or Aerojet-derived methods, Ref. 1-2. It is assumed that the reactor itself has no losses, and therefore engine efficiency is determined by nozzle-related factors. The efficiencies (or losses) calculated by NESS are the nozzle boundary layer efficiency, divergence efficiency, and nozzle barrier cooling efficiency. The gas generator bleed efficiency is calculated when applicable. A thorough explanation of these efficiencies is given in the ELES Technical Information Manual, Ref. 1-2, and the key equations are summarized below.

The boundary layer loss equation was developed by Aerojet as a result of their experience in defining this loss. The equation is as follows:

$$\mathrm{ETABL} = 0.997 - (\ln(\mathrm{EPS})/100)*[1.-0.065*\ln(0.01*\mathrm{Pc}*\mathrm{Fvac})+ 0.001*(\ln(0.01*\mathrm{Pc}*\mathrm{Fvac}))^2]$$

where

EPS = Nozzle Exit Area Ratio
Pc = Chamber Pressure (psia)
Fvac = Vacuum Delivered Thrust (lbf)

This equation is accurate for engines with a radiation or film cooled nozzle, but does not take into account the energy returned to the core flow by a regen-cooled nozzle. In this case, the energy lost by the nozzle is retained by the regen coolant flow and fed back into the engine, and therefore should not be considered a true loss. A nozzle that is completely regen cooled should have a boundary layer efficiency of 1.0, while a partially regen-cooled nozzle, as is typically used, should have an ETABL less than 1.0, but higher than that predicted by the above equation. To provide accurate modeling of the regen-cooled nozzle option, an input adjustment factor, ADJBL, is applied to the efficiency calculated by the above equation. The adjustment factor is applied as:

$$\mathrm{ETABL} = 1.0 - (1.0 - \mathrm{ETABL})*\mathrm{ADJBL}$$

The current value used for ADJBL of 0.2 (code default = 1.0) was determined by comparison with Rocketdyne performance values, see Ref. 2-3, which were calculated in much greater detail than is possible with NESS.

The divergence loss is a function of nozzle shape and was derived as curve-fits of the information presented in Appendix A of the CPIA document No. 178, see Ref. 2-4. The equations are as follows:

For conical nozzles:

ETADIV = 0.5 + cos(alpha)/2. alpha = half angle in deg.

For RAO nozzles:

ETADIV = 1.0-(1.-C)*[(1.75-RATMLR)/0.75)]$^{1.7}$ for RATMLR <= 1.75

or

ETADIV = 1.0 for RATMLR > 1.75

where

C = constant	= 0.945 + 0.01*ln(EPS)	for EPS <= 20
	= 0.958 + 0.00566*ln(EPS)	for EPS > 20

EPS = Nozzle Area Ratio

RATMLR = ratio of nozzle length to the length of a minimum length RAO nozzle; an input

The divergence efficiency can also be adjusted, if desired, with the input factor ADJDIV used as:

ETADIV = 1.0 - (1.0 - ETADIV)*ADJDIV

The barrier cooling loss is a function of the amount of coolant fluid needed to maintain the nozzle wall temperature below the maximum allowable for the material used. Aerojet chose a simplified barrier cooling loss routine consisting of a stream tube analysis which flow-averages the performance of the core stream tube with that of the barrier stream tube. The procedure for calculating stream tube flow areas and flow rates is detailed in the ELES Technical Manual, Ref. 1-2. The maximum barrier temperature is input as described in section 2.2.2, and is used to calculate barrier Isp and C*, and ultimately barrier mass flux. The fraction of fuel used for barrier film cooling (FFFC) is calculated as:

FFFC = barrier flowrate/(barrier flowrate + core flowrate)

The barrier loss (ETABAR) is set at 0.95 and is put into the comprehensive barrier cooling loss equation:

$$ETAMRD = [(Isp*mdot)_{core} + (Isp*mdot*ETABAR)_{barrier}]/(Isp*mdot)_{total}$$

where all Isps are ideal.

This efficiency can be adjusted by the input ADJMRD in the same form as that used for the boundary layer and divergence losses. Note that the "barrier cooling loss" is referred to as the "mixture ratio maldistribution loss" in the ELES manuals.

For gas generator cycles, the gas generator bleed efficiency is calculated as a function of the bleed nozzle flowrate, pressure, and area ratio. It can be adjusted with ADJGGB in the form:

ETAGGB = ETAGGB * ADJGGB

All other efficiencies described in the ELES Technical Manual, Ref. 1-2, were set equal to 1.0 because of their inapplicability to the nuclear engine; for example, injector or fuel and ox mixing efficiencies.

2.2.2 Nozzle Cooling

The nozzle can be cooled by a number of methods. The converging portion of the nozzle, including the throat, is automatically regen cooled. It is of milled slot construction to upstream area ratio of 4 with an adapter of regen tubes connecting the nozzle to the reactor. The remainder of the nozzle is cooled by regen tubes, radiation, a cold film of turbine exhaust (GG cycles only), or by a combination of these. A detailed explanation of regen cooling calculations is given in the ELES Technical Information Manual, Ref. 1-2, and Section 2.2.3 of this report gives nozzle modeling options.

The nozzle regen cooling requirements are based on the nozzle wall material properties, chamber temperature, regen coolant flowrate, regen inlet temperature and pressure, and regen channel size. The maximum wall material temperature in input as TGWNOM and is the temperature above which the material will begin to degrade. For copper, a common converging nozzle material, this max temperature is 1460°R. The 1460°R temperature limit is typical of that used for the maximum design nozzle wall temperature for the Space Shuttle Main Engine (SSME) which is made of NARLOY-Z, a copper alloy, Ref. 2-5. For the high chamber temperatures typical of nuclear reactors, the regen coolant is unable to maintain this maximum wall temperature if the fluid on the other side of the wall is at chamber temperature. Therefore, a small amount of cool fluid from the regen outlet is dumped into the chamber at the top of the converging nozzle and is used to form a cool barrier between the wall and the hot core fluid. The loss in efficiency due to this barrier cooling is detailed in Section 2.2.1 of this report and in the ELES Technical Manual, Ref. 1-2. The greater the temperature mismatch between the barrier fluid and the core fluid, the larger the cooling loss, and therefore the highest possible barrier fluid temperature should be chosen that can still maintain the required material wall temperature. The barrier temperature is input as a relation between the core temperature and max wall temperature, TGWNOM. The input variable DIFTBF is used as follows:

$$T_{barrier} = TGWNOM + DIFTBF*(T_{core} - TGWNOM)$$

Ideally, DIFTBF = 1.0 and the barrier temperature equals the core temperature to minimize flow losses. If DIFTBF = 0.0, the barrier temperature is set equal to the max wall temperature. For a copper wall with max temperature 1460°R and a core temperature of 4860°R (2700°K), the maximum barrier temperature that could still maintain the required wall temperature is 1630_R, which means the input DIFTBF = 0.05. A good value for DIFTBF can really only be determined by past experience and trial and error; the larger the difference between the maximum wall temperature and the core temperature, the lower the value for DIFTBF will have to be.

Other key regen cooling inputs include the gas wall material thermal conductivity and minimum gauge. The land width (WLTHR) and channel width (WTHR) of the regen cooling channels at the throat are also important inputs because they will strongly affect the regen pressure drop, i.e., small channels => high velocity => large delta P. There is also an option for user-input regen pressure and temperature drops, initiated with the flag INDPDT set equal to 1 and DELTAT and DELTAP input.

2.2.3 Nozzle Modeling Options

The user has a number of different nozzle modeling options. The most basic option is to set the nozzle extension flag KEXNOZ to zero and have regen slots all the way out to the exit area ratio EPS. This type of nozzle is almost never used in practice because of excess weight, and therefore a nozzle extension option is allowed. If the nozzle type flag NOZTYP is set to zero and KEXNOZ = 1, an extension will be added to the regen slots. This section extends from area ratio EPSATT to EPS, and can be regen, radiation, or film cooled (GG cycles only), with cooling option selected with the variable KOOLNZ. The new and final option is for NOZTYP=1, which models a three-section nozzle made up of regen slots, regen tubes, and a radiation cooled extension. The user must set KEXNOZ = 1, KOOLNZ = 2 (regen tubes in portion 2), and area ratios EPS, EPSATT (attach point of second section) and EPSAT2 (attach point of third section). Figure 2-4 shows the three nozzle modeling options and key input variables.

The regen slot portion of the nozzle extends out to an upstream area ratio of 4 where it attaches to a nozzle/reactor adapter that is made of aluminum regen tubes covered by a load-bearing casing of aluminum. The weight of this assembly is calculated in the reactor weight subroutine, and is included in the reactor pressure vessel weight.

Material density and strength are input for the converging nozzle, first nozzle extension, and second nozzle extension with RHCSTR, RHONZE, RHONZ2 and SIGCHM, SIGNZE, SIGNZ2, respectively. The minimum thicknesses of the two possible extensions are input as TNZMIN and TNZMN2. The volume of material used for the regen slots is calculated and the total converging nozzle weight is a function of this volume, the density of the material used for each region of the slots, and total surface area. The weight of the regen tubes is a function of the maximum pressure in the tubes, surface area, and material density, strength, and minimum gauge. The radiation-cooled extension weight is simply a function of surface area and material density and thickness.

2.2.4 Reactor

A solid core, ENABLER-type reactor design module was developed by Westinghouse Electric Corporation and integrated with ELES to form NESS. The reactor design is made up of two segments: the first calculates fuel requirements and reactor operating conditions, the second calculates approximately 30 reactor component weights along with key reactor dimensions. NESS provides hydrogen data, Isp, core flowrate, and nozzle heat load to the reactor module (ENABLER) for its calculations. In return, ENABLER provides the reactor inlet and tie tube outlet conditions needed for pressure and temperature schedule analysis. A detailed discussion of the reactor model can be found in Section 3.0.

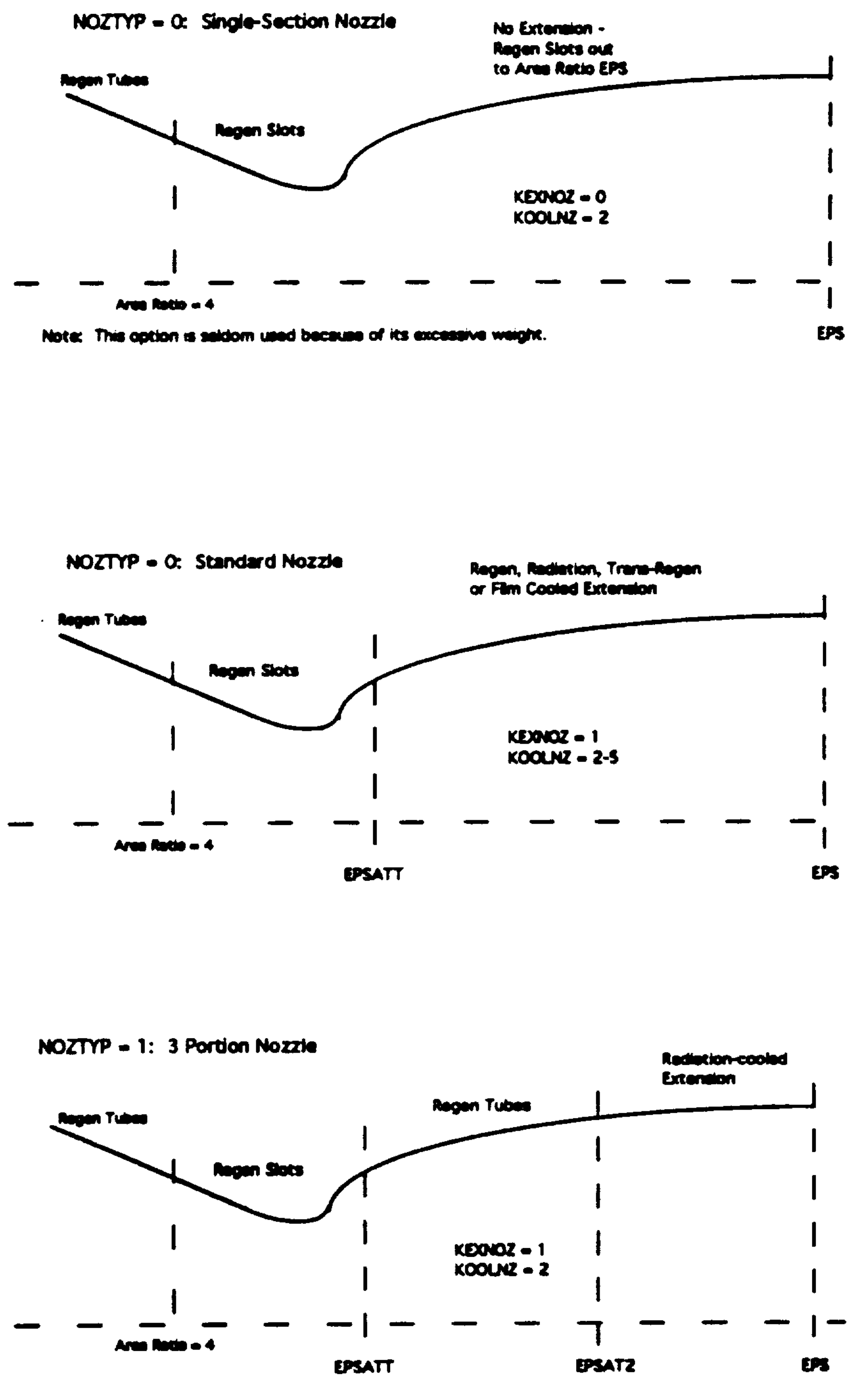

Figure 2-4. Nozzle Modeling Options and Key Input Variables

The ENABLER reactor design module consists of two distinct reactor modeling options. The first is ENABLER I, a near-term solid core reactor design based on the NERVA reactor. The second option, ENABLER II, provides a more advanced reactor design, with different flow paths and scaled fuel, reflecting state-of-the-art technology. This option yields reactor designs with higher power densities and lower weights. By properly utilizing the inputs to the NESS reactor design module (ENABLER), these NTP reactor options can be represented.

One key reactor input is the nozzle flow fraction, NFF, which determines the percentage of flow going to the tie tubes and to regen cooling. The user also selects the fuel type as either graphite, composite, or carbide using the variable FTYPE. The reactor temperature is input as TCHAMBER, and is used extensively in the reactor design process, along with determining the overall engine performance.

The input variable SPAT is used to select the ratio of fuel to support elements in the reactor, and may be input as a support pattern of 2:1, 3:1, or 6:1. The support pattern will affect the reactor weight, overall engine cycle performance, and reactor criticality. The support pattern should always be set as high as possible (6:1) to reduce weight. However, for small engines and scaled fuel engines, this ratio will often need to be reduced in order to achieve reactor criticality. Also, for some high pressure expander cycles, the tie tube flow will not contain enough energy to drive the turbines and the support pattern can be reduced to increase the tie tube outlet temperature and thus add more energy to the flow.

Two reactor flow path options are currently available for the expander cycle. Standard operation utilizes tie tube flow plus some input percentage of reflector outflow to drive the turbines. This reflector flow percentage is input as turbine bypass ratio, BYPTUR, (see Section 2.2.10 for a detailed explanation), and is used to determine what fraction of the reflector outflow bypasses the turbine. The second flow path option is always used with the ENABLER II reactor design option and results in the turbines being driven by the tie tube flow only, with all reflector flow being dumped directly into the core. This flow option can be set in one of two ways: either set BYPTUR = 1.0 or set CONFIG = 2; either choice automatically sets the other variable, i.e., if BYPTUR = 1.0 in the input file, CONFIG is automatically set to 2 by the code and vice versa. This option yields reduced reflector pressures, and therefore a lighter-weight pressure vessel. This cycle can be difficult to power balance, especially for high chamber pressures, and the typical reactor support pattern of 6:1 must occasionally be reduced to 3:1 in order to increase the tie tube outlet temperature and add enough energy to the turbine drive fluid for successful cycle balance.

This support ratio reduction yields a much higher support mass that often outweighs the reduction in pressure vessel mass.

An important reactor input is the fuel scaling factor, FALPHA. It provides a means of including state-of-the-art technology in the reactor design. If FALPHA is equal to 1.0, the resulting reactor design represents an ENABLER I NTP reactor configuration which is typical of NERVA technology. A value for FALPHA less than 1.0 simulates the advances made in fuel element design and corresponds to an ENABLER II NTP reactor system design. This multiplier is applied to all fuel element cross-sectional dimensions. To scale the fuel element length as well, the variable LEL must be set to a value other than zero so that it overrides the input core length LC. This length scaling is used in the form:

$$\text{if } LEL > 0: \quad LC = FALPHA * LEL$$

The power per fuel element is input with PMW, and is actually the power per a 52 inch length that is reduced based on the scaled element length. The minimum value physically possible for FALPHA is 0.5; in practice, however, the recommended minimum value is 0.67.

The flag IREACTR is used to determine the reactor option to be used for the run, i.e., ENABLER I or ENABLER II. If IREACTR = 1, the ENABLER I method is used, and the fuel scaling factor (FALPHA) is automatically set to 1.0. The variables CONFIG and BYPTUR are input by the user to set the flow paths. For IREACTR = 2, the user inputs FALPHA (default = 0.67) and the flow paths are automatically set to the second option, CONFIG = 2 and BYPTUR = 1.0, so that only the tie tube flow drives the turbines.

During reactor design, a criticality check involving the number of ZrH loaded tie tubes is made, and a warning printed out if criticality cannot be achieved. For small engines (< approximately 35,000 lbf) this warning will typically be issued, but the user should further evaluate the design. The criticality determination is based on a comparison of the minimum fuel volume required for each support pattern with the actual calculated volumes. Some small engines may not pass this fuel volume check, but could actually achieve criticality if other parts of the reactor, such as the reflector, were designed differently. The detailed design analysis that would be required for an alternate reflector design, for example, is not available in ENABLER.

An estimate of fuel life is calculated based on the allowable mass loss rate. For scaled fuel, the support to fuel element ratio (SPAT) will often need to be reduced in order to achieve criticality. This ratio reduction will yield a smaller minimum fuel volume requirement that can be now be met with the scaled fuel volume.

As can be seen in the worksheet, the user can input a number of variables related to heat pickup in various sections of the reactor, as well as several fuel element characteristics. The channel coating thickness at various locations may be input with the variables ZRCI, ZRCO, and ZRCH. The pressure vessel material properties such as specific gravity and allowable stress may also be input.

The fraction of possible ZrH loading in the tie tubes is input with the variable FZRH and varies with engine size. This fraction has not been studied extensively, and therefore the values presented in this section are merely suggested values. For small engines with a diameter less than approximately 25 inches, FZRH will typically be equal to 1.0. For large engines with unscaled fuel (diameter > approximately 34 in.), FZRH should be 0.0. For scaled fuel engines, compare the core volume with the standard NERVA 35 in. x 52 in. length reactor core, for which FZRH=0.0, and scale FZRH accordingly. A core diameter of 31 in. uses an FZRH of approximately 0.4.

The weight of the control safety rods required by the reactor during launch is calculated by ENABLER, but is not added into the nominal reactor weight. During standard operation, these safety rods are placed in the reactor during launch and are then discarded upon achieving a safe orbit. In both the reactor summary and final engine summary, the safety rod weight is listed after the reactor or engine weights, and a total launch weight is then calculated.

2.2.5 Auxiliary Components

The category "auxiliary components" consists of instrumentation, a pneumatic supply system, thrust structure, gimbal, and reactor cooldown assembly. Previously in ELES, some of these component weights were calculated as a percentage of the total engine weight, some were a function of thrust only, and some were not calculated at all. Also, these weights were originally calculated assuming a standard liquid rocket engine rather than a nuclear rocket engine.

A report issued by TRW, Ref. 1-1, includes equations for various nuclear rocket engine auxiliary component weights. These correlations relating component weight to reactor power were developed as curve fits of NERVA-type reactor data. The TRW equations applicable to the ENABLER-type rocket engine design have been programmed into NESS and which are:

Instrumentation:	weight = $166.9 + 0.00743*P - 1.64E\text{-}7*P^2$
Pneumatic Supply System:	weight = $751.6 - 0.00208*P + 2.35E\text{-}6*P^2$
Reactor Cooldown Assembly:	weight = $238.1 + 0.0254*P - 8.04E\text{-}7*P^2$
Upper Thrust Structure:	weight = $786.25 - 0.1868*P + 5.2E\text{-}5*P^2$
Lower Thrust Structure:	weight = $492.9 + 0.0911*P + 1.463E\text{-}6*P^2$

where P = power in MW

The upper and lower thrust structures are combined into the "thrust mount" weight. The other three weights make up the "support hardware weight".

Although these equations provide a useful starting point for auxiliary component weight calculations, they represent NERVA-era technology rather than state-of-the-art designs. To account for advances in technology, weight multipliers are input that decrease these weights to values more in line with current engine designs. The instrumentation multiplier, CXWINST, is left at 1.0. The pneumatic supply system weight was compared with similar system weights on current engines, such as the SSME, and was found to be extremely high, see Refs. 2-5, and 2-6. It should be noted that the TRW pneumatic supply system weight correlations assume that the complete pneumatic supply is part of the NTP engine system, while for the SSME the main supply is located in the Space Shuttle. This is one major contributor to the weight difference as well as the higher pressure and lighter weight components associated with today's systems. Therefore, the pneumatic system weight multiplier, CXWPNEU, is input as 0.25. The reactor cooldown assembly multiplier, CXWTNKAS, is input as 0.9 to account for technology advances. The thrust structure multiplier, CXWTHM, is set to 0.9 to allow for lighter weight materials and improved technology. If NERVA-era technology is desired, all above multipliers should be input as 1.0.

2.2.6 Materials of Construction

The NESS user is allowed to select the material of construction of all major subsystem components. Standard library tank materials include 6061-T6 aluminum and 6Al-4V titanium, or the user may input density, strength, and minimum gauge for a previously undefined material. A discussion/comparison of candidate cryogenic tank materials is given in the ELES Technical Information Manual, Ref. 1-2. The input worksheet includes a table of the most common engine materials along with their densities and strengths. This data is typically used for valves, nozzles, lines, and regen channels, and the user may input data for any unlisted material desired. The nozzle designs also require input of minimum material thicknesses. The turbine blade strength and density, as well as an overall TPA density that is used in pump and turbine weight calculations, can also be input.

2.2.7 Tankage

The main tankage options in NESS are either tandem tankage, in which fuel and oxidizer are stacked on top of each other to fit within a common shroud, or non-conventional tankage, where the user selects the number of tanks as well as their shapes and placement on the stage. The tandem tanks option should probably not be used for nuclear thermal rockets because they use only hydrogen as propellant, and may carry only a very small amount of oxidizer for use with a gas generator. The tandem tank model automatically calculates an oxidizer tank weight even if the amount of oxidizer carried is very small or zero, and this tank is sized to fit in the tank shroud with a diameter based on the size of the large fuel tank. The non-conventional tankage design option should give a better estimate of actual tank sizes.

The tank sizes for both tank geometries are dependent on amount of burned propellant, ullage fractions, acquisition system design, residual propellant, propellant boiloff, and autogenous pressurization. The approach taken in sizing the propellant tanks is as follows:

a. Amount of fuel burned is input; calculate amount of oxidizer burned in GG if necessary.

b. Add weight of autogenous pressurization requirements to each propellant

c. Calculate the tank free volumes using the propellant densities and ullage fractions

d. Calculate propellant residuals and acquisition device volumetric displacement based on tank free volume estimate

e. Calculate tank surface area as needed for heat transfer calculations to determine propellant boiloff

f. Total tank volume is now calculated as the sum of the above volumes: burnt propellant, ullage, residuals, boiloff, autogenous pressurant, and acquisition devices

These tank volumes are now used to determine pressurization requirements and update initial estimates.

The large variety of possible tandem tank configurations is shown in the ELES Technical Information Manual, Ref. 1-2, along with the equations used to calculate many of the tank dimensions and volumes. All tanks can be cylindrical, spherical, or elliptical (CSE tanks), and the non-conventional tankage option allows toroidal tanks as well. Non-conventional tank weights are calculated from an ideal tank weight through the use of a tank non-optimum factor, which is defined as the ratio of actual tank mass to ideal tank mass. The ideal tank mass is based on tank wall thickness and size. The actual mass includes any additional material required for weld lands and fittings. For conventional tanks that require feedlines, supports, pressurization, and a propellant management device, a tank non-optimum factor of 1.7 is suggested. Different factors are recommended for different tank types, and these factors are listed in Table 7.3.1.1 in the ELES Technical Manual, Ref. 1-2. The tank nonoptimum factor is input as the variable CXWTNK.

When preparing inputs for tankage design, the user must first set the variable NCTNK equal to either 0 for tandem tanks or 1 for non-conventional tanks. If tandem tanks are chosen, the user now determines such factors as arrangement of propellant (fuel forward or aft, etc), common or separate dome tanks, monocoque or suspended arrangement, tank head ellipse ratio, tank dome orientation, safety factor (SFFLTK, SFOXTK, SFPRTK), and tank material (MTNKFL, MTNKOX, MATPT).

To use the non-conventional tank option, the user should first sketch the arrangement of tanks and engines on the stage. The total number of non-conventional tanks is input with NTANKS (includes ox, fuel, and pressurant), up to the maximum of 15 tanks. The type of fluid contained within each tank is input with the variable INTNK1, where an input of 1 is for ox tanks, 2 is fuel, 3 is pressurant. For example, if two ox and two fuel tanks are desired, input INTNK1 = 1,2,1,2. This indicates that tanks 1 and 3 are ox tanks, and tanks 2 and 4 are fuel tanks; retain this same numbering scheme when defining the remaining tank parameters. Input the tank ellipse ratio for each tank with ELTNK1. The tank type is selected as either CSE or torus with the variable KTANK1. The angular location of each tank gives its relative position on the stage and is input as TANGL1. Tank radial location indicates the tank distance from the center of the stage, RADLO1 = 4*1.0 places all four tanks at the edge of the stage and RADLO1 = 0 places a tank at the center of the stage. Engine angular and radial locations are input similarly with the variables ENGAN1 and ENGRD1, with a maximum of five engines allowed. The material for each tank is selected with the variable MATNK1. Tank safety factors are input with SFTNK1, and tank weight multipliers are input with CXNCT1. More input variables for each tank geometry are contained in the worksheet, see Appendix A.

The forward and aft skirt length inputs are actually input as fractions of tank lengths. For tandem tankage, both aft and forward skirt lengths should be input as 1.0 to form a skirt fully covering both tanks. To shroud non-conventional tankage, the forward skirt should be set to 0.0

and the aft skirt length should be 1.0. This will yield a skirt that covers all tankage and is as long as the tallest non-conventional tank. DMOTOR is used to input the stage diameter.

2.2.7.1 Tank Heat Transfer. For the long duration missions proposed for nuclear rockets, tank heat transfer and insulation are important aspects of vehicle design. A detailed discussion of this area is provided in the ELES Technical Information Manual, Ref. 1-2, and includes information on optimizing insulation thicknesses.

NESS offers four possible tank heat transfer scenarios: ignore tank heat transfer, external boundary exposed to conductive source, worst case solar radiation, and ground hold ice formation. The desired option is selected with the variable KHXOPT. The most common options are either to ignore heat transfer (when tank design is not important) or worst case solar radiation. The solar radiation option requires input of insulation characteristics, space hold time, flight time, average orbital distance from earth, and earth and solar heat flux parameters. The insulation is typically composed of a layer of spray-on foam insulation (SOFI) plus a multi-layer insulation (MLI) blanket. The density, thermal conductivity, and thickness of each type can be input. Table 2-2 lists these values for a variety of types of MLI.

Table 2-2. Multi-Layer Insulation Data Comparison

MLI Configuration	No. (cm)	No. (in)	Kg (m^3)	Lbm (ft^3)	Watts (m-K)	BTU (hrft°R)
DAM/DBL silk net	19.7	50.0	45.2	2.82	$4.5x10^{-5}$	$2.5x10^{-5}$
DAM/Tissue glass	39.4	100.0	51.9	3.24	$2.5x10^{-5}$	$1.4x10^{-5}$
SAM Crinkled	15.7	40.0	14.6	0.91	$4.7x10^{-5}$	$2.6x10^{-5}$
DAM/SGL Nylon Net	31.5	80.0	53.8	3.36	$3.0x10^{-5}$	$1.7x10^{-5}$
DAM/Dexiglass	23.6	60.0	58.8	3.67	$5.0x10^{-5}$	$2.8x10^{-5}$
DAM Crinkled/Tissue glass	23.6	60.0	31.1	1.94	$7.0x10^{-5}$	$3.9x10^{-5}$
Superfloc	11.8	30.0	13.8	0.86	$4.5x10^{-5}$	$2.5x10^{-5}$

2.2.7.2 Propellant Tank Pressurization. Propellant tanks can be pressurized by cold helium gas, a solid gas generator, or autogenously. The method of pressurization is selected with the variables KGAS, KGASFL, and KGASOX as shown in the worksheet. The selection of a propellant acquisition device, either some sort of bladder or surface tension device, has a strong effect on the pressurization calculations. An extremely detailed discussion of tank pressurization is presented in the ELES Technical Information Manual, Ref. 1-2.

When cold gas pressurization is selected, KGASFL,KGASOX = 0 and KGAS = 2, the user also inputs the cold helium storage pressure as PICG and the helium tank final pressure fraction, FPULCG, where a value less than 1.0 indicates a blowdown tank. If KGAS is set equal to 1 instead of 2, a solid gas generator will be used which requires fairly extensive user inputs regarding solid fuel characteristics and burn rates (see worksheet). If KGASFL, KGASOX are set to 1, the tanks will be pressurized autogenously. This option has an advantage over helium pressurization when the additional weight of the evaporated propellants is less than that of the helium storage vessel, as occurs in pump fed stages with low NPSH requirements. The propellant used in autogenous pressurization of the hydrogen tank will be bled off from the turbine exhaust for all engine cycles. Because only a small amount of oxidizer is used in the GG cycle, the oxidizer tank is assumed to be pressurized with cold gas to reduce cycle complexity. If autogenous pressurization is selected, the pressurizing oxygen flow will be bled off from the oxidizer pump outlet flow.

2.2.8 Propellant Pressure/Temperature/Flowrate Schedules

The propellant pressure, temperature, and flowrate are calculated at key points within each engine cycle. The pressure schedule is calculated "backwards", beginning with the chamber pressure and working back up through the cycle using input and calculated pressure changes. The temperature and flowrate schedules begin at the tank outlet and flow down through the cycle to the reactor inlet conditions. NESS can handle expander, gas generator and bleed cycles.

For all engine cycles, the tank outflow is divided into tie tube and regen/reflector flow based on the input flow fraction, NFF. The regen flow is used to cool both the nozzle and reflector, with a small amount bled off to form a cool barrier inside the nozzle.

As can be seen in the expander cycle flow paths shown in the schematic in Figure 2-3, the reflector outflow can be either dumped directly into the core or used to run the turbine. Reflector outflow going to the turbine is mixed with the tie tube flow, and turbine inlet temperature is calculated by an energy balance of tie tube and reflector flows, i.e.

$$T_{turbine\ inlet} = [(T*mdot*Cp)_{reflector} + (T*mdot*Cp)_{tie\ tube}] / (Cp*mdot)_{turbine\ inlet}$$

where

T	=	temperature
mdot	=	mass flow rate
Cp	=	specific heat coefficient for constant pressure

Turbine outflow is dumped into the reactor core, with a small amount bled off for autogenous pressurization if needed.

The key pressure assignments for the expander cycle are the turbine and reflector outlet pressures. The reactor inlet pressure and temperature are calculated by the reactor model, and are therefore known. The tie tube pressure drop is fixed at 250 psid, and the reflector pressure drop is 25 psid. These pressure drops are typical of solid-core reactor systems, based on past Westinghouse NTP reactor design experience. Pressure drops could be higher for large, high-heat-load NTP reactor designs. The reflector, turbine, and reactor pressures are related by the following list which includes the key pressure variable names and descriptions, along with some key pressure cycle assumptions:

PTURBI, PTURBO = turbine inlet and outlet pressure, respectively
PREFI, PREFO = reflector inlet and outlet pressure, respectively
PTTI, PTTO = tie tube inlet and outlet pressures, respectively
PREGI, PREGO = regen inlet and outlet pressures, respectively
PCI = core inlet pressure
PVLVFO = main valve outlet pressure
TURBPR = turbine pressure ratio
DELTAP = regen pressure drop

PTURBO = PTURBI/TURBPR
PREFO = PREFI - 25
PTTO = PTTI-250

For the expander cycle with partial or no turbine bypass (some or all reflector flow goes to the turbine), the reflector (PREFO) and tie tube outlet (PTTO) pressures are set equal to the turbine inlet pressure, PTURBI. The turbine outlet pressure is set equal to the reactor inlet pressure, PTURBO=PCI.

Once the reflector outlet pressure is known, the reflector inlet pressure, which equals the regen outlet pressure, can be calculated so that the regen cooling analysis can be performed and all other pressures in the cycle can be calculated. For multiple feed leg TPA designs, the individual turbine flow rates are multiplied by the number of legs to accurately calculate the pressures.

For all cycles, the main valve outlet pressure is normally calculated as the reflector outlet pressure plus the pressure drop across the regen and reflector, but the valve pressure must be high enough to allow for all pressure drops across the tie tubes and turbine. Therefore, the valve outlet pressure is set equal to the maximum of the required tie tube inlet pressure and the reflector outlet pressure plus regen and reflector pressure drops, i.e.,

PVLVFO=MAXIMUM((PTTO+250),(PREGO+DELTAP))

Another option for the expander cycle is to set the input variable BYPTUR equal to 1, which sends all reflector flow directly into the reactor so that the turbines are driven by the tie tube flow only. The user must exercise caution when choosing this flow option as the tie tube flow will occasionally not have enough energy to power the turbines, especially at high chamber pressures and when the reactor support pattern is set at 6:1. A support ratio of 3:1 or 2:1 will yield higher tie tube temperatures, and therefore more energy to drive the turbine, but the turbine inlet temperature will also be increased, and may exceed the accepted temperature limits of approximately 1400°R. A lower support ratio will also substantially increase the weight of the reactor.

When this option is selected, the reflector (PREFO) and turbine outlet (PTURBO) pressures are set equal to the previously determined reactor inlet pressure (PCI). The tie tube outlet pressure is set equal to the required turbine inlet pressure, and the tie tube inlet pressure allows for the fixed 250 psi pressure drop across the tie tubes. The valve outlet pressure is calculated as shown above, and once the valve outlet pressure is set, the pump discharge pressure can be determined.

The gas generator bleed cycle flow schematic shown in Figure 2-3 uses small amounts of oxidizer and fuel to feed the gas generator that drives the turbine. The turbine exhaust is either dumped overboard through a small bleed nozzle or is dumped into the main nozzle for film cooling. Although this exhaust dump results in a performance loss, the GG cycle has the advantages of relatively simple cycle design (TPA and regen design are not coupled) and lower pump discharge pressures. Since the turbine is powered by the GG, the reflector and tie tube flows are dumped directly into the reactor core. PREFO and PTTO are set equal to PCI, and the remaining calculations proceed as usual. The tie tube inlet pressure, PTTI, is now calculated and compared with the valve outlet pressure, PVLVFO, and if PTTI is greater than the valve outlet, PVLVFO is set equal to PTTI. This adjustment will occur whenever the regen pressure drop (delta P) is less than the fixed tie tube pressure drop of 250 psid. As in the expander case, once the reflector outlet pressure is known, the regen cooling analysis can then be performed and all other pressures calculated.

The bleed cycle is analyzed using the same pressure assignments as those used for the GG cycle. For the bleed cycle, a small amount of flow from the cold, high pressure propellant pump outlet flow is tapped off to combine with the hot, lower pressure flow bled off from the reactor chamber exit region to drive the turbine. This cycle is analyzed using the same pressure assignments as those used for the GG cycle. The chamber bleed flow undergoes a pressure drop as it travels through the line to the mixer. The cold bleed line pressure at the mixer inlet is set equal to the chamber bleed line pressure at the mixer inlet to prevent flow backup. The cold bleed flow also undergoes a pressure drop as it travels through the lines. These line pressure drops are determined by the inputs CPLINH, CPLINC. The remaining pressure drop in the cold bleed flow required to match the hot bleed pressure occurs in the cold bleed valve and is calculated automatically. After the two flows are mixed, further pressure drops occur across the turbine inlet line and turbine throttling valve; these drops are determined by the fractional inputs CPLINT, CPVLVT. The remaining pressure schedule for the bleed cycle is calculated by the same methods used for the GG cycle. The temperature at the mixer outlet is calculated using an energy balance:

$$(Cp*T*mdot)_{mixer\ outlet}=(Cp*T*mdot)_{hot\ bleed}+(Cp*T*mdot)_{cold\ bleed}$$

To evaluate the bleed cycle, the user must select from the two solver options using the input variable ISOLVE. If ISOLVE equals 1, the user inputs the turbine inlet temperature with TURBTIN and the code determines the mass flow fractions of hot and cold bleed flow required to provide that temperature. The other option is for the user to set ISOLVE equal to zero, input the hot and cold mass flow fractions FRACHB and FRACCB, and have the code determine the turbine inlet temperature. In practice, the first method will be selected most often because it eliminates the extra step required by the second method, namely evaluation of the output to determine whether the calculated turbine inlet temperature falls within acceptable limits, and if not, another run must be made with mass flow fractions adjusted appropriately.

For all engine cycles, tank outflow is equal to the core flowrate plus the nozzle barrier flowrate, autogenous pressurant flowrate, and gas generator or bleed flow.

2.2.9 Propellant Properties

Propellant properties are required over a very wide range for the variety of models used in NESS, including both gas and liquid phases. The approach used to obtain these values is to begin with a known value of the propellant property at some reference point, and then scale that value to some other condition based on empirical or theoretical correlations. The exceptions to this method include hydrogen and helium, which require separate, extensive data bases from which desired values are interpolated. A detailed discussion of the methods used to determine property data can be found in the ELES Technical Information Manual, Ref. 1-2. Hydrogen data is stored in the routine H2DATA.

A computer program was recently developed at NASA Lewis Research Center to provide parahydrogen thermal and transport properties that match the National Bureau of Standards (NBS) parahydrogen data, see Ref. 2-7. The NBS data represents the most recent compilation of hydrogen properties available in the nation. The program NBSPH2 has been incorporated in the NESS program. The routine PH2 was developed to match NBS data exactly across the pressure range 29 to 2320 psia (0.2 to 16 MPa) and temperature range 24.8 to 54,000°R (13.8 to 3,000°K). The routine includes data tables for density, thermal conductivity, viscosity, Prandtl number, speed of sound, enthalpy, and specific heat. All data is stored in SI units and a routine was written to convert the data into the English engineering units required by NESS.

NESS will occasionally require hydrogen data outside of the pressure or temperature range available in NBSPH2. In this case, the original hydrogen data routine, H2DATA, will be called instead. For pressures in the range from 2320 psia to 2600 psia, the old routine H2DATA will be called with a pressure of 2600 psia and the new routine, NBSPH2, is called with a pressure of 2320 psia. A linear interpolation using the actual pressure is then performed to find average property values. This interpolation was added to prevent fluid property discontinuities in the above pressure range. The original (non-NBS) hydrogen data is also used for fluid at the high temperatures associated with carbide fuel reactors. If more extensive NBS hydrogen data becomes available, that data could be incorporated into the NESS properties at a later date.

An option exists in ELES that allows for user-defined propellants, which requires that the user input certain propellant properties and then select a propellant from the existing ELES library that the new propellant is most similar to. The code next evaluates this new propellant performance based on comparison with the chosen similar propellant. This option is set up for use by non-nuclear, chemical bipropellant propulsion systems, and therefore cannot be used for reactor designs without major code modification. Hydrogen is currently the only propellant with full performance data tables programmed into the code, and the current method of determining Isp is different than that used for bipropellants and may not be compatible with the ELES user-defined propellant evaluation method.

2.2.10 Turbopump Assembly

The purpose of the turbopump assembly (TPA) model is to determine the size, weight, and performance of all pumps and turbines for expander, gas generator, and bleed cycles. The code can evaluate both centrifugal and axial turbopumps. NESS offers the following turbomachinery configurations:

1. Single turbine driving a gearbox which powers an oxidizer and fuel pump on a common shaft.
2. Single turbine driving ox and fuel pumps on a common shaft.
3. Twin TPAs, series drive fluid flow.
4. Twin TPAs, parallel drive fluid flow.
5. Multiple propellant feed leg TPA - each leg is identical and sees 1/NTPA of the flow

The desired option is indicated with the input variable JCNFIG. If the multiple feed leg option is chosen (JCNFIG=5), the number of feed legs is input as NTPA. Boost pumps may be included in the propellant circuit by setting JBPFL, JBPOX=1, with the boost pump fraction of total propellant head rise input as BPFRFL, BPFROX.

NESS checks the necessity for pump or turbine staging, allowing up to four stages for centrifugal pumps, twenty stages for axial pumps, and two stage turbines. To avoid unrealistic designs, the code checks the maximum allowable tip speeds and the turbine blade root stresses. Pump head coefficients and pump and turbine efficiencies are calculated from tables included in the program. A partial admission turbine is designed if blade height falls below 0.3 in. The equations used to design the centrifugal pumps and turbines are given in the ELES Technical Information Manual, Ref. 1-2.

For high flow rates, the low fluid density of hydrogen leads to a high volumetric flow rate, a regime for which the multi-stage axial pump is well suited. The axial pump is attractive for such applications compared to the centrifugal pump in terms of weight, construction, and performance.

For this reason, an axial pump option has been added to NESS. A typical axial turbopump schematic is shown in Figure 2-5. Axial pump design is selected with the input variable IPTYPE=1. Code modifications assumed that an axial pump will not be used for oxygen flow (very poor design selection due to the high density of oxygen) and will therefore not be used for the gas generator cycle. The logic embedded in NESS to design an axial pump is displayed in Figure 2-6.

The performance calculation methods for the axial pumps are essentially the same as those for the centrifugal pumps. Key axial pump design modeling considerations are that the maximum number of stages allowed is twenty, and the specific speed (SS) at which the pump will stage is 3200 (vs. 800 for centrifugal pumps). The pump head coefficient is interpolated from data tables containing values based on existing axial pump designs (see Figure 2-7 and Ref. 2-8). The best-fit equation used to calculate the head coefficient as a function of main pump specific speed is:

$$\text{Head coef.} = 0.88237 - 2.3145E\text{-}4*SS + 2.3161E\text{-}8*SS^2 - 7.7028E\text{-}13*SS^3$$

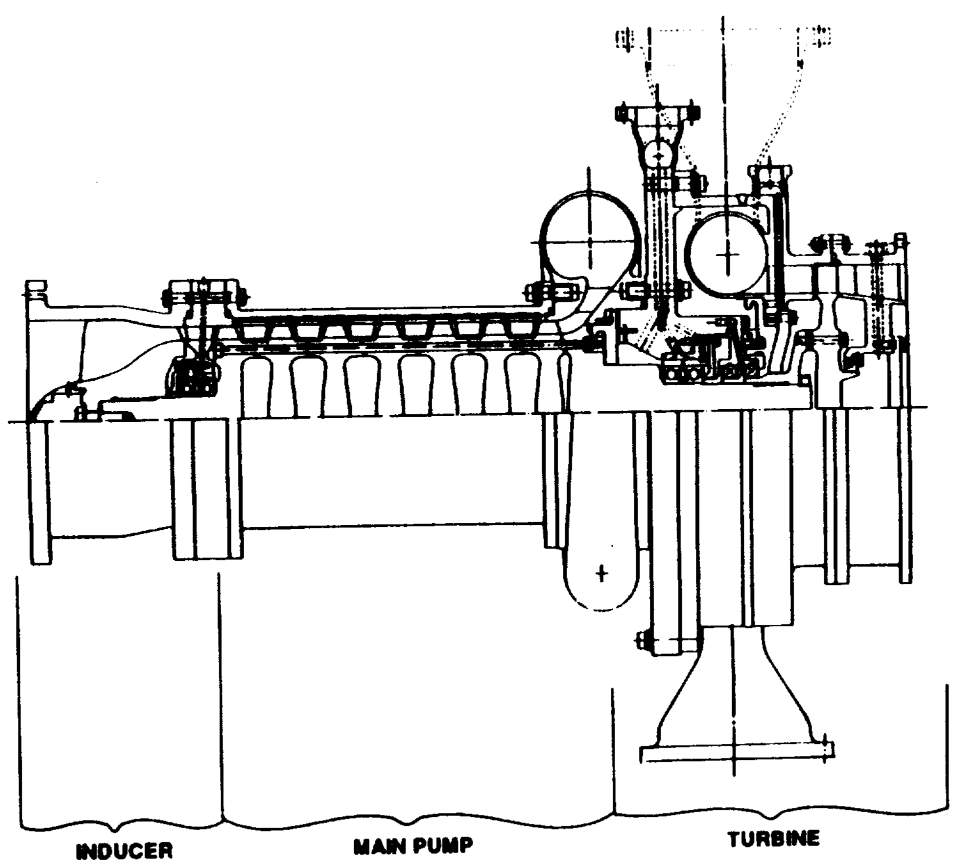

Figure 2-5. Typical Axial Turbopump Design

Calculate main pump RPM based on NPSP, suction specific speed, volumetric flowrate.

↓

Calculate total pump head rise.

↓

Calculate inducer head rise based on input inducer/boost pump fraction

↓

Recalculate pump RPM using the new, high inlet pressure.

↓

Design main pump => number of stages, diameter, efficiency, horsepower.

↓

Set inducer diameter and RPM to match that of the main pump.

↓

Calculate inducer performance => specific speed, efficiency, horsepower.

↓

Total horsepower = main pump + inducer.

↓

Overall efficiency = weighted average of pump + inducer efficiencies, using horsepower as the weighting factor.

↓

Calculate weights and lengths; total pump weight = main pump + inducer. Weight calculations use a length to diameter ratio based on existing axial pump designs.

Figure 2-6. Axial Pump Design Logic

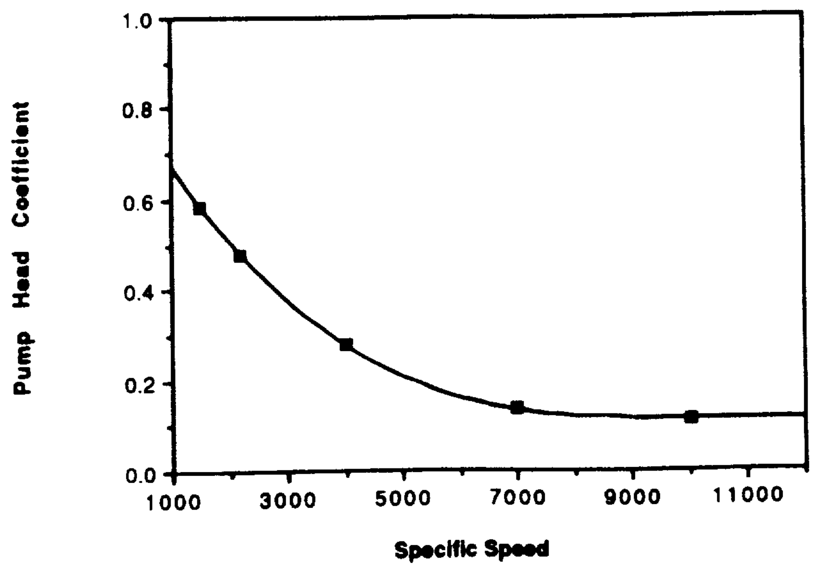

Figure 2-7. Axial Pump Head Coefficient as a Function of Specific Speed

The maximum allowable tip speed is 1500 ft/sec for hydrogen, above which the pump will stage. The axial pump inducer is modeled as a single stage boost pump, with the boost pump flag, JBPFL, initialized automatically within the code when the axial pump option is selected. The inducer is forced to operate at the same speed (RPMs) and have the same diameter as the main pump. Its pressure-head is determined by the input fraction BPFRFL.

The inducer efficiency is calculated from the existing boost pump efficiency curves in ELES, and the main pump efficiency is interpolated from the data shown in Figure 2-8, which is also based on existing axial pump design data, see Ref. 2-8. The best-fit equation used to calculate main pump efficiency as a function of main pump specific speed is:

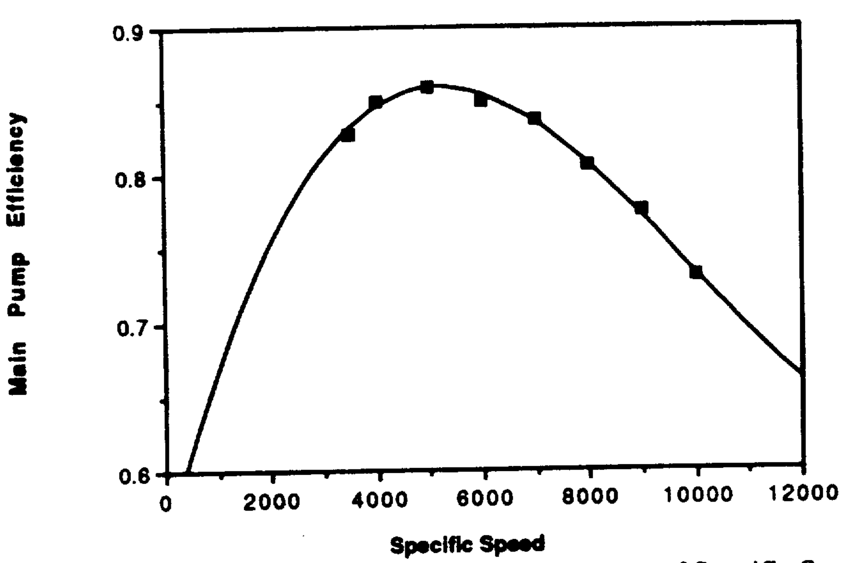

Figure 2-8. Axial Main Pump Efficiency as a Function of Specific Speed

$$\text{Main Pump Efficiency} = 0.54854 + 1.3501\text{E-}4*SS - 1.7544\text{E-}8*SS^2 + 5.901\text{E-}13*SS^3$$

The overall axial pump efficiency is calculated as a weighted average of the inducer and main pump efficiencies, using pump horsepower as the weighting quantity, shown as:

$$\text{Overall Efficiency} = [(HP*eff)_{inducer}+(HP*eff)_{pump}]/\text{total HP}$$

Inducer weight is calculated using the standard boost pump method. The axial main pump differs only slightly from the centrifugal main pump weight and is as follows:

$$\text{Main Pump Weight} = rho*(pi/4)*D^3*(L/D)*N*f_m$$

where:

rho = pump material density (lb/in^3)

D = pump tip diameter (in.)

(L/D) = pump length to diameter ratio per stage

N = number of pump stages

f_m = pump material fraction = ((0.12*D + 0.9)/D

The length to diameter ratios (L/D) per stage for both the main pump and inducer are calculated by correlations of the data on length to diameter ratios of existing axial pump designs, see Ref. 2-8, is shown in Figures 2-9 and 2-10, respectively. The points on the graph indicate existing design values, while the curve defines the correlation used in the L/D calculation as given by:

$$(L/D)_{inducer} = 1.992 - 0.23348*D + 0.0106*D^2$$

$$(L/D)_{main\ pump} = (0.52415 - 0.02714*D + 0.0011387*D^2)*N$$

Total axial pump weight combines the main pump and inducer weights. Comparison with existing axial pump weights, as shown in Section 2.2.11, indicates that a multiplying factor may be necessary to bring the pump weight to within the accepted range.

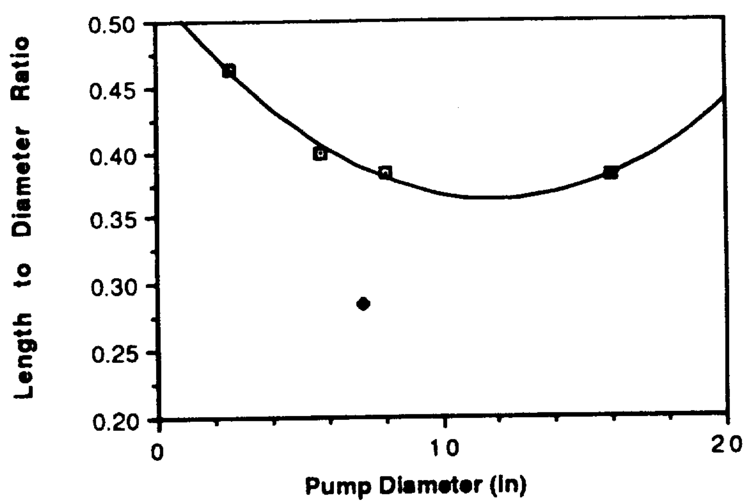

Figure 2-9. Axial Main Pump Length to Diameter Ratio (Per Stage)

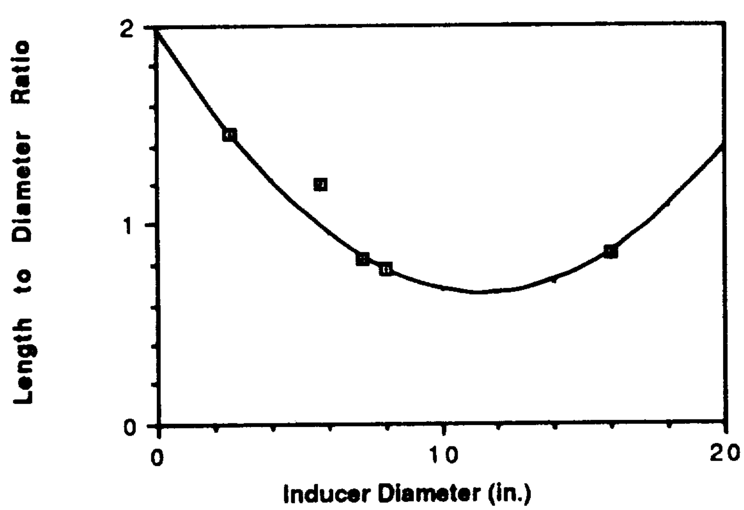

Figure 2-10. Inducer Length to Diameter Ratio (Per Stage)

Turbopump lengths are determined so that a feed system mounting length can be calculated. This mount length is the distance between the bottom of the propellant tank and the gimbal attach point at the top of the reactor where the turbomachinery, lines, and valves are located. If a value other than 0.0 is input for the mount length, XMOUNT, that value will be used in finding the total engine length. If XMOUNT = 0.0, it is calculated by the program as:

XMOUNT = 0.5*Reactor length + Total pump length

where,

Total axial pump length = $\text{Nstages}*((L/D)*\text{Dia})_{\text{main pump}} + ((L/D)*\text{Dia})_{\text{inducer}} + ((L/D)*\text{Dia})_{\text{turbine}}$

Total centrifical pump length = $((L/D)*\text{Dia})_{\text{main pump}} + ((L/D)*\text{Dia})_{\text{boost pump}} + ((L/D)*\text{Dia})_{\text{turbine}}$

L/D = length to diameter ratio (per stage for axial pumps)

Dia = diameter

An expander engine cycle is considered balanced when the ratio of required pump horsepower to delivered turbine horsepower is approximately equal to 1.0. If the cycle is not balanced, a new value for turbine pressure ratio is calculated and the entire design process is repeated. For the gas generator and bleed cycles, the turbine mass flowrate is calculated based on the horsepower required by the pump and boost pump/inducer, and a balance is achieved in this manner rather than through pressure ratio adjustment.

Some important, yet easily overlooked inputs are fluid specific heat ratio, GAMGPB, and heat capacity, CPGGPB. Despite the misleading variable names that seem to refer only to the GG cycle, these values are used for all cycles in various locations, such as the turbine enthalpy calculation. In general, the code calculates the heat capacity at each point where it is needed based on conditions at that point, but CPGGPB is used often enough to require a reasonable value be input, and it can be the factor that causes an expander cycle to either balance or fail. Default values for these variables are for a mixture of hydrogen and oxygen at a ratio of 0.75. However, for code operation using an expander or bleed cycle, these values should be set to values appropriate for hydrogen at similar conditions as those experienced at the turbine inlet during the cycle of interest.

Some sample values for hydrogen at 1400°R and 1000 psi are GAMGPB=1.46 and CPGGPB=3.51; these values were obtained from the new hydrogen properties data (see Ref. 2-7).

An important input for expander cycle TPA design is the turbine bypass ratio, BYPTUR; it is the ratio of reflector outflow that goes directly to the core divided by the total reflector outflow. The tie tube flow goes directly to the turbine and is therefore not affected by this bypass. As the bypass ratio acts only on the reflector flow, the user must be careful when determining this value. For example, if an overall turbine bypass of 50% is desired and the nozzle flow fraction is 0.70 (30% of flow goes to tie tubes, 70% to nozzle), the turbine bypass ratio BYPTUR is calculated and input as 0.5/0.7 = 0.71. Setting BYPTUR equal to 1.0 will cause all reflector flow to be dumped directly into the core so that the turbines are driven by tie tube flow only.

The gas generator cycle requires input of the GG mixture ratio, OFGGPB, the ratio of specific heats, GAMGPB, the specific heat, CPGGPB, and the molecular weight, WMGGPB. The default values for these variables are for LOX/H_2 at approximately 1400 psia. The ratio of specific heats, specific heat, and molecular weight were determined by a run of the ODE module of the TDK computer code using the desired pressure and mixture ratio. The user also inputs the turbine outlet pressure, PTURBO, and the pressure ratio across the gas generator/pre-burner, PBPFR, PBPRO. For the bleed cycle, the user selects the analysis method and then inputs either the turbine inlet temperature, TURBTIN, or the bleed mass flow fractions, FRACHB, FRACCB, along with turbine outlet pressure, PTURBO.

The multiple propellant feed leg TPA option (JCNFIG=5) was added to ELES to allow for the redundancy usually desired with NTP engines. Typically, two feed legs will be desired, with one half of the total flow running through each pump and turbine during normal operation, as can be seen in the cycle schematics in Figure 2-3. This option is normally used with the pump-out (double run) option as described in Section 2.3.1. If three feed legs are desired, the initial pump-out design run is made assuming one pump is out and two are operational. These two remaining pumps are typically designed to handle the full thrust level (FFRAC = 1.0). When multiple feed legs are used, the TPA output lists the weight for each pump and turbine in their corresponding output sections, while the final engine system TPA summary section lists weights for the total turbopump feed system.

Another new code option is the evaluation of a user-defined TPA, which is described in detail in Section 2.3.3. This option allows evaluation of off-design pump and turbine performance. It is used automatically with the double run option in which turbomachinery is designed at a pump-out thrust level and then multiple pumps and turbines possessing the previously determined characteristics are evaluated at full thrust level. The flag to initiate the user-defined TPA design option is ISTSET = 1, and INPTPA = 1 indicates that TPA-related weights will be input.

2.2.11 Weight Multipliers

Due to the wide range of possible design strategies available for most engine components, weight multipliers are provided for all major components. These multipliers are useful when trying to match existing designs or design methods. They are also used to account for excess component weight not specifically calculated in the code; for example, the standard tank weight multiplier is 1.7 to allow for the extra material required for weld lands and fittings, see Ref. 1-2. Some of these weight multipliers have been discussed in detail elsewhere in this report; all will be summarized here.

The weight multipliers are listed in the worksheet, see Appendix A, along with their default values. All tank-related multipliers are set to 1.0 as NESS will primarily be used for engine design; the user must input any desired value other than this default. The total nozzle and hardware multiplier, CXWENG, is set to 1.0 as it is more likely that the multipliers for individual components will be used to account for extra weight rather than adjusting the entire engine weight. The valve multiplier, CXVALV, is set to 2.8 to account for dual valves (for redundancy) and a factor of 1.4 to include some extra valve weights (other than the main valve) not explicitly calculated in NESS. The convergent nozzle multiplier, CXWCHM, is set to 1.0. CXWNZE is the nozzle extension multiplier and is used on all portions of the nozzle extension (tubes + radiation-cooled portion when used); its value of 1.1 allows for flanges and fittings.

Hot gas ducting weight is adjusted with CXWDUC that is set to a value of 3.5 to account for the weight of flanges, bolts, bellows, bosses, insulation, etc. The gimbal system (excluding the power supply) is multiplied by a factor of 1.4 as set by the variable CXWGIM. The thrust mount multiplier CXWTHM is set to 0.9 to allow for technology advances not included in the NERVA-era weight correlation between thrust structure and reactor power. The gas generator injector weight is multiplied by 1.4 as input by CXWIGG. The turbine weight is multiplied by a factor of 1.3 using CXWTPA, and all pump weights are multiplied by CXWPMP, a factor of either 1.3 (centrifugal pumps) as was deemed necessary after comparison with other engine designs. The multiplier for axial pump weights depends on the thrust level, with a value of 4.93 recommended for thrust levels below 50,000 lbf, a value of 5.75 used over the range 50,000-

100,000 lbf, and a value of 6.0 used for thrust greater than 100,000 lbf. A comparison with the few existing design weights, and the multiplier used to achieve these weights is displayed in Table 2-3.

Table 2-3. Axial Pump Weight Comparison and Multipliers

Thrust Level (lbf)	Single Leg Design Wt. (lbm)	Single Leg NESS Wt. (lbm)	Dual Leg Design Wt. (lbm)	Dual Leg NESS Wt. (lbm)	Multiplier Used
25,000	90*	87.8	130*	141.7	4.93
50,000	200*	172.7	270*	274.0	5.75
75,000	--		400*	396.9	5.75
104,000	1030**	1037.5	--	--	6.0

*Ref. 2-9
**Ref. 2-10

Comparison with existing designs gives an ignition system multiplier CXWIGN with a value of 1.3. Engine bay lines are multiplied by 2.5 to allow for flanges, bolts, bellows, etc. The TPA components, valves, and engine bay lines are all multiplied automatically by the number of propellant feed legs, NTPA, when appropriate.

The support hardware multipliers, CXWPNEU, CXWINST, and CXWTNKAS, are discussed in the support hardware section of this report, and reflect the technology advances made since the correlations used to calculate the component weights were developed.

2.3 Additional Features

A number of features have been added to the original ELES to more accurately model a nuclear thermal propulsion system.

2.3.1 Pump-Out Option

A typical nuclear propulsion system will include multiple propellant feed legs for redundancy. Each feed leg will be designed to a desired pump-out thrust level that is less than the nominal operating value. To accurately model this feature, a computer run would have to be made at this reduced thrust level to design/size a single pump and turbine for these conditions, and then these values would be used for a second run at full thrust level with multiple pumps to determine nominal operating conditions. To simplify this process, a pump-out (double-run) option is available for all engine cycles. The first pass through the code designs a single shaft turbopump that operates at a reduced thrust level and corresponding reduced chamber pressure (pump-out conditions) specified by the user. The second pass automatically assigns the pump and turbine parameters calculated by the first run to be inputs for the user-defined TPA option. The valve and engine bay line weights from the first run are also retained to be output with the total engine summary. The second pass will design a system using an input number of identical propellant feed legs, each with characteristics as calculated in the first pass.

If the number of feed legs is greater than two, the first pass through the code, the pump-out run, will be made assuming NTPA-1 feed legs. For example, if the desired number of feed legs is 3, the first run will be made assuming a single pump failure and will perform the cycle analysis with 2 pumps. The individual pump, turbine, valve, and line weights will be retained from the first run and later multiplied by the total number of feed legs as usual.

To utilize this option, the input file must contain IDBLRUN = 1 and a corresponding thrust level fraction FFRAC (default = 0.8, or 80% thrust level), based on a dual propellant feed system. The user must set the pump configuration flag to the single shaft option, or JCNFIG = 2; the code automatically sets JCNFIG = 5 and assigns the pump and turbine parameters calculated in the first pass to the appropriate user-defined TPA variables for the second pass. In the input file, the user specifies the number of identical feed legs to be used for the second pass as NTPA.

Upon completion of a double run, the user must examine the turbopump output for the off-design run to determine whether the design is feasible for operation in both thrust regimes. An option has been added to NESS to be used with the double run option that will perform this evaluation automatically, and if the design fails either of the tests used, the thrust fraction FFRAC set for the initial pump design run will be reduced by 5% and the entire process repeated until either an acceptable design is achieved or the thrust fraction becomes less than the fraction of flow through each pump at full thrust level (i.e., FFRAC < 1/NTPA). To select this option, set ITRATE=1. The tests used to determine adequate off-design performance include a check for axial pump specific speed above 800. Also, the axial pumps cannot be throttled below 60% and therefore a test is made to determine whether the axial pump volumetric flow is at least 60% of the volumetric flow handled by the pump in the initial low-thrust design run. This same test is performed for the centrifugal pumps, with the throttling limit set to 40% instead of the 60% limit used for the axial pumps.

For all runs made using the pump-out option, whether iterative or not, the speed (RPMs) of the pumps calculated during off-design (full thrust) operation is compared with the calculated blade root stress speed limit. This speed limit is based on turbine size and blade material properties. If the calculated pump RPMs are more than 3% higher than the speed limit, a warning is printed out in the warning section of the output indicating that pump RPMs are too high and pump design is nominal. This speed limit problem can often be overcome by using a higher pump-out design thrust fraction (FFRAC).

2.3.2 User-Defined Engine Burn Time

An option has been added which allows the user to input the engine burn time rather than have the code calculate the burn time based on flowrates and input amount of propellant. This option is useful when the amount of propellant to be used is unknown or the tankage design is not important. This burn time is used mainly to size the gimbal power supply, whose weight is time-dependent. To use this option, set the flag IUSRBRN equal to 1 and then input burn time in seconds as TUSRBRN.

2.3.3 User-Defined Turbomachinery

The user-defined turbomachinery option of NESS allows evaluation of pump and turbine performance at off-design operating characteristics and with a variety of propellants. The parameters input to define the TPA for off-design evaluation are detailed in the worksheets following, and include number of stages for all pumps and turbines, pump and turbine diameters, turbine annulus area, turbine admission fraction, and various gas generator/mixer parameters.

NESS calculates pump head rise and volumetric flowrate, and turbine horsepower, mass flowrate, and pressure ratio based on cycle balance requirements. For the centrifugal pumps, these values are used to calculate the pump rpm as a function of input pump diameter. To perform this calculation, a correlation had to be developed for pump head coefficient as a function of specific speed (standard cases interpolate this coefficient from a data table), and is of the form:

$$HC = \text{const} * SS^{x}$$

where

HC = head coefficient
SS = pump specific speed

For example, the main pump correlation is:

$$HC = 3.7852 * SS^{-0.28786}$$

This correlation is different for main pumps and boost pumps. The specific speed is a function of pump rpm, head rise, and volumetric flowrate, as is shown below:

$$SS = RPM * SQRT(\text{volumetric flowrate})/(\text{pump head rise}^{0.75})$$

The pump diameter is calculated as:

$$Dia = (720/pi*RPM) * SQRT(32.2*\text{pump head rise/head coefficient})$$

Substituting the head coefficient and specific speed equations into the equation for pump diameter and rearranging gives an equation for pump rpms as a function of input pump diameter only. Once the rpms are known, the specific speed, efficiency, and horsepower are easily found from the standard ELES equations.

The axial pump user-defined TPA method is slightly different from that used for the centrifugal pumps. Using the equations listed above for specific speed (SS) and pump diameter, along with the best-fit equation determined for pump head coefficient as a function of specific speed, the following equation is found:

$$52525*32.2*QFL/(Dia^2*sqrt(HFL))=SS^2(0.88237-2.3145E\text{-}4*SS+2.3161E\text{-}8*SS^2-7.7028E\text{-}13*SS^3)$$

where:

QFL = volumetric flowrate (gpm)
HFL = pump pressure-head rise (ft)
Dia = pump diameter (in.)

This equation is a function of specific speed only, and is of the form of a fifth-order polynomial that can now be solved by the iterative secant method. Once the specific speed is known, the pump rpms can be found and the rest of the calculation proceeds the same as for the centrifugal pumps. The inducer is again modeled as a boost pump with its speed (rpm) and diameter fixed to that of the main pump. The inducer head rise is determined by the input fraction BPFRFL, and the specific speed, efficiency, and horsepower are now easily calculated by the standard equations.

The user-defined TPA option of NESS calculates the required turbine mass flowrate and horsepower and then evaluates the user input turbine to see how well it performs in meeting these requirements. The first step is to calculate the isentropic spouting velocity (Co) based on the number of turbine stages. Now calculate the ratio of turbine blade tangential velocity to Co based on input turbine diameter (U/Co) and check whether this ratio is within the accepted range of 0.2 - 0.6; if not, print a warning. Next, calculate the turbine inlet mach number and check whether it is below the accepted maximum value of 1.7; issue a warning if not. Finally, calculate turbine specific speed, efficiency, and horsepower provided. Compare the horsepower provided with the horsepower required and if not within 3%, calculate a new turbine pressure ratio and repeat the entire process.

To use this option, first set the variables ISTSET = 1 and INPTPA=1 to indicate that the TPA is user-defined and the TPA-related weights will be input. The number of pump stages are input with PDIAFL and PDIAOX. Turbine stages are input with either TSTGES for a single shaft turbine, or TSTAGF and TSTAGO for fuel and ox turbines (can be used only for GG cycles). Diameters are input in inches with PDIAFL and PDIAOX, and either TDIAM or TDIAFL and TDIAOX. Boost pump diameters can be input with BPDIAF and BPDIAO. Turbines also need to have admission fraction and annulus area input using the variables listed in the worksheet. TPA-related weights will not be calculated for the user-defined TPA option and therefore the user may input these weights for total TPA, TPAWT, start system, WSTART, ignition system, WIGNIT, hot gas manifolding, WHGMF, autogenous heat exchanger, WTHTX, and gas generator/preburner, WGGPB. If not input, the weight summaries will list these weights as zero unless a double run is being made, in which case the weights calculated in the first pass are retained and printed out in the output summaries.

The user-defined gas generator cycle requires many more inputs than are required for the expander cycle. First set the flag IUSRGG equal to 1 to indicate a user-defined GG and input all pump and turbine parameters as described above. In order to insure that the GG and turbine are modeled correctly, the turbine inlet and outlet pressures, PUSRTI and PTURBO, respectively, must be set to the values calculated/input for the NESS-calculated case. For example, if a NESS-calculated GG cycle using LO2/H2 is designed at 80% thrust level and is next to be evaluated at

50% thrust level, the turbine inlet and outlet pressures calculated by NESS in the first run must be used as inputs for the user-defined run. The turbine inlet temperature, TUSRGG, should be set to the actual value found for the propellant combination at given mixture ratio and pressure; normally this temperature will simply be the same as that found in the 80% run. If a different propellant is to be evaluated or the GG is being input based on an existing design (not NESS-generated), this temperature can be found most easily by an initial NESS run where the user-defined option is not used and the GG is at conditions similar to those to be used for the actual user-defined run. The turbine flowrate, although listed as an input, is actually calculated by NESS as the correct amount of fluid flow required for the given operating conditions. The GG bleed flowrate, Isp, and efficiency can be set to any reasonable values. The drive fluid parameters must be input to any value other than zero.

Inputs required for the user-defined bleed cycle include IUSRGG=1 and a matched turbine outlet pressure PTURBO and inlet temperature TUSRGG. The standard pump and turbine parameters, such as diameters and number of stages, are retained or input as usual.

2.3.4 Weight Margin

The user may now input a fraction of the total non-nuclear weight to be added in as a margin weight. Inside the code, non-nuclear weight is the sum of nozzle weight, total TPA weight, lines, valves, thrust mount, support hardware, and total gimbal system. The percent (fraction) of this weight to be used as margin is input with FMARG, whose default is 0.02 (2% margin). In the output summary, the "non-nuclear weight" includes the weight margin.

2.3.5 Bleed Cycle Component Models

The bleed cycle requires a number of extra lines and valves which differ from those required by the other engine cycles. The hot bleed flow is tapped off the reactor chamber flow at the exit region. NESS assumes that a single line is used for all hot bleed flow regardless of the number of TPA propellant feed legs. If required, the hot bleed flow is split into the necessary number of feed lines prior to entering the mixers. Cold bleed flow is tapped off from the pump outlet flow, and one line is needed for each feed leg. Each cold bleed line includes a valve that steps the pressure down as needed to meet the required mixer inlet pressure. One mixer is used for each propellant feed leg, and consists of a hot bleed line wrapped by a cold flow line. The flows are merged at the mixer outlet and then sent to the turbine. Each turbine has its own inlet line containing a throttling valve for flow regulation. Pressure drops across all lines and the turbine throttling valve are input as fractions of the line/valve inlet pressure using the variables CPLINH, CPLINC, CPLINT, CPVLVT. The cold bleed valve pressure drop is calculated automatically based on the mixer pressure requirement. The hydrogen velocity was assumed to be 200 ft/sec, a typical value used elsewhere in NESS for line calculations. For pump-out (double-run) cases, the bleed components are designed on the second pass (the full thrust run).

Table 2-4. Bleed Line Component Design Characteristics

Component	Equivalent Length
Flange	0.2*Line diameter
Bellows	1.0*Line diameter
Elbow	5.5*Line diameter

Table 2-5. Bleed Cycle Line Characteristics

Component	Number of items	Number Flanges	Number Bellows	Number Elbows	Line Length
Cold bleed line	NTPA	2	2	2	1.5*Reactor Pressure Vessel Diameter
Hot bleed line	1	2	1	2	1.5*Reactor Pressure Vessel Length
Turbine inlet line	NTPA	2	2	3	0.7*Reactor Pressure Vessel Diameter
Mixer	NTPA	2	1	0	3.5*Turbine Line Diameter

Each flow line consists of the line itself plus a number of flanges, bellows, and elbows. Using a method described in the TRW report, see Ref. 1-1, each line length was calculated as a series of equivalent lengths, most of which are functions of the line diameter. It was assumed that each flange would add a length that was 20% of the line diameter, a bellows adds 100% of the line diameter in length, and an elbow has a length 5.5 times the line diameter (see Figure 2-4). The lengths of the lines themselves are functions of the reactor diameter and length. A summary of bleed line component design characteristics is shown in Figure 2-5. Total assumed line lengths are as follows:

Cold bleed line = $1.5*D_{reactor}$ + 2 bellows + 2 elbows + 2 flanges

Hot bleed line = $1.5*L_{reactor}$ + 1 bellows + 2 elbows + 2 flanges

Turbine inlet line = $0.7*D_{reactor}$ + 2 bellows + 3 elbows + 2 flanges

Line diameters are calculated as a function of mass flowrate, and fluid density and velocity. Line thickness is a function of pressure, line diameter, and line material strength, see Ref. 2-1. Once the line length, diameter, and thickness are known, the volume of material can be found and finally the weight of each line is determined. Hot bleed line weight assumes all hot bleed flow travels through a single line, while each cold bleed and turbine inlet line are sized assuming (1/NTPA)*flowrate.

The cold bleed and turbine throttling valves are sized using the standard NESS/ELES valve weight procedure. Valve weights are a function of valve material density, mass flowrate, pressure drop across the valve, and fluid density in the form:

$$\text{Valve Weight} = 1.476*rho_{vlv}*mdot/sqrt(rho_{H_2}*delta\text{-}P)$$

where:

rho_{vlv}	=	valve material density (lb/in^3)
mdot	=	fluid mass flowrate (lb/sec)
rho_{H_2}	=	fluid density (lb/in^3)
delta-P	=	pressure drop across the valve (psi)

The typical valve multiplying factor, CXVALV, of 2.8 (=2*1.4) is applied to the bleed line valves along with all other valves in the cycle. The factor of 2 doubles the number of required valves to provide redundancy. For example, a typical bleed cycle has two feed legs and therefore requires one cold bleed and turbine valve for each leg; application of the valve multiplier will instead allow for two valves of each sort for each feed leg to satisfy the usual redundancy requirements. The 1.4 factor accounts for valve weight not specifically calculated by NESS, see Ref. 2-1.

The mixer design is shown in Figure 2-11. It consists of diverging and cylindrical cold flow portions plus a hot flow line. The overall mixer length is assumed to be:

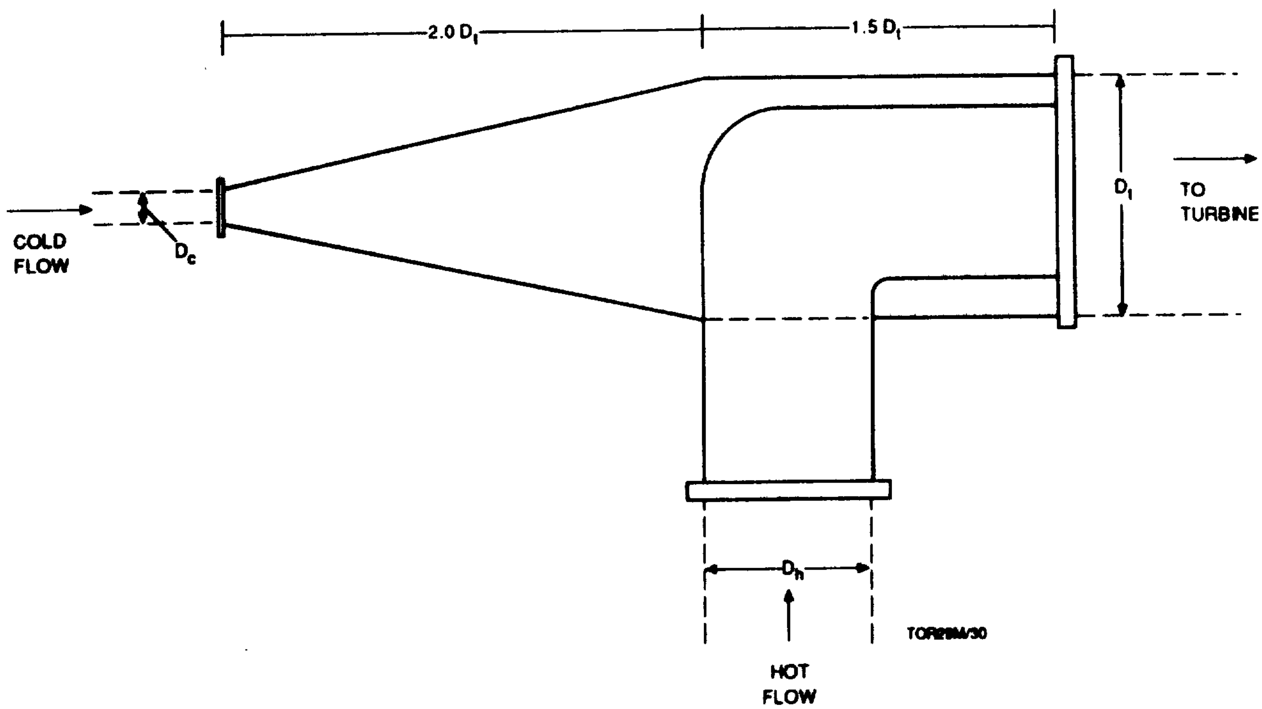

Figure 2-11. Bleed Cycle Mixer Design

Mixer Length = $3.5 * D_{turbine\ inlet}$ + 1 flange (cold side)+1 flange (mixer outlet) + 1 bellows (mixer outlet)

where:

$D_{turbine\ inlet}$ = Turbine inlet line diameter

The hot flow line length within the mixer is assumed to be:

Hot Line Length = $2.5 * D_{turbine\ inlet}$ + 1 flange + 1 bellows

The length of the diverging section of the cold flow portion of the mixer is set to:

Divergent Length= $2 * D_{turbine\ inlet}$ + 1 flange

The volume of material needed for each portion of the mixer is now calculated individually so that the weight for each portion, and finally the entire mixer weight, is determined.

2.4 Code Setup and Execution

NESS is written in FORTRAN 77 and currently resides on a VAX mainframe computer system. It has recently been modified for use on a personal computer (PC) as well. Allowing a much larger range of potential users. The major NESS modification required for transport to a PC was a reformatting of the input file from a VAX-specific namelist file to an unformatted read file that contains all possible input variables along with a brief description of each variable's function, see Appendix A.

The entire NESS code is made up of four parts: the source code, the executable, the library of subroutine object files, and a library of propellant performance data. The NESS executable takes up approximately 4700 blocks of storage space on the VAX and about 1.6 MB on a PC. The source code for NESS is made up of approximately 220 subroutines that have been separated into individual files for easier editing. The subroutines take up approximately 4800 blocks of storage space on the VAX, and 1.9 MB on a PC. The object library ELES_LIB.OLB takes up about 6,000 block of storage space, or about 2 MB on the PC. The propellant performance library is included with the code, but may not be needed as all hydrogen performance data has been entered elsewhere in the code; this data uses 72 blocks of storage. If storage space is a problem, the executable alone could be loaded onto the computer while the rest of the code is left on disk to be loaded as needed.

The standard NESS operation requires creation of a structured series of directories whenever the code is loaded onto a new computer system. The executable and propellant data file must be put into a directory called [account name.ELES]. The input files reside in the directory [account name.ELES.INPUT], and the output appears in the directory [account name.ELES.OUTPUT]. The source code and object file library are loaded into [account name.TEMP.CURRENT]. If the code will be run in debug mode, a directory [account name.TEST] must be set up that includes the propellant library file PROPLIB.DAT and an input file with the name ELES.INP. This directory structure is especially suited for VAX operation.

To simplify the code structure, PC users may wish to edit the governing .COM (or batch) files - ELES_SETUP.COM and RUN.COM - to allow placement of all code parts (executable, source, input, output, etc.) into a single directory. The code itself can be easily edited to operate off a single input file (always the same name), if desired. NESS has been successfully tested on a PC using Lahey FORTRAN 77/EM-32 with the entire code contained in a single directory. The code was edited to always open a certain input file and can be run by simply typing the word NESS (or whatever the code file is called); .COM files are not required at all.

For standard (VAX) code operation, a number of *.COM files are necessary/useful for code execution. The file ELES_SETUP.COM must be run at some point before the code is run to insure proper directory and file initialization; this is most simply achieved by adding this file to the LOGIN.COM file and having it execute automatically with each login. In the [..CURRENT] directory, the file FL.COM is used to compile an individual subroutine and add/replace it in the object library; it is used as "@FL filename". FALL.COM will recompile all subroutines and replace their previous versions in the object library. To link the governing routine with the object library, type "@LD" to execute LD.COM and a new NESS executable will be created.

If the code has been edited to always open the same input file, all input files must have the name assigned by the programmer (NESS.INP, for example), otherwise, the filename must have the extension .inp and must contain 10 characters or less, excluding the extension. To run the code (standard operation, unmodified code) type "MODEC filename" without the filename extension of .inp; for example, typing "MODEC NTPREGEN" will run NESS with the input file NTPREGEN.INP and place the output in a file called NTPREGEN.OUT in the output directory. A file called NTPREGEN_ELES.OUT is also created in the output directory that is essentially a printout of the input file. If the computer has a debug mode, enter the [account name.TEST] directory and type "RUN ELES:MODEC" and the code will execute using the input file ELES.INP. For PC operation, the programmer/user may compile and link all source code into an executable, called NESS for example, and edit the code to open a single input file, such as NESS.INP. If this is done, the user need only type "NESS" to run the code, and the output will appear in the same directory as the code with a name assigned by the programmer.

3.0 REACTOR SYSTEM

This section describes the Westinghouse ENABLER NTP reactor system series models (ENABLER I and ENABLER II) including their internal shield, modeling assumptions, and scaling relations.

3.1 Reactor System Description

An engineering description of the reactor's major subassemblies for both the ENABLER I and II reactor systems are given in the following sections.

3.1.1 Reactor Assembly

For both reactor types, their assembly consists of a nuclear reactor and an actuation system for reactivity control devices with associated instrumentation and controls are shown in Figure 3-1. The reactor consists of fuel elements, support elements, a core periphery, support plates and plena, an internal shield, a reflector assembly, and control drum drive assemblies. Reflector coolant is provided from the nozzle coolant channel exhausts. The support stem coolant exhaust is used as drive power for the engine turbopump. Additional turbopump flow may also be obtained by routing the reflector coolant exhaust to the turbopump. The turbine exhaust gas flows through the dome flow baffle, internal shield, plena between the core support plate and the internal shield and reactor core, and through the reactor core. This gas is heated by the reactor assembly to operating temperatures and exhausted out the nozzle.

3.1.2 Fuel and Support Elements

The fuel elements in Figure 3-2 for the ENABLER class reactor serve the combined function of providing the energy for heating both the hydrogen propellant and the required heat exchanger surfaces. The energy is provided through the fission of ^{235}U contained in the fuel element. Table 3-1 lists the characteristics of the three fuel materials defined in the NESS code. Multiple coolant channels coated with ZrC (for graphite and composite) form flow passages through the elements. The exterior surfaces of the hexagonal fuel elements (except carbide) are also coated with ZrC. This coating protects the carbon from reaction with the hydrogen propellant. The fuel element dimensions were established by the NERVA program, i.e., a nominal 0.75 inch hexagonal with 19 holes 0.100 to 0.110 inches in diameter. Other basic fuel dimensions such as coating thicknesses are setup in NESS as default values for user variables. The NESS code permits the user to specify scaled fuel, see Refs. 3-1 and 3-2, that allows an increase in the allowable fuel power density.

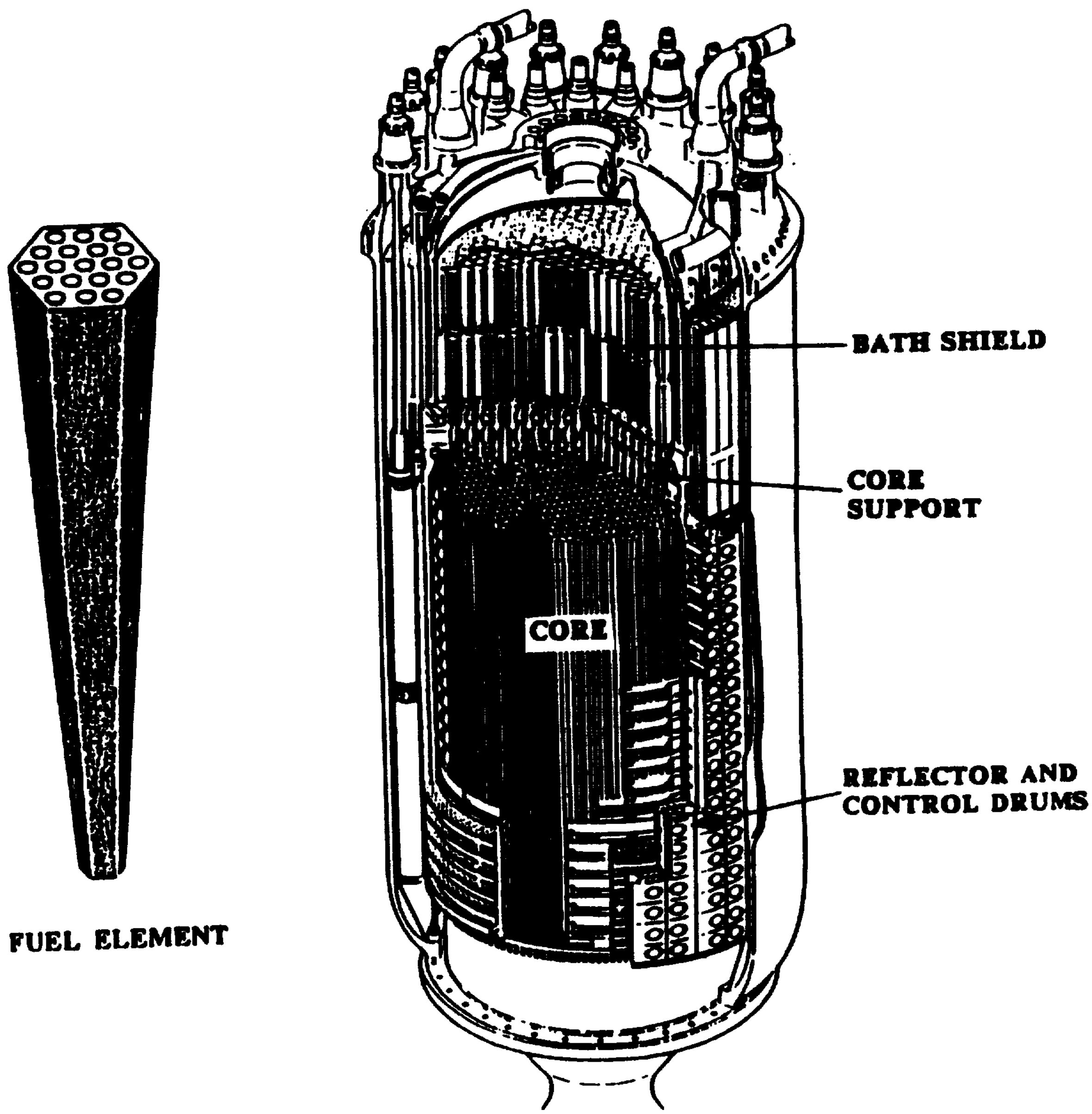

Figure 3-1. ENABLER Class (NERVA Type) Nuclear Thermal Rocket Engine Reactor

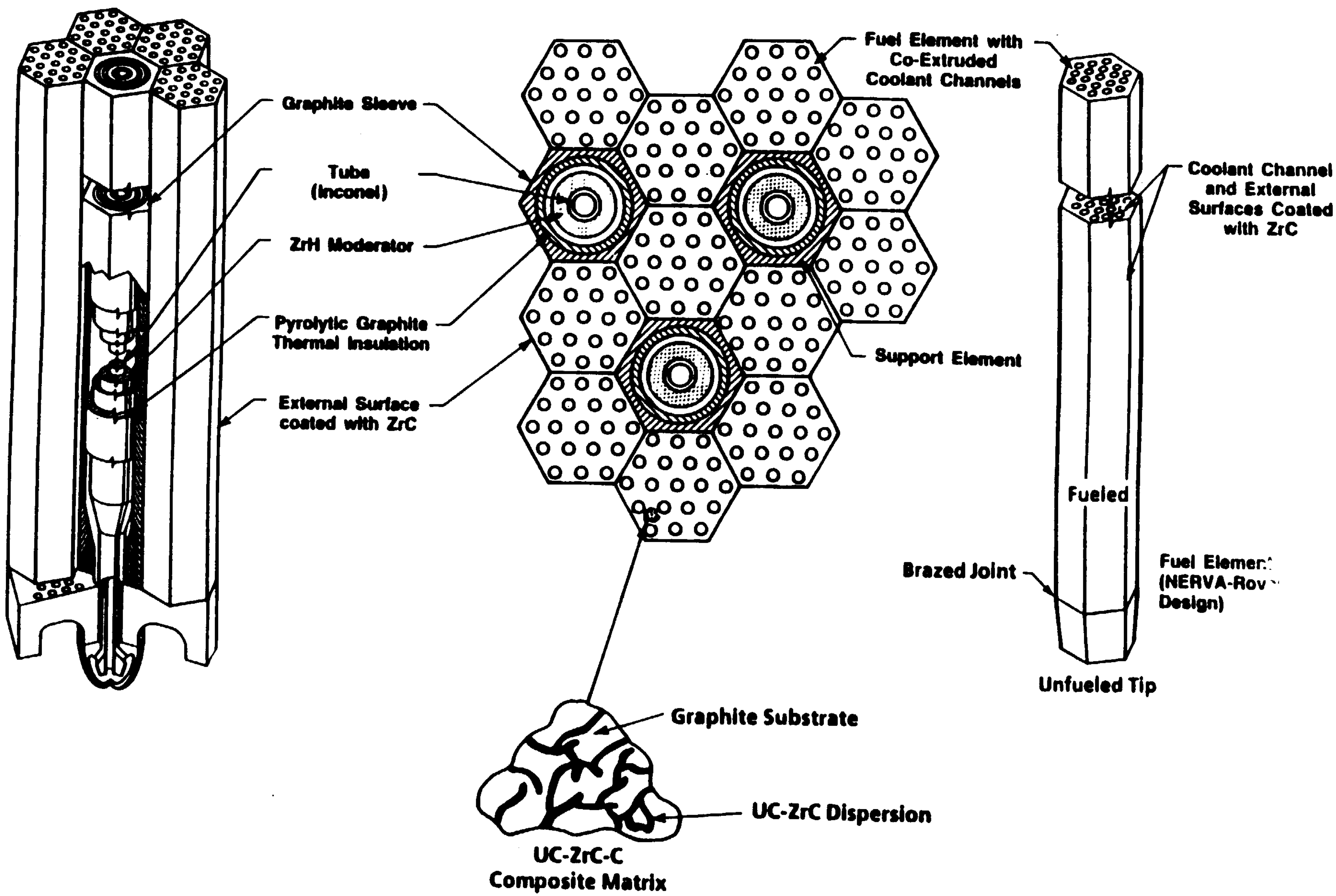

Figure 3-2. Prismatic Fuel Elements and Supports

Table 3-1. Fuel and Support Element Parameters

Fuel Element Composition	Graphite	Composite	Carbide
Temperature Range (°K)	2200-2500	2500-2900	2900-3300
Fuel	Coated Particle	UC . ZrC Solid Solution and Carbon	(U,Zr) C Solid Solution
Coating	ZrC	ZrC	—
Unfueled Support Element Composition	Graphite	ZrC-Graphite Composite	ZrC
Unfueled Element Coating	ZrC	ZrC	—

The reactor core is supported in the longitudinal direction by tie-tubes anchored in the core support plate above (inlet end) the core. The tie-tubes run the full length of the reactor core and connect to fuel support blocks below (exhaust end) the core. These tie-tubes are located inside unfueled support elements, which have the same length and external dimensions as the fuel elements. The support elements have a single, large longitudinal hole with a porous ZrC insulating liner. Within the hole is located the tie tube assembly, which may incorporate ZrH_2 moderator as required. The support element composition is given in Table 3-1.

The reactor core is sized based on an average fuel element power of 1.2 MW per element and one support element per six fuel elements in Table 3-2 at thrust levels greater than 50,000 pounds. The 1.2 MW per fuel element was demonstrated in the Pewee reactor (402 fuel elements with a power level of 503 MW) and was the design level for the Phoebus-2A reactor (4068 fuel elements with a 5000 MW design power level). For the smaller reactors, sufficient reactivity is obtained by increasing the relative number of support elements to fuel elements (Table 3-2) which increases the amount of zirconium hydride moderator to the desired level. Also to keep a reasonable core length to diameter ratio (<2) for the smaller reactors (15000-25000 lbf. thrust) the element length was set at 35 inches. At the 25000 thrust level (Pewee size core volume) the relative power density of the fuel element is the same as the larger reactors (1.2 MW/52 inch). However, at the lowest thrust level (15,000 lbf.) the fuel element power density had to be reduced in order to obtain a core large enough for criticality. Fuel volume, zirconium hydride loading, and reflector thickness all act to increase core reactivity. Neutronic analysis to determine the exact combination of these parameters that achieves criticality is not part of the NESS code at this time. The NESS code does provide a warning message if the selected combination of parameters is questionable.

Table 3-2. Reactor Parameters as a Function of Thrust Level

Thrust (lbf)	15,000	25,000	>50,000
Reactor Power Range	275-400	460-670	920-6700
Fuel and Support Element Length (inch)	35	35	52
Pressure Vessel Length (inch)	82.6	84	101.6
Fuel Element Power (MW)	0.629	0.808	1.20
Relative Fuel Element Power Density	0.778	1.0	1.0
Ratio of Fuel Elements (N) to Support Elements	2:1	3:1	6:1

3.1.3 Radiation Shield

A radiation shield internal to the pressure vessel is used to reduce the gamma and neutron flux levels in the engine components forward of the reactor. This internal shield limits radiation leakage through a plane 63 inches forward of the core center, perpendicular to the engine axis, to the levels given in Table 3-3. The shield is located immediately upstream of the core support plate, see Figure 3-1. The reactor internal shields for the thrust levels over 50,000 lbf. have about 12.5 inches of Borated Aluminum Titanium Hydride (BATH) and about 1.3 inches of lead. At the lower thrust levels the thickness of the BATH and lead is slightly reduced due to lower core power density.

Table 3-3. Radiation Leakage Limits at a Plane 63 Inches Forward of the Core Center

Type of Radiation	Radiation Leakage Limits Within Pressure Vessel Outside Radius
Gamma Carbon KERMA Rate	1.8×10^7 Rad(c)/hr
Fast Neutron Flux	2.0×10^{12} n/cm^2-sec
Intermediate Neutron Flux	3.0×10^{12} n/cm^2-sec, 0.4 eV $\leq$ En $\leq$ 1.0 MeV
Thermal Neutron Flux	6.0×10^{11} n/cm^2-sec En < 0.4 ev

3.1.4 Reactor Propellant/Coolant Circuits

In an NTP system, a nuclear reactor supplies the energy to heat the propellant flowing through the engine. The hot propellant flows into a nozzle that functions in the same manner as a chemical engine. The reactor in an ENABLER reactor-based NTP engine system generally has three propellant (coolant) circuits as shown in Figure 3-3. The primary circuit is through the central shield and core into the chamber. This circuit provides more than 90% of the heat to the propellant. All the components surrounding the core require cooling due to the radiation induced heating and heat transfer from the primary stream. The propellant cooling of the ex-core components is divided into two additional circuits: the tie tube (core support) circuit and the peripheral component circuit that includes the core reflector and extension shield. These circuits along with the nozzle regenerative cooling circuit provide the first pass through the reactor system for the propellant, which acts as component coolant. The heat supplied by these secondary circuits provides the energy to power the turbopump. After passing through the turbine, all the propellant passes through the primary core circuit and into the nozzle to provide the engine thrust.

HEAT GENERATION	
Core	~1,500 MW
Tie Tubes	3-7%
Reflector	1-2%
Central Shield	~0.2%
Ext. Shield	~0.03%

COMPONENT BLOCK DIAGRAM

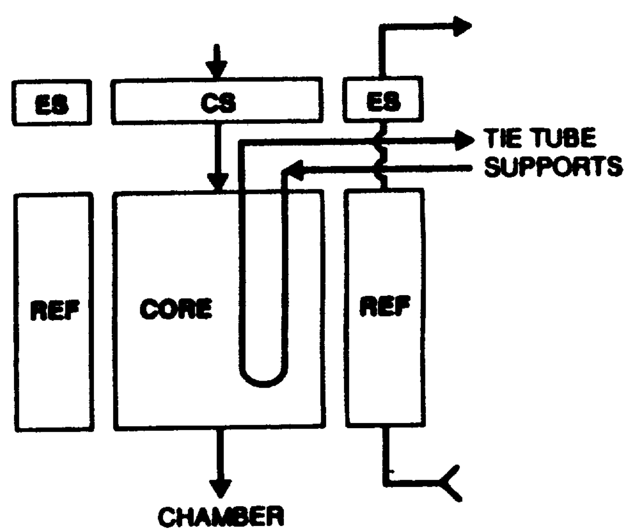

Figure 3-3. Propellant Flow Circuits Through the Reactor

The NESS code allows the user to choose one of two propellant circuit connection options. The first option routes the outlet of both the tie tube circuit and the peripheral component circuit to the turbopump. This arrangement was selected for the NERVA flight engine, the R-1, and it provides sufficient energy to the turbopump to allow operation of the engine at high chamber pressures (approximately 2000 psia) for small engine systems (≤40,000 lbf thrust). The second option routes only the tie tube circuit outlet to the turbopump, while the outlet of the peripheral component circuit is routed directly to the core inlet. This configuration saves weight by eliminating a massive flow baffle at the top of the core and by reducing the pressure vessel design pressure, thus decreasing its thickness. With this configuration, the energy available to drive the turbopump is reduced and therefore engine operation at high chamber pressures (> 1000 psia) may not be possible in engines with a 6:1 fuel to support ratio. The second configuration is generally preferable if a cycle balance can be achieved.

3.2 Baseline Reactor Design

The Rover/NERVA database provides numerous reference designs for reactors and engines in the size range of 15,000 lbf to greater than 250,000 lbf thrust range. The engine modeled in the NESS program is the ENABLER reactor class of NTP engine systems, which is discussed in Ref. 1-4, that is derived from the nuclear rocket technology developed in the Rover/NERVA programs. The ENABLER designs incorporates NERVA type fuel elements which are 0.75 inch (19 mm) hexagonal extrusions of graphite based fuel with a 19 coolant channel array within the element. The code allows the user to select from one of the three fuel materials developed during the Rover/NERVA program: Graphitic, Composite, or Carbide. The ENABLER engine is generally specified with fuel elements fabricated from the (U,Zr)C-Graphite composite material developed late in the Rover/NERVA program, which exhibits improved corrosion resistance and allows higher operating temperatures and power densities, see Refs. 3-3 and 3-4. Zirconium-hydride moderator is placed in the core support elements (demonstrated in the Pewee reactor) to increase the neutronic reactivity and thereby decrease the required uranium fuel loading.

Detailed data is available on the breakdown of actual reactor system component masses. In the NESS model the core size is based on the number of fuel elements needed to meet the required power level. The design of the reactor peripheral regions follows the R-1 engine design shown in Figure 3-4, but the peripheral components are sized according to the core dimensions. For the R-1 reactor shown in Figure 3-4, the nominal core dimensions are 38 inch (96 cm) diameter by 52 inch (132 cm) long. The components surrounding the core are sized to satisfy structural and neutronic requirements. The major components are the core barrel, reflector, pressure vessel, core support plate, flow baffles, and top shields.

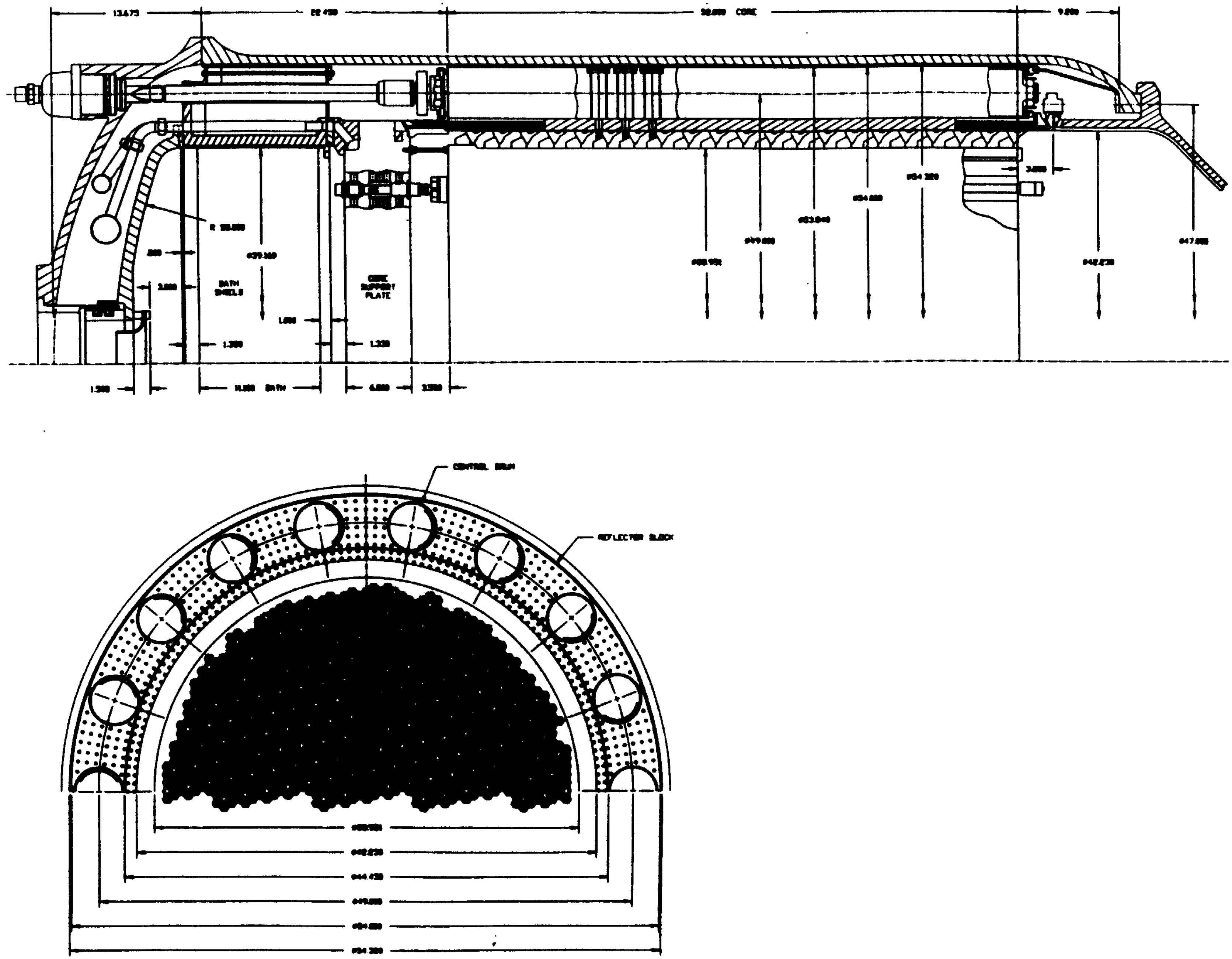

Figure 3-4. Layout Drawing of the R-1 Reactor

3.3 Reactor Core Design and Thermal-Hydraulic Model

The required core power level is determined from the specified engine flow and chamber temperature. The core power level and the average allowable heat generation of a fuel element determines the total number of fuel elements and support elements in the core. Based on the core peaking factor, a single channel analysis is performed to calculate the thermal and pressure profile for the peak channel of the peak element in the core. The calculation uses finite increments along the channel length beginning at the core exit where the chamber conditions are specified. The governing equations are given below.

The convective heat transfer between the fluid and channel wall is defined by:

$$q = h_c A_S (T_W - T_r)$$

where T_W is the channel wall temperature and T_r is the coolant gas stagnation recovery temperature. For small Mach numbers (<<1.0) the difference between the recovery temperature (T_r) and the fluid free stream bulk temperature (T_b) is not significant, so that the equation may be written as:

$$q = h_c A_s (T_w - T_b)$$

The heat transfer (q) must match the heat generation in the fuel material. The heat generation in the fuel is determined by the fuel loading, fuel volume, and neutron fluence. For the purposes of the thermal hydraulic calculations it is sufficient to specify a power profile and the total power produced by the element. The NESS code uses a cosine power profile typical of that observed in the NERVA reactors:

$$P = P_n \cos(0.891\pi (x/L - 0.452))$$

where P_n is the normalized element power factor and x/L is the normalized axial location in the core measured from the inlet. The peak temperature in the fuel (T_f) is determined from the following correlations for a heat generating solid with a hexagon array of coolant channels of diameter D and pitch S:

$$\varepsilon = \frac{\pi D^2}{3.4641\, S^2}$$

$$K = \frac{D}{4}\left(\frac{1}{\varepsilon} - 1\right)$$

$$\psi = \left(\frac{S}{2}\right)^2 \left(0.55133 \ln\left(\frac{S}{D}\right) + 0.25\left(\frac{D}{S}\right)^2 - 0.23446\right)$$

$$T_f - T_w = \frac{q_i \psi}{K\, k_s}$$

where k_s is the thermal conductivity of the solid.

The convective heat transfer coefficient, h_c, is determined by the McCarthy-Wolf, see Ref. 3-5, correlation:

$$h_c = 0.025 \frac{k_b}{D} Re_b^{0.8} Pr_b^{0.4} \left(\frac{T_b}{T_w}\right)^{0.55} \left(1 + 0.3\left(\frac{x}{D}\right)^{-0.7}\right)$$

where the fluid properties are evaluated at the fluid bulk temperature. The entrance effect term $(1 + 0.3 (x/D)^{-0.7})$ is limited to 1.1 for small x.

As the coolant flows along the channel, it experiences a pressure loss due to wall friction and fluid acceleration. The momentum equation for one dimensional flow in finite increment form is:

$$P_i - P_{i+1} = \frac{G_n^2}{g}\,(v_{i+1} - v_i) + f_i \,\frac{G_n^2\, \Delta x}{g\, D_h}\,(v_{i+1} + v_i)$$

where P_i is the coolant pressure at station i, G_n is the mass flow per unit area, v_i is the specific volume of the coolant, D_h is the hydraulic diameter of the channel, f_i is the Fanning friction factor, and Dx is the length increment along the channel. The friction factor is obtained from the Taylor, see Ref. 3-6, correlation for gaseous flow through a smooth tube:

$$f = \left(0.0014 + \frac{0.125}{Re_w^{0.32}}\right) \left(\frac{T_b}{T_w}\right)^{0.5}$$

where Re_w is a modified surface Reynolds number in which the gas density is evaluated at the fluid bulk temperature, but the viscosity is evaluated at the channel wall temperature:

$$Re_w = \left(\frac{G_n D}{\mu_w} \right) \left(\frac{T_b}{T_w} \right)$$

The evaluation of these equations for the peak channel in the core determines the required core pressure drop.

After the calculation of the core profile and pressure drop, the heat generation rates for the core peripheral regions are calculated. Because NESS does not have neutronics analysis capabilities, the heat generation in the peripheral regions is defined as a fraction of the total core power. After completion of the thermal hydraulics, code control returns to the NESS engine code for determination of the cycle balances.

In addition to the basic thermal-hydraulic parameters of the core, NESS calculates the estimated life of the fuel based on the hot end corrosion correlations obtained from the Nuclear Furnace 1 and electrical testing, see Ref. 3-3. Fuel life is given by:

$$rh = 30.5 \exp\left(- \frac{35114}{T_w} \right)$$

$$t_l = m_{limit} A_f / rh$$

where T_w is the peak wall temperature of the fuel channel at the hot end in degrees Kelvin, is the fuel mass loss rate in g/sec per cm of fuel element length, A_f is the fuel area, m_{limit} is the allowable mass loss in g/cm^3, and t_l is the fuel life in seconds. NESS contains the necessary corrections for calculating the life of scaled fuel. The fuel life estimate is not valid for the carbide fuel type.

3.4 Reactor Weight Model

The reactor mass model divides the reactor system into 53 regions for both types in an R-Z model as shown in Figure 3-5 and Table 3-4. Each region contains one, or at most a few, components. The masses of all the components and their constituent parts within a region have been tallied and converted into a pseudodensity for each region, see Ref. 3-7. The dimensions of the regions are based on the core size determined above, with appropriate dimensional dependency algorithms.

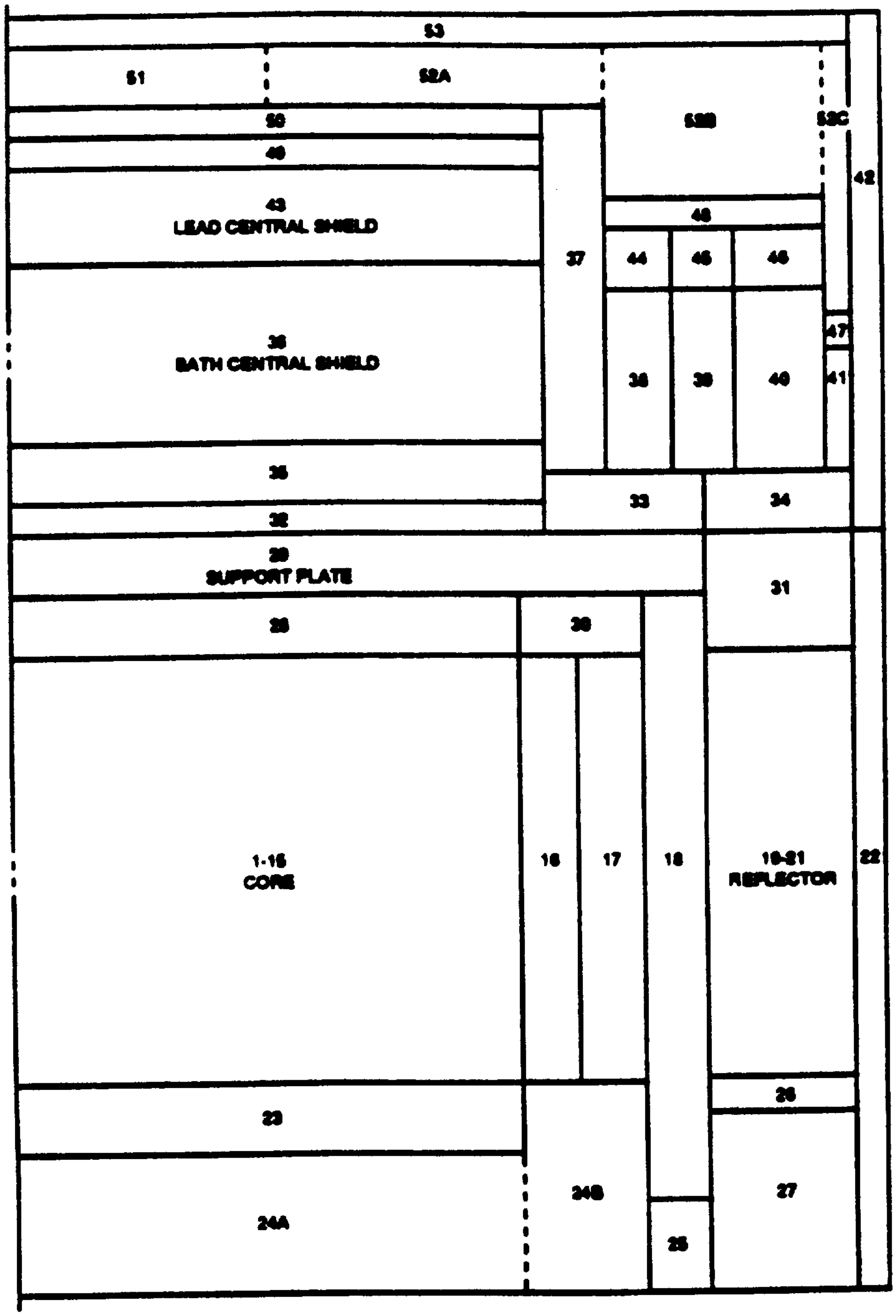

Figure 3-5. R-Z Model of the Regions in the R-1 Reactor

Table 3-4. Reactor Weight Model Regions

REGION NUMBER	REGION DESCRIPTION	MATERIAL
1 - 15	Core	Fueled Element Unfueled Element Pyro Sleeve A-286 SS-304 Hydrogen
16	Core Periphery	Graphitite-G Pyrofoil ZrC (60% Dense) TZM Moly Hydrogen
17	Lateral Support	P03 Graphite ZTA Graphite Pyrofoil Hydrogen
18	Structure	P03 Graphite Al-6061 A-286 Hydrogen
19 - 21	Reflector	P03 Graphite Pyrofoil Beryllium Al-6061 A-286 Control Vane Hydrogen
22	Pressure Vessel Side A	Al-7039 Hydrogen
23	CHESH	Pyrographite Pyrofoil NbC/C Comp. W-ThO A-286 SS-304 SS-316 Hydrogen
24	Nozzle Chamber	Hydrogen
25	Nozzle Barrel	SS-347
26	Aft Reflector Hardware	Al-6061 A-286 SS-440C Hydrogen
27	Aft Reflector Plenum	Hydrogen

TOR29K/14a

Table 3-4. Reactor Weight Model Regions (Cont.)

REGION NUMBER	REGION DESCRIPTION	MATERIAL
28	Core Plenum	TZM Moly Copper-Boron A-286 SS-302 SS-304 Hydrogen
29	Support Plate	Pyrofoil Al-6061 A-286 SS-302 SS-304 Hydrogen
30	Lateral Support-Forward	Al-6061 A-286 Hydrogen
31	Forward Reflector Hardware I	Al-6061 A-286 SS-304 SS-440C Hydrogen
32	Support Plate Plenum	A-286 SS-304 Hydrogen
33	Instrumentation Ring	Al-6061 SS-304 Hydrogen
34	Forward Reflector Hardware II	Al-6061 A-286 SS-304 Hydrogen
35	Aft Central Shield Plate	Al-6061 Hydrogen
36	BATH Central Shield	BATH Al-6061 Hydrogen
37	Flow Baffle I	Al-6061 SS-304 Hydrogen
38	BATH Peripheral Shield I	BATH Al-6061 Hydrogen
39	BATH Peripheral Shield II	BATH Hydrogen
40	BATH Peripheral Shield III	BATH Al-6061 A-286 SS-304 Hydrogen

TOR29K/14b

Table 3-4. Reactor Weight Model Regions (Cont.)

REGION NUMBER	REGION DESCRIPTION	MATERIAL
41	BATH Peripheral Shield IV	BATH Al-6061 Hydrogen
42	Pressure Vessel Side B	Al-7039 Hydrogen
43	Lead Central Shield	Lead Alloy Al-6061 Hydrogen
44	Lead Peripheral Shield I	Lead Alloy Al-6061 Hydrogen
45	Lead Peripheral Shield II	Load Alloy Hydrogen
46	Lead Peripheral Shield III	Lead Alloy Hydrogen Al-6061 A-286 SS-304 Hydrogen
47	Lead Peripheral Shield IV	Lead Alloy Al-6061 Hydrogen
48	Peripheral Shield Plate	A-6061 A-286 SS-304 Hydrogen
49	Shield Plenum	Al-6061 SS-304 Hydrogen
50	Flow Battle II	Al-6061
51	Central Dome Plenum	Hydrogen
52	Peripheral Dome Plenum	Al-6061 A-286 SS-304 Hydrogen
53	Pressure Vessel Dome	Al-7039
	NERVA Nuclear Subsystem	---

TOR29K/14c

The pseudodensity is applied to each region to yield the mass schedule of the reactor for everything out to and including the nressure vessel. The weight algorithms automatically delete the flow baffles if they are not required based on the choice of flow circuits, see Section 3.1.4. Thrust structure, turbopumps, and nozzle masses are not calculated in this module; the NESS code determines the balance of engine masses, which is discussed in Section 2.0.

3.5 Design Variable Options

User inputs can be divided into three categories: engine parameters, reactor parameters, and fuel element parameters. The primary engine parameters are thrust level, chamber temperature, chamber pressure, and nozzle expansion ratio. These primary variables are used by the code to define the engine specific impulse, propellant flow rate, and required reactor power. The reactor parameters include reactor pressure vessel material, power fractions in the peripheral components, and tie tube power levels.

The user supplies the governing parameters for the fuel elements. These include mean fuel element power, element dimensions, fuel scaling, and material. The code modules provides for a choice from three fuel materials: graphitic (UC_2 beads in graphite), composite ((U,Zr)C-Graphite), or carbide ((U,Zr)C). Each fuel type exhibits different properties with regard to mass density, power density, and temperature limits. The fuel to support ratio within the core may be set to one of three patterns: 2:1, 3:1, or 6:1. The fuel parameters are strictly user defined in that the code does not attempt to judge the validity of the inputs. For guidance, Tables 3-1 and 3-2 provide information on typical parameters based on the Rover/NERVA technology. The reflector thickness and zirconium hydride loading of the tie tubes are also user selected based on the user's estimate of criticality requirements.

3.6 Key Assumptions

The code assumes that the same basic design will be used at every size level within the specified code domain. This provides the basis for calculating the size of the core periphery.

The code assumes that the user has specified a viable combination of input criteria. For example, the code does not verify core criticality and control span. This cannot be accomplished until core neutronics is integrated into the code. In particular, engine weights are strongly influenced (upward) by criticality considerations for engines with thrust ratings below 50000 lb.

Many of the input variables are based on NERVA test experience and should not be altered. This includes such things as the limiting fuel element power density and the power distribution in the peripheral regions, which are based on external data sources such as test measurements.

4.0 SAMPLE NTP ENGINE SYSTEM DESIGN CASES

Eight NESS NTP engine design problems are presented in this section. These sample design cases demonstrate many of the design capabilities associated with NESS. Key engine system design parameters associated with these sample cases are presented in Table 4-1. For each sample design case, the NESS VAX mainframe computer input file and engine design output file are given (see Tables 4-2 through 4-9). For Sample Case No. 2, initialized NESS program input sheets are shown. A clean set of input worksheet forms is given in Appendix A.

Table 4-1. Sample Design Case Summary

Case No./ Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Cycle Type	Expander	Expander	Bleed	Gas Generator	Expander	Bleed	Gas Generator	Expander
Thrust Level (lbf/N)	75,000/ 333,600	75,000/ 333,600	75,000/ 333,600	75,000/ 333,600	75,000/ 333,600	35,000/ 155,700	250,000/ 1,112,000	75,000/ 333,600
Reactor Type	ENABLER I	ENABLER II	ENABLER II	ENABLER II	ENABLER II	ENABLER I	ENABLER I	ENABLER I
Reactor Fuel Type	Composite	Composite	Composite	Composite	Carbide	Composite	Composite	Composite
Chamber Pressure (psia/KPa)	1,000/ 6,895	500/ 3,348	500/ 3,348	500/ 3,348	1,000/ 6,895	500/ 3,348	500/ 3,348	1,000/ 6,895
Chamber Temperature (°R/°K)	4,860/ 2,700	4,860/ 2,700	4,860/ 2,700	4,860/ 2,700	5,580/ 3,100	4,860/ 2,700	4,860/ 2,700	4,860/ 2,700
Nozzle Area Ratio	500:1	200:1	200:1	200:1	500:1	200:1	200:1	500:1
No. of Propellant Feed Legs	2	2	2	2	2	1	3	2
Turbopump Type	Centrifugal	Centrifugal	Centrifugal	Centrifugal	Axial	Centrifugal	Axial	Axial
Reactor Fuel Scaling Factor	1.00	0.67	0.67	0.67	0.67	0.67	1.00	1.00

Table 4-2. Sample Case No. 1

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
1000.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
3	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
0	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
0.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.0	CPLINH	Hot bleed line loss fraction
0.0	CPLINC	Cold bleed line loss fraction
0.0	CPLINT	Turbine inlet line loss fraction
0.0	CPVLVT	Turbine throttling valve loss frac.
0	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
500.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
150.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.48	GAMGPB	GG ratio of specific heats
4.2	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
1	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
1	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
3	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.7	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.0	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
1	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
25.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
1.3	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.2	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
2.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

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                 OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

      PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
      ASSUMPTIONS:
                     TEMP       ENTHALPY
               LOX   90.18 K  -3093. CAL/MOL
               LH2   20.27 K  -2154. CAL/MOL

          ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
           C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL
    TURBINE PRESSURE RATIO=    1.572594292212296
    TURBINE PRESSURE RATIO=    1.660545879986024
    TURBINE PRESSURE RATIO=    1.720100935248108
    TURBINE PRESSURE RATIO=    1.761992772871283
    SUCCESSFUL CYCLE POWER BALANCE
    TURBINE PRESSURE RATIO=    1.761992772871283
    SUCCESSFUL CYCLE POWER BALANCE
    TURBINE PRESSURE RATIO=    1.761992772871283
    SUCCESSFUL CYCLE POWER BALANCE
    TURBINE PRESSURE RATIO=    1.761992772871283


          KEY INPUTS

      THRUST LEVEL =                        75000. (lbf)
      CYCLE TYPE =                       EXPANDER CYCLE
      REACTOR TYPE =                     ENABLER I
      FUEL TYPE =                        COMPOSITE FUEL
      NOZZLE EXIT AREA RATIO =              500.
      PROPELLANT USED =                     LH2
      CHAMBER PRESSURE =                   1000. (psia)
      CHAMBER TEMPERATURE =                4860. (deg R)
      NUMBER OF PROPELLANT FEED LEGS =        2


               TANKAGE SUMMARY FOR STAGE #1
                    EXPANDER CYCLE (FUEL SIDE)
                    AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                    FUEL TANK IS PRESSURIZED WITH COLD GAS
                    TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )
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.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	1012.55
TOTAL TANK LENGTH	541.46
NOZZLE LENGTH	328.85
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	78.24

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	2317.37
PRESSURE TANK	4540.87
TANK CONSTRUCTION WEIGHT	4855.67
STRUCTURAL WALL	16.52
AFT SKIRT	424.27

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TANK HEAD ELLIPSE RATIO                1.38      FORWARD SKIRT                       107.30
PRESSURE TANK ELLIPSE RATIO            1.00      TANK MOUNT                            0.00
AFT TANK HEAD HEIGHT                  35.34
FORWARD TANK HEAD HEIGHT              36.04      PRESSURE TANK INSULATION              0.00
PRESSURE TANK HEAD HEIGHT             38.13      FUEL TANK INSULATION                255.96
PRESSURE TANK DIAMETER                76.26      OXIDIZER TANK INSULATION            407.04
AFT TANK CYLINDRICAL LENGTH            0.00
FORWARD TANK CYLINDRICAL LENGTH      464.10      REVERSE HEAD STIFFENER              217.00
PRESSURE TANK CYLINDRICAL LNGTH        0.00      FUEL ACQUISITION SYSTEM              11.30
                                                 OXIDIZER ACQUISITION SYSTEM           0.00
AFT LINE DIAMETER                      0.00      PRESSURANT CONTROL HARDWARE          60.79
FORWARD LINE DIAMETER                  4.03      TANK LINES                           25.81
AFT SKIRT LENGTH                     454.42
FORWARD SKIRT LENGTH                  36.04      BURNED FUEL                        8000.00
                                                 BURNED OXIDIZER                       0.00
STRUCTURAL WALL THICKNESS              0.090     FUEL RESIDUAL                         6.90
AFT TANK WALL THICKNESS                0.030     OXIDIZER RESIDUAL                     0.00
FORWARD TANK WALL THICKNESS            0.078     OXIDIZER AUTOGENOUS PRESSURANT        0.00
PRESSURE TANK WALL THICKNESS           0.937     STORED PRESSURANT                   323.76
AFT TANK DOME THICKNESS                0.030     HOLD TIME FUEL BOILOFF                0.00
FORWARD TANK DOME THICKNESS            0.054     HOLD TIME OX BOILOFF                  0.00
PRESSURE TANK DOME THICKNESS           0.937     FLIGHT FUEL BOILOFF                 754.19
                                                 FLIGHT OXIDIZER BOILOFF               0.00
FUEL TANK MLI THICKNESS                0.02
FUEL TANK SOFI THICKNESS               0.50      MISC EXPENDED FUEL                    0.00
OXIDIZER TANK MLI THICKNESS            1.97      MISC EXPENDED OXIDIZER                0.00
OXIDIZER TANK SOFI THICKNESS           0.50
PRESSURE TANK INSULATION THICK         0.00      MISCELLANEOUS WEIGHT                  0.00
                                                 INTERSTAGE WEIGHT                     0.00

FUEL TNK HEAT FLUX(BTU/HR IN**2)       0.07   ... INPUT MINIMUM SAFETY FACTORS ...
OX TANK HEAT FLUX(BTU/HR IN**2)        0.00
FUEL BOILOFF RATE (LB/SEC)             0.003     STRUCTURAL WALL                       1.25
OX BOILOFF RATE (LB/SEC)               0.000     LINES                                 2.00
                                                 OXIDIZER TANK                         1.25
                                                 FUEL TANK                             1.25
                                                 PRESSURE TANK                         1.50


            PROPELLANT SUMMARY FOR STAGE #1
                 PROPELLANT IS LH2


                    NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0025

.. OXIDIZER ...                                ... FUEL ...

     NOMINAL TANK PRESSURE(PSIA)          0.0      NOMINAL TANK PRESSURE(PSIA)          56.3

     NOMINAL PROPELLANT TEMP(DEGR)        0.0      NOMINAL PROPELLANT TEMP(DEGR)        38.5
     NOMINAL DENSITY(LB/IN**3)            0.0000   NOMINAL DENSITY(LB/IN**3)             0.0025
     NOMINAL VAPOR PRESSURE(PSIA)         0.0      NOMINAL VAPOR PRESSURE(PSIA)         20.0

     MAX PROPELLANT TEMP(DEGR)            0.0      MAX PROPELLANT TEMP(DEGR)            40.0
     MAX TEMP DENSITY(LB/IN**3)           0.0000   MAX TEMP DENSITY(LB/IN**3)            0.0025
     MAX TEMP VAPOR PRESSURE(PSIA)        0.0      MAX TEMP VAPOR PRESSURE(PSIA)        25.0

     MIN PROPELLANT TEMP(DEGR)            0.0      MIN PROPELLANT TEMP(DEGR)            38.5
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MIN TEMP DENSITY(LB/IN**3)          0.0000        MIN TEMP DENSITY(LB/IN**3)          0.0025
MIN TEMP VAPOR PRESSURE(PSIA)       0.0           MIN TEMP VAPOR PRESSURE(PSIA)      20.0


          ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
                EXPANDER CYCLE
                CONVERGENT NOZZLE IS REGEN  COOLED   (MILLED SLOT CONSTRUCTION)
                NOZZLE IS REGEN COOLED   (TUBE CONSTRUCTION)
                PROPELLANT IS LH2


.. ENGINE DIMENSIONS (INCHES) ...                          ... PERFORMANCE ...
     THROAT DIAMETER                          7.43
     REACTOR SUPPORT DIAMETER                35.81              DELIVERED ISP(VAC),SEC               912.78
     PRESSURE VESSEL O.D.                    49.83              IDEAL ISP(ODE),SEC                   933.79
     NOZZLE EXIT DIAMETER                   166.06
     NOZZLE EXTENSION ATTACH DIAM            18.19              DELIVERED CSTAR,FT/SEC             16491.
     CONVERGENT NOZZLE LENGTH                12.00              IDEAL CSTAR,FT/SEC                 16709.
     CONV. NOZZLE STRUCTURAL THICK.           1.220
     GAS SIDE WALL THICKNESS                  0.248             CHAMBER PRESSURE,PSIA               1000.
     NOZZLE EXTENSION THICKNESS               0.010             THRUST PER ENGINE(VAC),LBF         75000.
     SECOND NOZZLE EXTENSION THICKNESS        0.100             TOTAL VAC THRUST,LBF               75000.
                                                                BURN TIME,SEC                       3600.00
     NOZZLE EXIT AREA RATIO                 500.00
     CONTRACTION RATIO                       15.13              OVERALL EFFICIENCY                     0.977
     NOZ EXTENSION ATTCH AREA RATIO           6.00
     SECOND NOZ EXT ATTACH AREA RATI        150.00              KINETIC EFFICIENCY                     1.000
     NOZZLE LENGTH/(MIN RAO LENGTH)           1.187             BARRIER COOLING EFFICIENCY             0.986
     NOZZLE LENGTH                          328.85              BOUNDARY LAYER EFFICIENCY              0.996
     FEED SYSTEM MOUNT LENGTH                78.24              DIVERGENCE EFFICIENCY                  0.996
     REACTOR LENGTH                          52.00
                                                                FOR   1 ENGINE
                                                                OXIDIZER FLOWRATE,LB/SEC               0.00
                                                                FUEL FLOWRATE,LB/SEC                  82.17
                                                                TOTAL FLOWRATE,LB/SEC                 82.17

                                                                CORE TEMPERATURE,DEG R              4860.
                                                                BARRIER TEMPERATURE,DEG R           1630.
                                                                ENGINE MIXTURE RATIO                   0.00
                                                                FUEL FILM COOLING FRACTION             0.03

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS  1 THROUGH  6 ARE BOUNDS TO THE   5      16.706 INCH LONG NOZZLE SECTIONS
STATIONS  6 THROUGH 11 ARE BOUNDS TO THE   5       3.220 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE   0       0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS =    0.248
GAS WALL THERMAL CONDUCTIVITY  =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE=    1460. (DEG R)
```

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.224E+04	.995E+02	.158E+01	.198E+02	.324E-02	0.116E+03	.118E+03	.197E-04	.197E-03	.150E+03	.283E+03
2	.224E+04	.996E+02	.128E+01	.300E+02	.630E-02	0.122E+03	.126E+03	.316E-04	.277E-03	.100E+03	.326E+03
3	.224E+04	.999E+02	.986E+00	.508E+02	.141E-01	0.133E+03	.142E+03	.570E-04	.423E-03	.600E+02	.390E+03
4	.224E+04	.100E+03	.690E+00	.104E+03	.399E-01	0.155E+03	.181E+03	.125E-03	.726E-03	.302E+02	.501E+03
5	.224E+04	.102E+03	.395E+00	.321E+03	.177E+00	0.216E+03	.328E+03	.401E-03	.156E-02	.106E+02	.769E+03
6	.202E+04	.109E+03	.100E+00	.554E+04	.177E+01	0.207E+03	.133E+04	.591E-02	.181E-01	.100E+01	.163E+04
7	.202E+04	.110E+03	.176E+00	.180E+04	.131E+01	0.335E+03	.116E+04	.280E-02	.579E-02	.249E+01	.163E+04
8	.202E+04	.110E+03	.252E+00	.885E+03	.954E+00	0.429E+03	.104E+04	.160E-02	.300E-02	.465E+01	.163E+04
9	.202E+04	.111E+03	.328E+00	.525E+03	.713E+00	0.496E+03	.949E+03	.105E-02	.185E-02	.747E+01	.163E+04
10	.202E+04	.111E+03	.403E+00	.348E+03	.549E+00	0.541E+03	.890E+03	.742E-03	.128E-02	.110E+02	.163E+04
11	.202E+04	.112E+03	.479E+00	.248E+03	.434E+00	0.574E+03	.849E+03	.555E-03	.939E-03	.151E+02	.163E+04

DELTA T= 12.5
DELTA P= -218.2
NOZZLE DELTA T = 10.7
NOZZLE DELTA P = -218.1
ADAPTER DELTA T = 1.8
ADAPTER DELTA P = -0.1
TOTAL HEAT TRANSFER = 1852.7 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	TEMPERATURE(DEG R) OXIDIZER
... PRESSURANT ...				
MAX STORAGE	4365.0	—	550.0	—
VENT	62.0	0.0	47.2	0.0 (SATURATION TEMP OF PROPELLANT)
ULLAGE	56.3	0.0	—	0.0
... PROPELLANT ...				
TANK PROPELLANT	56.3	0.0	38.5	0.0
MAIN PUMP INLET	45.0	0.0	38.5	0.0
MAIN VALVE INLET	2324.1	0.0	99.2	0.0
MAIN VALVE OUTLET	2244.8	0.0	99.2	0.0
TIE TUBE OUTLET	1994.8	—	924.6	—
REGEN OUTLET (REFL I	2019.8	—	111.7	—
REFLECTOR OUTLET	1994.8	—	201.6	—
REACTOR INLET	1132.1		349.0	
REACTOR CORE	1000.0		4860.0	
TURBINE INLET	1994.8		633.9	

TURBINE OUTLET	1132.1	527.5

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
ACQUISITION DEVICE	0.0	0.0		
FEED LINE	11.3	0.0	0.0	0.0
MAIN PUMP	2267.7	0.0	60.7	0.0
MAIN VALVE	79.2	0.0	0.0	0.0
TIE TUBES	250.0	——	825.3	——
REGEN JACKET	218.2	——	12.5	——
REFLECTOR	25.0	——	89.9	——
TURBINE				
	862.7		106.4	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	82.167		0.000
MAIN PUMP - EACH	41.083		0.000
MAIN VALVE	82.167		0.000
TOTAL TIE TUBES	23.947		——
REGEN JACKET INFLOW	58.219		——
NOZZLE BARRIER COOLING		2.342	
REGEN/REFL OUTLET TO CORE	39.673		——
TURBINE - EACH		20.076	
TURBINE TO CORE	40.152		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.09	
CORE	79.825		——

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	79.82	LB/SEC
REACTOR POWER	1587.01	MW
CORE FLOW AREA	198.34	IN2
CORE MASS FLOW RATE	0.40	LB/IN2
FUEL ELEMENT POWER	1.20	MW/Element
FUEL ELEMENT OPERATING LIFE	1.78	HR
NUMBER OF FUEL ELEMENTS	1277.54	
NUMBER OF SUPPORT ELEMENTS	248.92	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	1000.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	348.97	DEG R
CORE INLET PRESSURE	1132.13	PSIA
CORE INLET ENTHALPY	1102.02	BTU/LB
HEAT PICKUP PER TIE TUBE	0.31	MW/TUBE
HEAT PICKUP IN TIE TUBES	73153.70	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1852.69	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	
HEAT PICKUP IN REFLECTOR	18354.71	BTU/S

FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2602.76	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	466.39	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4948.22	DEG R
PEAK FUEL TEMPERATURE	5077.55	DEG R

REACTOR DIMENSIONS

CORE LENGTH	52.00	IN
CORE DIAMETER	32.53	IN
FUEL ELEMENT CHANNEL DIAMETER	0.11	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	30.89	IN
LATERAL SUPPORT DIAMETER	35.81	IN
STRUCTURE OD	38.01	IN
REFLECTOR OD	47.58	IN
PRESSURE VESSEL ID	47.90	IN
PRESSURE VESSEL OD	49.83	IN
THICKNESS OF BATH SHIELD	12.43	IN
THICKNESS OF LEAD SHIELD	1.31	IN
PRESSURE VESSEL LENGTH	101.54	IN
FUEL VOLUME	22307.26	IN3

REACTOR MASSES

FUEL MASS	3078.40	LB
SUPPORT MASS	640.38	LB
CORE PERIPHERY MASS	364.04	LB
LATERAL SUPPORT MASS	335.77	LB
STRUCTURE MASS	691.06	LB
REFLECTOR MASS	2244.61	LB
HOT END HARDWARE MASS	118.52	LB
AFT REFLECTOR MASS	65.20	LB
CORE INLET PLENUM MASS	165.28	LB
SUPPORT PLATE MASS	545.93	LB
LATERAL SUPPORT FORWARD MASS	44.06	LB
REFLECTOR HARDWARE FORWARD MASS	115.50	LB
SUPPORT PLATE PLENUM MASS	38.14	LB
INSTRUMENTATION RING MASS	32.25	LB
FORWARD REFLECTOR HARDWARE MASS	22.88	LB
SUBTOTAL CORE A	8502.04	LB
FLOW BAFFLE MASS	105.13	LB
FLOW BAFFLE 1 MASS	195.02	LB
TOTAL CORE SUBSYSTEM MASS	8802.19	LB
PRESSURE VESSEL A MASS	1068.34	LB
PRESSURE VESSEL B MASS	404.12	LB
PRESSURE VESSEL DOME MASS	186.70	LB
NOZZLE/REACTOR ADAPTER MASS	107.04	LB
TOTAL PRESSURE VESSEL MASS	1766.21	LB
BATH CENTRAL SHIELD MASS	1036.13	LB
BATH PERIPHERAL SHIELD MASS	737.10	LB
BATH PERIPHERAL SHIELD 2 MASS	257.78	LB
LEAD CENTRAL SHIELD MASS	372.31	LB
LEAD PERIPHERAL SHIELD MASS	0.20	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.09	LB
PERIPHERAL SHIELD PLATE MASS	40.52	LB
TOTAL SHIELD MASS	2444.13	LB
REACTOR MASS w/o SHIELD	10568.40	LB
REACTOR MASS w/ SHIELD	13012.53	LB
SAFETY RODS-FOR LAUNCH ONLY	607.68	LB

REACTOR MASS w/o SHIELD-LAUNCH WT.	11176.08	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	13620.21	LB

* * * TPA SUMMARY FOR STAGE #1 * * *
EXPANDER CYCLE
2 PROPELLANT FEED LEGS
CENTRIFUGAL PUMPS
TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	45566.
SPECIFIC SPEED	650.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	25.00
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	2324.06
VOLUMETRIC FLOWRATE(GPM)	4297.88
MASS FLOWRATE(LBM/SEC)	41.08
PUMP HORSEPOWER(HP)	8867.01
PUMP EFFICIENCY	0.644
PUMP DIAMETER(IN)	10.29
PUMP WT.(LB) - EACH PUMP	101.71

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.679
PRESSURE RATIO	1.762
MASS FLOWRATE(LB/SEC)	20.08
DIAMETER(IN)	6.09
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52371.
ROOT STRESS SPEED LIMIT(RPM)	48583.
SPECIFIC SPEED	23.
TURBINE SPEED(RPM)	45566.
TURBINE WT(LB) - EACH TURBINE	37.10
TURBINE ANNULUS AREA(IN2)	16.095
U OVER C	0.36
INLET MACH NUMBER	0.70

... TPA ...

TPA START SYSTEM WT.	0.00
GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	0.00
GEARBOX WT.-TOTAL	0.00
BOOST PUMP WT. - EACH	0.00
MAIN TURBOPUMP WT. - EACH	138.81

TOTAL TURBOPUMP WT.	277.63
TOTAL TPA WT.	309.87

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	2317.37
PRESSURE TANK	4540.87
TANK CONSTRUCTION WEIGHT	4855.67
TANK LINES	25.81
AFT SKIRT	424.27
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	255.96
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.30
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	60.79
ENGINE WEIGHTS:	
1 REACTOR	10568.40
1 REACTOR INTERNAL SHIELD	2444.13
1 NOZZLE	1179.25
1 THRUST MOUNT(S)	1669.35
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	201.92
2 MAIN VALVE(S)	418.21
1 SUPPORT HARDWARE	615.58
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	0.00
2 GAS GENERATOR/PREBURNER	0.00
2 TPA ASSY(S)	277.63
1 GEARBOX(S)	0.00
2 TPA START SYSTEM(S)	0.00
1 GAS GENERATOR/PREBURNER(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	93.94
TOTAL ENGINE WEIGHT	17803.41
FLIGHT FUEL BOILOFF	754.19
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	607.68
TOTAL INERT WEIGHT	32266.61

INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	6.90
OXIDIZER RESIDUAL	0.00
OXIDIZER AUTOGENOUS PRESSURANT	0.00
STORED PRESSURANT	323.76
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00

GROSS IGNITION WEIGHT	40597.27
GROSS BURNOUT WEIGHT	31225.40
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	166.06
NUMBER OF NOZZLES	1
STAGE LENGTH	1012.55
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	1012.55
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	1000.0
NOZZLE AREA RATIO	500.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	912.8
ISP EFFICIENCY	0.977
TOTAL PROP. FLOWRATE, LB/SEC	82.17
CORE PROP. FLOWRATE, LB/SEC	79.82

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL		PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL		TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		——	550.0		——	
VENT	60.1		0.0	46.9		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	54.6		0.0	——		0.0	
... PROPELLANT ...							
TANK PROPELLANT	54.6		0.0	38.5		0.0	
MAIN PUMP INLET	45.0		0.0	38.5		0.0	
MAIN VALVE INLET	1695.6		0.0	78.4		0.0	
MAIN VALVE OUTLET	1628.3		0.0	78.4		0.0	
TIE TUBE OUTLET	1378.3		——	937.7		——	
REGEN OUTLET (REFL I	1403.3		——	92.5		——	
REFLECTOR OUTLET	1378.3		——	181.3		——	
REACTOR INLET		962.5			358.4		
REACTOR CORE		800.0			4860.0		
TURBINE INLET		1378.3			629.4		
TURBINE OUTLET		962.5			560.2		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)			TEMPERATURE CHANGES (DEG R)		
ACQUISITION DEVICE	0.0		0.0	0.0		0.0
FEED LINE	9.6		0.0	39.9		0.0
MAIN PUMP	1641.0		0.0	0.0		0.0
MAIN VALVE	67.4		0.0	859.3		——
TIE TUBES	250.0		——	14.0		——
REGEN JACKET	139.9		——	88.9		——
REFLECTOR	25.0		——			
TURBINE		415.8			69.2	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	65.663		0.000
MAIN PUMP	65.663		0.000
MAIN VALVE	65.663		0.000
TOTAL TIE TUBES	19.138		——
REGEN JACKET INFLOW	46.525		——
NOZZLE BARRIER COOLING		1.871	——
REGEN/REFL OUTLET TO CORE	31.705		——
TURBINE		32.087	
TURBINE TO CORE	32.087		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.08	
CORE	63.792		——

* * * TPA SUMMARY FOR STAGE #1 * * *
SUMMARY FOR TPA AT THRUST LEVEL FRACTION 0.80
EXPANDER CYCLE
SINGLE SHAFT TPA
CENTRIFUGAL PUMPS

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	40583.
SPECIFIC SPEED	932.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	25.00
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1695.63
VOLUMETRIC FLOWRATE(GPM)	6871.14
MASS FLOWRATE(LBM/SEC)	65.66
PUMP HORSEPOWER(HP)	9329.16
PUMP EFFICIENCY	0.708
PUMP DIAMETER(IN)	10.29
PUMP WT.(LB)	101.71

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.700
PRESSURE RATIO	1.432
MASS FLOWRATE(LB/SEC)	32.09
DIAMETER(IN)	6.09
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52366.
ROOT STRESS SPEED LIMIT(RPM)	48580.
SPECIFIC SPEED	67.
TURBINE SPEED(RPM)	40583.
TURBINE WT(LB)	37.10
TURBINE ANNULUS AREA(IN2)	16.095

ENGINE SUMMARY

EXPANDER CYCLE
ENABLER I
CENTRIFUGAL PUMPS

THRUST LEVEL =	75000.0	lbf	333600.0	N
CHAMBER PRESSURE =	1000.0	psia	6895.0	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	500.0		500.0	
NUMBER OF FEED LEGS =	2		2	
TOTAL PROPELLANT FLOWRATE =	82.2	lbm/s	37.3	kg/s

REACTOR
COMPOSITE FUEL

REACTOR WEIGHT	10568.4	lbm	4792.9	kg
SHIELD WEIGHT	2444.1	lbm	1108.4	kg
PRESSURE VESSEL DIA.	49.8	in	126.6	cm

PRESSURE VESSEL LENGTH	101.5	in	257.9	cm
CORE PROPELLANT MASS FLOW	79.8	lbm/sec	36.2	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	182.1	lbm	82.6	kg
NOZZLE EXTENSION WEIGHT	399.0	lbm	181.0	kg
SECOND NOZZLE EXTENSION WEIGHT	598.1	lbm	271.3	kg
TOTAL NOZZLE WEIGHT	1179.3	lbm	534.8	kg
AREA RATIO	500.0		500.0	
THROAT DIAMETER	7.4	in	18.9	cm
EXIT DIAMETER	166.1	in	421.8	cm
NOZZLE LENGTH	328.8	in	835.3	cm
DELIVERED VACUUM ISP	912.8	sec	8945.2	N-sec/kg
DELIVERED THRUST	75000.0	lbf	333600.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	277.6	lbm	125.9	kg
PROPELLANT BOOST PUMP WT	0.0	lbm	0.0	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	32.2	lbm	14.6	kg
BLEED LINE/VALVE WEIGHT	0.0	lbm	0.0	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1669.3	lbm	757.1	kg
SUPPORT HARDWARE	615.6	lbm	279.2	kg
ENGINE LINES	201.9	lbm	91.6	kg
MAIN VALVE	418.2	lbm	189.7	kg
GIMBAL + POWER SUPPLY	302.8	lbm	137.3	kg
MARGIN (2.0%)	93.9	lbm	42.6	kg
TOTAL NONNUCLEAR WEIGHT	4790.9	lbm	2172.7	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	17803.4	lbm	8074.1	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	15359.3	lbm	6965.7	kg
THRUST/WEIGHT RATIO WITH SHIELD	4.2	lbf/lbm	41.3	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	4.9	lbf/lbm	47.9	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	607.7	lbm	275.6	kg
TOTAL ENGINE LAUNCH WEIGHT	18411.1	lbm	8349.7	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	15967.0	lbm	7241.3	kg
PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	60000.0	lbf	266880.0	N
PUMP-OUT CHAMBER PRESSURE	800.0	psia	5516.0	kPa
PUMP-OUT ISP	913.8	sec	8954.8	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	508.6	in	1291.9	cm
OVERALL ENGINE DIAMETER =	166.1	in	421.8	cm

WARNING

```
                    THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 15.130          RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM =  166.1     STAGE DIAM =  100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS  FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

THE FUEL PUMP TIP SPEED EXCEEDS 2000 FPS AND HAS THE MAXIMUM OF 4 STAGES
GAS PHASE ENCOUNTERED IN REGEN JACKET
TPA CALCULATIONS TERMINATED BY ACHIEVING DESIRED ACCURACY

END NOMINAL STAGE DESIGN
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Table 4-3. Sample Case No. 2

Input Worksheet Forms

TITLE: Nuclear Thermal Vehicle		VARIABLE	NAMELIST	UNITS	DEFAULT
Vacuum Thrust (lbf)	75000	FVAC	LIQUID	lbf	75000
Chamber Pressure	500	PC	INPGEN	psia	500
Propellant: 5) LH2 Note: GG cycle will use LO2 as needed		IPROP	LFLAG		5
Vehicle Payload wt. (lbm)	________	WPAYLD	INPGEN	lbm	0
Miscellaneous Stage wt. (lbm)	________	WMISC	INPGEN	lbm	0
Expendable Stage wt. (lbm)	________	WEXPND	INPGEN	lbm	0
Cycle Type: 1) Gas Generator 3) Expander 7) Bleed		KCYCLE	LFLAG		3
Pump Configuration: 1) Gearbox 2) Single Shaft TPA 3) Twin TPA in series 4) Twin TPA in parallel 5) Multiple feed leg TPA Note: If a double run is being made, choose JCNFIG=2 in the input file; the code automatically sets JCNFIG=5 for the second pass.		JCNFIG	PUMP		2

		VARIABLE	NAMELIST	UNITS	DEFAULT
Pump Type: IPTYPE =		IPTYPE			0
0 Centrifugal Pumps					
1 Axial Pumps					
Bleed Cycle solver option: ISOLVE =		ISOLVE			1
0 Input bleed flow fractions; solve for turbine inlet temperature					
1 Input turbine inlet temperature; solve for bleed mass flows					
Turbine Inlet Temperature (ISOLVE=1)		TURBTIN		deg. R	0.0
Bleed mass flow fractions (ISOLVE=0)					
Hot bleed fraction of total bleed	_______	FRACHB			0.0
Cold bleed fraction of total bleed	_______	FRACCB			0.0
Bleed Cycle Line/Valve losses (fractions)					
Hot bleed line loss	_______	CPLINH			0.07
Cold bleed line loss	_______	CPLINC			0.07
Turbine inlet line loss	_______	CPLINT			0.07
Turbine throttling valve loss	_______	CPVLVT			0.08

		VARIABLE	NAMELIST	UNITS	DEFAULT
Boost Pumps: (0 = no, 1 = yes) Oxidizer Fuel	1	JBPOX JBPFL	PUMP PUMP		0 0
Number of Identical Turbopump Propellant Feed Assemblies (Used if JCNFIG=5 or IDBLRUN=1)	2	NTPA	PUMP		2
Do a double run? (0 = no, 1 = yes) (If yes, first run made at reduced thrust level to size turbomachinery that will be used as part of a multiple-leg feed system used in the second run at full thrust level)	1	IDBLRUN	LFLAG		1
Percent (fraction) of total thrust to be used for the first run (IDBLRUN=1)	0.8	FFRAC	LFLAG		0.8
Input the engine burn time? (0 = no, 1 = yes) (If no, code calculates burn time based on amount of propellant and mass flow rate)	[illegible]	IUSRBRN	LIQUID		1
Engine burn time (sec) (IUSRBRN = 1)		TUSRBRN	LIQUID	sec.	3600.0
Percent (fraction) of Non-nuclear weight to be added as margin		FMARG	LIQUID		0.02
Iterate on pump design? (0=no, 1=yes) This option checks whether the off-design performance of the pumps meets certain criteria; if not, FFRAC is reduced and the entire design process is repeated.	0	ITRATE			0

		VARIABLE	NAMELIST	UNITS	DEFAULT
Engine Expansion Area Ratio	200	EPS	INPGEN		500
Use a Nozzle Extension? (0 = no, 1 = yes)	1	KEXNOZ	LIQENG		1
Use a 3-portion Nozzle? (regen slots+tubes+extension) (0 = no, 1 = yes)	1	NOZTYP	LFLAG		1
Nozzle Extension 1 Attach Area Ratio	6	EPSATT	INPGEN		6
Nozzle Extension 2 Attach Area Ratio (NOZTYP = 1)	25	EPSAT2	INPGEN		25
Convergent Nozzle Length (in)	12	XLN	LIQENG	in.	12.
Nozzle Type:		KNOZ	LIQENG		2
		IPLUG	LIQUID		0
Ratio of Nozzle Length to Minimum Rao Nozzle Length	1.1868	RATMLR	LIQENG		1.177
Gas Generator/Pre-Burner: Mixture Ratio	0	OFOGPB	PUMP		0.75
Ratio of Specific Heats	1.46	GAMGPB	PUMP		1.378
Specific Heat (BTU/lb°R)	3.55	CPOGPB	PUMP	BTU/lb °R	2.054
Molecular Weight	2.016	WMOGPB	PUMP		3.53

Nozzle Type:	IPLUG	KNOZ
Conical	0	1
Rao/Bell	0	2
Plug Cluster	1	-
Annular	2	-

Solid Core (ENABLER) Reactor Inputs

VARIABLE	NAMELIST	UNITS	DEFAULT	Description
IREACTR			1	Reactor Model: 1) ENABLER I: automatically sets CONFIG=1, FALPHA=1.0 2) ENABLER II: automatically sets CONFIG=2, BYPTUR=1.0
CONFIG			1	Reactor Flow Path Option: (CONFIG affects only the expander cycle) 1) ENABLER I option: turbines driven by tie tube and some reflector flow 2) ENABLER II option: turbines driven tie tube flow only

Reactor Inputs (cont'd)

		VARIABLE	NAMELIST	UNITS	DEFAULT
Chamber Temperature	4860	TCHAMBER	REACTR	°R	4860
Fuel Element Channel Diameter	0.11	DC	REACTR	in.	0.10
Spacing between Holes		SC	REACTR	in.	0.173
Peak to Average Channel Factor		PAC	REACTR		1.2
Number of Holes per Element		HOLES	REACTR		19.0
Fuel Type 1) Graphite 2) Composite 3) Carbide		FTYPE	REACTR		2
Support Pattern 1) 2:1 2) 3:1 3) 6:1		SPAT	REACTR		3
Core Length	52	LC	REACTR	in.	52.
Power in each Element per 52 inches	1.2	PMW	REACTR	MW/52"	1.2
Nozzle Flow Percent (fraction) (= Regen flow)	0.25	NFF	REACTR		0.7

Reactor Inputs (cont'd)

		VARIABLE	NAMELIST	UNITS	DEFAULT
Heat Pickup per Tie Tube		QTT	REACTR	MW/tube	0.31
Enthalpy of Coolant Entering System		HTANK	REACTR	BTU/lb	-106.0
Fractional Heat Pickup in Reflector		FREF	REACTR		0.0122
Fractional Heat Pickup in External Shield		FES	REACTR		0.00031
Fractional Heat Pickup in Central Shield		FCS	REACTR		0.00173
Fuel scaling factor; applies to fuel cross-section dimensions		FALPHA			0.67
Uncoated fuel hex flat dimension		HEX		in.	0.75
Scalable fuel element length; overrides LC if LEL is not zero		LEL		in.	52.
Channel coating thickness at inlet		ZRCI		in.	0.002
Channel coating thickness at outlet		ZRCO		in.	0.006
Element external coating thickness		ZRCH		in.	0.0015
Pressure vessel material specific gravity		PVSG			2.74
Pressure vessel material allowable stress		PVSA		psi	50000.
Thickness of beryllium reflector		TREFL		in.	4.785
Fraction of maximum ZrH loading in tie tubes	0.8	FZRH			1.0

		VARIABLE	NAMELIST	UNITS	DEFAULT
Burned Propellant wt. (lbm)	8000	WTLPRP	LIQUID	lbm	50000
Ullage Fractions					
Oxidizer	______	ULLFOX	LTANK		.02
Fuel	______	ULLFFL	LTANK		.02
Propellant Acquisition Device		KACQOX	LFLAG		6
0) None 1) transverse collapsing AL bladder 2) full bonded rolling diaphram - AL 3) half bonded rolling diaphram - AL 4) full bonded rolling diaphram - stainless steel 5) half bonded rolling diaphram - stainless steel 6) surface tension device		KACQFL	LFLAG		6
Propellant Tank Pressurization **KGASOX, KGASFL =**		KGASOX KGASFL	LFLAG LFLAG		1 1
0) non-autogenous (KGAS=) 1) solid gas generator 2) cold helium		KGAS	LFLAG		2
1) autogenous					
Cold Helium Storage Pressure (psia)	______	PICG	COLDG	psia	4365
Helium Tank Final Pressure Fraction (less than 1.0 indicates blowdown)	______	FPULCG	COLDG		0.8

Description	Value	VARIABLE	NAMELIST	UNITS	DEFAULT
Propellant Tank Heat Transfer 0) ignore heat transfer 1) external boundary exposed to conductive source 2) worst case solar radiation 3) ground hold ice formation		KHXOPT	LFLAG		0
Propellant Tank Insulation (in.)					
Fuel Tank					
SOFI thickness	0.5	TSOFIF	TANKHX	in.	0.5
MLI thickness	0.018	TMLIF	TANKHX	in.	1.97
Oxidizer Tank					
SOFI thickness	0.5	TSOFIO	TANKHX	in.	0.5
MLI thickness	0.018	TMLIO	TANKHX	in.	1.97
Stage Operating Temperature Range (°F)					
Minimum temperature		TMIN	LIQUID	°F	60.0
Nominal temperature		TOP	LIQUID	°F	75.0
Maximum temperature		TMAX	LIQUID	°F	90.0

Description	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Nozzle Cooling Method (second portion) 2)Regenerative 3)Trans-Regen 4)Radiation 5)Film (GG only) Note: When used, third portion of nozzle extension is automatically radiation cooled		KOOLNZ	LFLAG		2
Nominal Convergent Wall material temperature (°R)	1460	TGWNOM	INREGN	°R	2000.0
Regen/Trans-regen input:					
Output a regen summary (0 = no, 1 = yes)	1	IRPRNT	INREGN		1
Gas wall minimum gauge (in.)	0.01275	GWMING	INREGN	in.	0.025
Gas wall thermal conductivity (BTU/in sec °R)	0.00039	WALLK	INREGN	BTU/in sec °R	0.00039
DIFTBF = ($T_{barrier}$-TGWNOM)/(T_{core}-TGWNOM)	0.05	DIFTBF	INREGN		0.05
Nominal nozzle material temperature (°R)	2000	TNENOM	LIQENG	°R	2000.0

Parameter	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Pressure Drop Across Valve (3-30% of Pc)					
Fuel	0.07	CPVLVF	LIQUID		0.07
Oxidizer		CPVLVO	LIQUID		0.07
Pressure Drop Across Lines (3-30% of Pc)					
Fuel	0.01	CPLINF	LIQUID		0.08
Oxidizer		CPLINO	LIQUID		0.08
Translating Nozzle 0) none 1) spring actuated 2) gas deployed skirt		KTRNOZ	LIQENG		0
Translating Nozzle Attach Area Ratio		EPTRAT	LIQENG		150
Number of Gimballing Engines		NGIMB	LIQUID		1
Gimbal Angle (deg)		GMBANG	LIQUID	deg	6.0

Engine Materials of Construction
(use density and strength at temperature)

Aluminum	0.098 lb/in3,	25000 psia
Stainless Steel	0.28 lb/in3,	25000 psia
Columbium	0.32 lb/in3,	25000 psia
Silica Phenolic	0.0632 lb/in3,	25000 psia
Inconel	0.298 lb/in3,	25000 psia
Copper	0.32 lb/in3,	25000 psia
Carbon-Carbon	0.061 lb/in3,	50000 psia

		VARIABLE	NAMELIST	UNITS	DEFAULT
Convergent Nozzle/Throat (regen slots)					
density	0.322	RHOCSTR	LIQMAT	lb/in^3	0.28
strength	25000	SIGCHM	LIQMAT	psi	25000.
Regen Closeout material					
density	0.322	RHOCLS	LIQMAT	lb/in^3	0.322
strength	25000	SIGCLS	LIQMAT	psi	25000.
Regen Gas Wall Material Density	0.322	RHOGW	LIQMAT	lb/in^3	0.28
Valve Material Density	0.298	RHOVLV	LIQMAT	lb/in^3	0.098
Nozzle Extension 1 (usually regen tubes)					
density	0.298	RHONZE	LIQMAT	lb/in^3	0.32
strength	37000	SIGNZE	LIQMAT	psi	25000
minimum thickness (in)	0.01	TNZMIN	LIQENG	in.	0.01
Nozzle Extension 2 (NOZTYP=1)					
density		RHONZ2	LIQMAT	lb/in^3	0.061
strength		SIGNZ2	LIQMAT	psi	50000
minimum thickness		TNZMN2	LIQENG	in.	0.1

		VARIABLE	NAMELIST	UNITS	DEFAULT
Translating Nozzle Material Density (lb/in^3)		ROTRNZ	LIQMAT	lb/in^3	0.28
Engine Weight Model:		KWTMOD	LFLAG		1
-1) input engine weight 1) physical engine weight model					
Engine size/weight input (KWTMOD = -1)					
nozzle length (in)	def	XLNOZ	LIQENG	in.	76.04
engine weight (lb)	def	WTLTCA	LIQENG	lbm	184.4
nozzle throat diameter (in)	def	THDUSR	LIQENG	in.	0.0
Regen Cooling:					
Turbine bypass flow fraction	1.0 (set internally)	BYPTUR	INREGN		0.0
Cooling channel multiplier	def	CHMULT	INREGN		1.0
Absolute surface roughness of regen channels	def	EPIPE	INREGN	in.	0.00008
Maximum depth to width ratio in cooling channels	3.2	HOWMAX	INREGN		5.0
Number of regen segments in:					
Convergent chamber section	def	NCON	INREGN		5
Nozzle	def	NNZL	INREGN		5

		VARIABLE	NAMELIST	UNITS	DEFAULT
Surface area multiplier on regen cooled engine	1.0	SAMULT	INREGN		1.0
Land width of regen cooling channels at throat (in.)	0.04	WLTHR	INREGN	in.	0.03
Channel width of regen cooling channels at throat (in.)	0.10	WTHR	INREGN	in.	0.03
User-defined Regen option:					
Input Regen Delta T and Delta P? (0 = no, 1 = yes)	∅	INDPDT	INREGN		0
Regen Jacket total Delta T (INDPDT = 1)		DELTAT	INREGN	°R	100.
Regen Jacket total Delta P		DELTAP	INREGN	psia	100.
Tank Outlet Net Positive Suction Pressures Oxidizer (psia)	10	OXNPSP	PUMP	psia	10.
Fuel (psia)	15	FLNPSP	PUMP	psia	10.

		VARIABLE	NAMELIST	UNITS	DEFAULT
<u>Engine Efficiency Adjustment Factors</u>:					
Gas Generator Bleed Efficiency Factor in the form: EFFGGB = EFFGGB*ADJGGB	1.0	ADJGGB	LQPERF		1.0
The following factors are used in the form: EFF = 1 - (1 - EFF)*adjustment factor					
Boundary Layer Efficiency Adjustment	0.2	ADJBL	LQPERF		1.0
Divergence Efficiency Adjustment	1.0	ADJDIV	LQPERF		1.0
Barrier Cooling Efficiency Adjustment	1.0	ADJMRD	LQPERF		1.0
Barrier liquid film length		XLFL	LQPERF	in.	1.0
Barrier mixing angle		ALFMIX	INJECT	deg.	0.15

Weight Multipliers		VARIABLE	NAMELIST	UNITS	DEFAULT
All Tanks	1.7	CXWTNK	CXWMLT		1.0
		CXNCTI	NCTINP		1.0
Fuel Tanks	1.7	CXWFLT	CXWMLT		1.0
Oxidizer Tanks	1.7	CXWOXT	CXWMLT		1.0
Pressure Tanks	1.7	CXWPTN	CXWMLT		1.0
Structure		CXWSTR	CXWMLT		1.0
Propellant Lines		CXWATL	CXWMLT		1.0
		CXWFIL	CXWMLT		1.0
		CXWPIL	CXWMLT		1.0
Total Nozzle + Hardware		CXWENG	CXWMLT		1.0
Valve		CXVALV	CXWMLT		2.8
Convergent Nozzle		CXWCHM	CXWMLT		1.0
Nozzle Extension		CXWNZE	CXWMLT		1.1
Hot Gas Ducts		CXWDUC	PUMP		3.5
Gimbal System (excl. power supply)		CXWGIM	CXWMLT		1.4
Thrust Mount		CXWTHM	CXWMLT		0.9
Gas Generator Injector		CXWIGG	PUMP		1.4
Turbines		CXWTPA	CXWMLT		1.3

	VARIABLE	NAMELIST	UNITS	DEFAULT
Weight Multipliers (cont'd)				
Pumps	CXWPMP			1.3
Engine Bay Lines	CXWLIN	PUMP		2.5
Support Hardware:				
Pneumatic Supply System - NERVA technology, CXWPNEU = 1.0 - Current technology, CXWPNEU = 0.25	CXWPNEU	CXWMLT		0.25
Instrumentation	CXWINST	CXWMLT		1.0
Reactor Cooldown Assembly (Shutoff and Reactor Cooldown Valve + Line)	CXWINKAS	CXWMLT		0.9
Ignition System	CXWIGN	CXWMLT		1.3

		VARIABLE	NAMBLIST	UNITS	DEFAULT
User-Defined Turbomachinery Option Note: These variables are assigned automatically on the second pass of a double run					
Input Turbomachinery Characteristics? (0 = no, 1 = yes)	ϕ	ISTSET	PUMP		0
Pump Inputs:					
Number of fuel pump stages		PSTAGF	PUMP		1
Number of ox pump stages		PSTAGO	PUMP		1
Fuel pump diameter		PDIAFL	PUMP	in.	0.0
Ox pump diameter		PDIAOX	PUMP	in.	0.0
Fuel boost pump diameter		BPDIAF	PUMP	in.	0.0
Ox boost pump diameter		BPDIAO	PUMP	in.	0.0
Turbine Inputs: Choose single shaft or fuel and ox turbines					
Number of turbine stages:					
Single shaft		TSTGES	PUMP		1
Fuel turbine		TSTAGF	PUMP		1
Ox turbine		TSTAGO	PUMP		1
Turbine Diameter:					
Single shaft		TDIAM	PUMP	in.	0.0
Fuel turbine		TDIAFL	PUMP	in.	0.0
Ox turbine		TDIAOX	PUMP	in.	0.0

User-Defined Turbomachinery (cont'd)

Description		VARIABLE	NAMELIST	UNITS	DEFAULT
Turbine Admission Fraction:					
Single shaft		ADMFR	PUMP		1.0
Fuel turbine		ADMFRF	PUMP		1.0
Ox turbine		ADMFRO	PUMP		1.0
Turbine Annulus Area:					
Single shaft		ANAREA	PUMP	in^2	0.0
Fuel turbine		ANARFL	PUMP	in^2	0.0
Ox turbine		ANAROX	PUMP	in^2	0.0
Input Turbopump Assembly Weights? (0 = no, 1 = yes)	____	INPTPA	PUMP		0
Total TPA Weight	____	TPAWT	PUMP	lbm	0.0
TPA Start System Weight	____	WSTART	PUMP	lbm	0.0
Ignition System Weight	____	WIGNIT	PUMP	lbm	0.0
Hot Gas Manifold Weight	____	WHGMF	PUMP	lbm	0.0
Gearbox Weight	____	WGBOX	PUMP	lbm	0.0
Autogenous Heat Exchanger Weight	____	WHHX	PUMP	lbm	0.0
Gas Generator/Preburner Weight	____	WGGPB	PUMP	lbm	0.0

__User-Defined Turbomachinery (cont'd)__

	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Have User-Defined Gas Generator? (0 = no, 1 = yes)	ϕ	IUSRGG	PUMP		0
Gas Generator Inputs: Bleed Nozzle Flowrate		WDBLNZ	PUMP	lb/sec	0.1
GG Bleed Efficiency		ETAGGB	PUMP		0.99
Max Turbine Temp. Limit		TTLIMT	PUMP	°R	5000.
Turbine/GG Inlet Temp.		TUSRGG	PUMP	°R	0.0
Turbine Flowrate		WDUSRG	PUMP	lb/sec	0.0
Isp of GG Bleed		USRGGI	PUMP	sec	0.0
Turbine Inlet Pressure		PUSRTI	PUMP	psia	0.0
User Defined Drive Fluid Weight		WPUSRG	PUMP	lbm	10.0
User Defined Drive Fluid Tank Weight		WIUSRG	PUMP	lbm	10.0
Density of Drive Fluid		ROUSRG	PUMP	lb/in^3	0.01
Yield Stress of Drive Fluid Tank		SYUSRG	PUMP	psi	25000.0
Density of Drive Fluid Tank Material		ROUSMT	PUMP	lb/in^3	0.098

	VARIABLE	NAMELIST	UNITS	DEFAULT
Transpiration Cooling Inputs:				
Transpiration Cooling Criteria 1) use QMAXTR 2) input EPSTRD and EPSTRU	IDTRAN	INREGN		2
Maximum heat flux before transpiration cooling (BTU/in^2 sec)	QMAXTR	INREGN	BTU/in^2 s	1.0
Upstream area ratio for transp. cooling	EPSTRU	INREGN		2.0
Downstream area ratio for transp. cooling	EPSTRD	INREGN		1.2
Transpiration section platelet dimensions				
etched platelet thickness	TGBOH	INREGN	in.	0.08
platelet land thickness	TGBOL	INREGN	in.	0.1
separator platelet thickness	TGBOS	INREGN	in.	0.04
flow passage widths	TGBOW	INREGN	in.	0.14
Transpiration cooling insert:				
material density	RHTRIN	LIQMAT	lb/in3	0.28
thickness	TRINST	LIQMAT	in.	0.3
thermal conductivity (BTU/in sec °R)	TRANKM	INREGN	BTU/in s °R	0.0004

Tank Geometry

(Draw Sketch Here)

Tandem Tanks

monocoque tanks (1)
suspended tanks (0)
separate domes (0)
common domes (1)

Pressure Tank Geometry
0) spherical in engine bay
number of tanks
1) suspended forward of forward tank
2) monocoque separate dome
3) monocoque common dome
4) cylindrical in forward tank

propellant tank head ellipse ratio 1.38

pressurant tank head ellipse ratio

propellant tank dome orientation
(-1 = convex forward)
(1 = convex aft

def

propellant location
(1 = fuel aft, not 1 = fuel not aft

VARIABLE	NAMELIST	UNITS	DEFAULT
NCTNK	LFLAG	-	0
MNCQA	TNKGEO	-	1
MNCQF	TNKGEO	-	1
KDOME	TNKGEO	-	1
KPRESS	TNKGEO	-	0
NPRB	TNKGEO	-	1
ELDOME	INPGEN	-	1.0
ELRP	LTANK	-	1.0
KXATAH	TNKGEO	-	1
KXATFH	TNKGEO	-	-1
KXFTAH	TNKGEO	-	-1
KXFTFH	TNKGEO	-	-1
KPRPA	TNKGEO	-	2

Non-Conventional Tanks

(Draw Sketch Here)

	VARIABLE	NAMELIST	UNITS	DEFAULT
Total number of tanks	NTANKS	NCTINP	-	3
Tank ellipse ratios	ELTNK1	NCTINP	-	1.0
Tank types (1 = CSE, 2 = torus)	KTANK1	NCTINP	-	1
Tank contents (1 = ox, 2 = fuel, 3 = press)	INTNK1	NCTINP	-	1
Tank angular location (deg)	TANGL1	NCTINP	deg	0.0
Tank radial location	RADLO1	NCTINP	-	0.0
Kind of dimensional input dimensionless (0) L_{cyl}/D ; R_{hub}/R_{tube}	KALHOD	NCTINP	-	0
	RDIM1	NCTINP	-	2.0
major dimension (in) (1) R_{tank} ; R_{hub}	RMAJ1	NCTINP	in	25.0
Engine angular location (deg)	ENGAN1	NCTINP	deg	0.0
Engine radial location	ENGRD1	NCTINP	-	0.0
Stage Diameter (in)	DMOTOR	INPGEN	in	66.0
Forward Skirt Length (in)	FFSKTL	LIQUID	-	0.3
Aft Skirt Length (in)	FASKTL	LIQUID	-	0.067

... of Construction
(fill in material IDs)

1-10) user defined
11) 6061-T6 aluminum @ 300°F
12) 6Al-4V titanium @ 300°F
13) aged 6Al-4V @ 300°F
14) cryoformed 301 CRES @ 500°F
15) aged 301 CRES @ 500°F

Fuel Tank	11
Oxidizer Tank	1
Pressurant Tank	2
Structure and Skirts	11

Design Safety Factors

Fuel Tank	
Oxidizer Tank	
Pressure Tank	
Structure and Skirts	
lines	

VARIABLE	NAMELIST	UNITS	DEFAUL
HINKFL	LIQMAT	-	1
HINKOX	LIQMAT	-	1
MATPT	LIQMAT	-	2
MATSTR	LIQMAT	-	1
MATNK1	NCTINP	-	1
RHO	LIQMAT	lb/in^3	-
YMOD	LIQMAT	psi	-
SIGMAX	LIQMAT	psi	-
SPHEAT	LIQMAT	BTU/lb °R	-
CONDCT	LIQMAT	BTU/in sec °R	-
THING	LIQMAT	in	0.035
THINGS	LIQMAT	in	0.035
SFFLTK	LIQMAT	-	1.25
SFOXTK	LIQMAT	-	1.25
SFPRTK	LIQMAT	-	1.5
SFSTRC	LIQMAT	-	1.25
SFLINE	LIQMAT	-	2.0
SFTNK1	NCTINP	-	1.5

		VARIABLE	NAMELIST	UNITS	DEFAULT
Engine Mounting Length Adjustment (in) To have NESS calculate a mounting length based on TPA component lengths and reactor length, input XMOUNT = 0.0	0.0	XMOUNT		in.	0.0
Propellant Expulsion Efficiency 0) Calculate 1) Input		INPEXF			0
		INPEXO			0
Fuel expulsion efficiency	[illegible]	EXPLFL			0.995
Oxidizer expulsion efficiency		EXPLOX			0.995

Tankage

	VARIABLE	NAMELIST	UNITS	DEFAULT
Propellant Acquisition device material density ($lb/in.^3$)				
fuel tank (KACQFL = 6) [ ]	DACQFL	LTANK	$lb/in.^3$	0.1
ox tank (KACQOX = 6) [ ]	DACQOX	LTANK	$lb/in.^3$	0.1
Cross sectional area of shroud stiffening rings ($in.^2$)				
forward shroud [ ]	AESSR	LTANK	in^2	0.152
aft shroud [ ]	AFSSR	LTANK	in^2	0.25

Figure (cont.)

General Input

Propellant temperatures input option for library propellants (IPROP > 0)

(Circle One)

0) use default temperatures

1) input temperatures

minimum fuel temperature (°R)	38.5
nominal fuel temperature (°R)	38.5
maximum fuel temperature (°R)	40.0
minimum ox temperature (°R)	
nominal ox temperature (°R)	
maximum ox temperature (°R)	

VARIABLE	NAMELIST	UNITS	DEFAULT
IPUTMP	LFLAG	-	0
TPMINF	LFUEL	°R	varies
TPNOMF	LFUEL	°R	varies
TPMAXF	LFUEL	°R	varies
TPMINO	LOXID	°R	varies
TPNOMO	LOXID	°R	varies
TPMAXO	LOXID	°R	varies

General Input

Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Lines full at burnout (Circle One) (0 = No, 1 = Yes)	LNFULL	LFLAG	-	1
Miscellaneous on-board propellant (lbm) (remains on stage at burnout) fuel [ ]	WMISFL	INPGEN	lbm	0.0
ox [ ]	WMISOX	INPGEN	lbm	0.0
Number of iterations on temperature schedule [2] (a value of 1 performs temperature schedule calculations only once)	NTMPIT	LIQUID	-	1

Figure 2.1 Contingent Input Worksheet

<u>Tandem Tanks</u> (NCTNK = 0)

Space between suspended tank and structural vehicle wall

aft tank (NNCQA = 0)

forward tank (NNCQF = 0)

pressure tank (KPRESS = 1)

def

Pressure tank insulation density [ ]

(NCTNK = 0)(lb/in.^{3})

Propellant feed line flag (Circle One)

0) external feed line

1) internal feed line

Number of pressure bottles in engine bay [ ]

(KPRESS = 0)

VARIABLE	NAMELIST	UNITS	DEFAULT
TSPCA	LTANK	in.	0.0
TSPCF	LTANK	in.	0.0
TSPCP	LTANK	in.	0.0
RHOINS	MATER	lb/in.^{3}	.0414
KLINEA	TNKGEO	-	1
NPRB	TNKGEO	-	1

Figure (cont.)

Positive Expulsion Bladders

Space between transverse collapsing bladder and tank wall (in.)

ox tank

fuel tank

Bond material density of bonded rolling diaphram (lb/in.^{3})

ox tank

fuel tank

Bladder thickness (for BRD only) (in.)

ox tank

fuel tank

VARIABLE	NAMELIST	UNITS	DEFAULT
BLSPOX	BLADER	in.	.01
BLSPFL	BLADER	in.	.01
DBNDOX	BLADER	lb/in.^{3}	.04
DBNDFL	BLADER	lb/in.^{3}	.04
TBLDOX	BLADER	in.	.025
TBLDFL	BLADER	in.	.025

Figure [illegible] (cont.)

Tandem Tanks (NCTNK = 0)

		VARIABLE	NAMELIST	UNITS	DEFAULT
Stage critical bending moment (NCTNK = 0) (in./lb_f)		CBM	LTANK	in./lb_f	0.0
Maximum carry moment (NCTNK = 0)(in./lb_f)		CMMAX	LTANK	in./lb_f	0.0
Space between aft and forward tank (KDOME = 0) (in.)		CLRAF	LTANK	in.	0.0
Space between forward tank and pressure tank (KPRESS = 1-3) (in.)		CLRFP	LTANK	in.	0.0
Density of pressure tank insulation (lb/m^3)		RHPTIN	LIQMAT	lb/m^3	0.04
Insulation thickness for pressure tank (in.)		TINSUL	LIQMAT	in.	0.0

Figure (cont.)

Non-Conventional Tanks (NCTNK = 1)

Non-conventional tank usable volume ratios

fuel tanks ______

ox tanks ______

pressure tanks ______

Minimum clearance between, non-conventional tanks (in.) ______

Minimum clearnace between nozzles in non-conventional model (in.) ______

Non-conventional models engine nesting mode (Circle One)

1) nest each engine independently

2) nest engines to highest common plane

3) nest engine exit plane to end of tankage + XMOUNT

Non-conventional tankage thickness option (Circle One)

0) variable wall thickness

1) constant wall thickness

VARIABLE	NAMELIST	UNITS	DEFAULT
RATNK1	NCTINP	-	1.0
CLRTNK	NCTINP	in.	2.0
ENGSPC	NCTINP	in.	2.0
KNEST	NCTINP	-	3
KTHCK1	NCTINP	-	1

Figur . (cont.)

Non-Conventional Tanks (NCTNK = 1)

Non-conventional tank feed line hydraulics

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
velocity heads lost in fuel lines including valves, bends, etc.	FLKFCT	LTANK	-	5.0
velocity heads lost in ox lines including valves, bends, etc.	OXKFCT	LTANK	-	5.0
absolute surface roughness of fuel lines (in.)	RUFFFL	LTANK	in.	.0001
absolute surface roughness of ox lines (in.)	RUFFOX	LTANK	in.	.0001

Cold Gas Pressurization

Pressurant Properties (default is Helium)

Description	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Isentropic ratio of specific heats (-)		GAMICG	COLDG	-	1.66
Polytropic ratio of specific heat at time equal infinity (-)		GAMPCG	COLDG	-	1.0
Time at which polytropic ratio falls to 1.1 (sec.)		TIMPCG	COLDG	-	240
Molecular wt. of pressurant (lb/lbmole)		WTMCG	COLDG	lb/lbmole	4.0

	VARIABLE	NAMELIST	UNITS	DEFAULT
Solid gas generator pressurization (default is TAL-8)				
Minimum port to throat area ratio	APATGG	SOLDGG	-	3.0
Ratio of equilibrium temperature in propellant tank to minimum operating temperature (TMIN)	BTEQGG	SOLDGG	-	1.5
Burn rate coefficient of solid grain (in./sec.)	CBRGG	SOLDGG	in./sec.	0.095
Design complexity multiplier solid g.g.	CDESGG	SOLDGG	-	1.25
Solid grain characteristic velocity (ft./sec.)	CSGG	SOLDGG	ft./sec.	3932
Minimum allowable solid grain diameter (in.)	DMINSG	SOLDGG	in.	3.0
Burn rate exponent of solid grain	EBRGG	SOLDGG	-	0.64
Molar fraction of water in combustion products	FH2OGG	SOLDGG	-	0.2662
Multiplying factor on ullage pressure to calculate minimum operating g.g. pressure	FPULGG	SOLDGG	-	1.1
Combustion products ratio of specific heats	GAMGG	SOLDGG	-	1.27
Temperature sensitivity of g.g. pressure (1/°R)	PIPKGG	SOLDGG	1/°R	0.0036
Solid grain density (lb/in.^{3})	RHOGG	SOLDGG	lb/in.^{3}	0.056

Figu. .. (cont.)

Solid gas generator pressurization

Burn rate temperature sensitivity of solid grain (1/°R)	
Gas generator combustion temperature (°R)	
Temperature decay time constant	
Reference temperature for burn rate coefficient (°R)	
Molecular weight of combustion products	

VARIABLE	NAMELIST	UNITS	DEFAULT
SIGGG	SOLDGG	1/°R	0.0013
TCMBGG	SOLDGG	°R	2130
TDCYGG	SOLDGG	sec.	100
TREFGG	SOLDGG	°F	80
WTMGG	SOLDGG	lb/lbmole	19.0

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Pump

Boost pump fraction of total propellant head rise

fuel

ox

Gas generator/pre-burner control valve pressure drop multiplier

Pressure ratio across gas generator/pre-burner

fuel side

ox side

Turbine outlet pressure (for gas generator bleed cycle) (KCYCLE = 1) (psia)

Number of turbo pump assemblies (Circle One)

1) 1 TPA per stage

2) 1 or more TPA per engine

Autogenous Pressurant temperature (°R)

fuel 100 (KGASFL = 1)

ox (KGASOX = 1)

VARIABLE	NAMELIST	UNITS	DEFAULT
BPFRFL	PUMP	-	.0464
BPFROX	PUMP	-	.0464
CVMLTF	PUMP	-	0.65
PBPRF	PUMP	-	1.2
PBPRO	PUMP	-	1.2
PTURBO	PUMP	psia	20.
KPUMP	PUMP	-	2
TULLFL	PUMP	°R	800
TULLOX	PUMP	°R	800

Figure 2.3. (cont.)

Pump

Description	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Suction specific speeds of propellant pumps					
main fuel pump	20000	SSSFL	PUMP	-	20000
main ox pump	20000	SSSOX	PUMP	-	20000
fuel boost pump	20000	SSSBPF	PUMP	-	30000
ox boost pump	20000	SSSBPO	PUMP	-	30000
Initial value of turbine pressure ratio (KCYCLE > = 2)	1.43	TURBPR	PUMP	-	2.0
Turbine pitch line velocity divided by isentropic spouting velocity		UOVERC	PUMP	-	0.4
Area ratio of bleed nozzle (KCYCLE = 1)		EPSGGB	PUMP	-	2.0
Gas generator or pre-burner contraction ratio		GGCR	PUMP	-	12.
Gas generator or pre-burner injector material density (lb/m^3)		ROINGG	PUMP	lb/in.^{3}	0.3
Gas generator or pre-burner injector yield strength (psi)		SYINGG	PUMP	psi	30000
Hot gas duct material density (lb/in.^{3})	0.298	ROSTAK	PUMP	lb/in.^{3}	0.3
Hot gas duct material yield strength (psi)		SYDUCT	PUMP	psi	30000

Figure (cont.)

Pump

TPA Start System design (Circle One)

0) tank head
1) cold gas spin
2) start tanks
3) solid cartridge

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
TPA Start System design (Circle One)	ISTART	PUMP	-	0
TPA Start System				
start valve complexity multiplier	CV	PUMP	-	1.0
accumulator valve complexity multiplier (ISTART = 2)	CVACUM	PUMP	-	1.0
solid grain burn rate (ISTART = 3) (in./sec.)	BURNRA	PUMP	in./sec.	0.14
molecular weight of pressurization gas (ISTART = 2)	GASMW	PUMP	lb/lbmole	28.
number of engine restarts	NR	PUMP	-	1
start bottle material density (ISTART = 2) (lb/in.^{3})	RHOBOT	PUMP	lb/in.^{3}	0.16
start cylinder material density (ISTART = 2) (lb/in.^{3})	RHOCYL	PUMP	lb/in.^{3}	3.3
start sphere material density (ISTART = 1) (lb/in.^{3})	RHOSPH	PUMP	lb/in.^{3}	0.1
start cartridge material density (ISTART = 3) (lb/in.^{3})	ROCART	PUMP	lb/in.^{3}	0.3
start cartridge grain density (ISTART = 3) (lb/in.^{3})	ROGRAN	PUMP	lb/in.^{3}	0.07
start bottle yield strength (ISTART = 2) (psi)	SYBOT	PUMP	psi	75000
start cartridge yield strength (ISTART = 3) (psi)	SYCART	PUMP	psi	100000
start cylinder yield strength (ISTART = 2) (psi)	SYCYL	PUMP	psi	30000
start system sphere yield strength (ISTART = 1) (psi)	SYSPH	PUMP	psi	47000
start bottle gas temperature (ISTART = 2) (°R)	TBOGAS	PUMP	°R	530
start system sphere temperature (ISTART = 1) (°R)	TSPH	PUMP	°R	210

Figure ... (cont.)

<u>Pump</u>

TPA Material properties

Property	Value	VARIABLE	NAMELIST	UNITS	DEFAULT
fuel turbine blade material density (JCNFIG = 3 or 4) (lb/in.^{3})	0.3	RHOTFL	PUMP	lb/in.^{3}	0.3
ox turbine blade material density (JCNFIG = 3 or 4) (lb/in.^{3})	0.3	RHOTOX	PUMP	lb/in.^{3}	0.3
turbine blade material density (JCNFIG = 1 or 2) (lb/in.^{3})	0.305	RHOTUR	PUMP	lb/in.^{3}	0.3
TPA effective material density (lb/in.^{3})	0.298	RHOTPA	PUMP	lb/in.^{3}	0.3
Turbine blade ultimate strength (psi)	134000	US	PUMP	psi	127000
Turbine blade yield strength (psi)	120000	YS	PUMP	psi	104000
Propellant line material density (enginebay) (lb/in.^{3})	0.298	ROLINE	PUMP	lb/in.^{3}	0.3
Propellant line material yield strength (psi)	30000	SYLIN	PUMP	psi	30000
Cold gas valve material density (ISTART = 1)		ROSPVL	PUMP	lb/in.^{3}	0.3
Accumulator valve material density (ISTART = 2)		ROACVL	PUMP	lb/in.^{3}	0.3

Tank Heat Transfer

Tank insulation conductivity flag (Circle One)

0) Input conductivity of MLI and SOFI

1) calculate conductivity of MLI and SOFI

Effective thermal conductivity of MLI (BTU/in.sec.°R) $\boxed{2.5917E-9}$

Effective thermal conductivity of SOFI (BTU/in.sec.°R) $\boxed{9.5647E-8}$

SOFI Thermal conductivity constants (KALCON = 1)

$$K = A + B * T$$

A (BTU/in.sec.°R) $\boxed{3.935E-8}$

B (BTU/in.sec.°R^2) $\boxed{5.676E-10}$

Insulation density (lb/in.^{3})

MLI

SOFI

Radiation shields per inch in MLI (#/in.)

Average stage acceleration (g's)

Iteration counter in heat transfer calcs

VARIABLE	NAMELIST	UNITS	DEFAULT
KALCON	TANKIIX	-	1
CNMLI	TANKIIX	BTU/in.sec°R	4.0E-9
CNSOFI	TANKIIX	BTU/in.sec°R	3.5E-7
SOFIA	TANKIIX	BTU/in.sec°R	3.935E-8
SOFIB	TANKIIX	BTU/in.sec°R^2	5.676E-10
DNMLI	TANKIIX	lb/in.^{3}	.002
DNSOFI	TANKIIX	lb/in.^{3}	.00127
RADPIN	TANKIIX	#/in.	40.
SACCEL	TANKIIX	g's	2.0
NITHX	TANKIIX	-	8

Figure . . (cont.)

Tank Heat Transfer

Fraction of propellant tank nominal ullage pressure at which venting occurs

fuel [def]

ox [def]

Stage action time (sec.) 259200

Stage hold time (sec.) 0

MLI environment flag (Circle One)

1) Ground hold with N_2 purge

2) Ground hold with He purge

3) Space hold with N_2 purge depleted to PRGMLI psia

4) Space hold with He purge depleted to PRGMLI psia

MLI purge gas pressure at space hold conditions (psia) def

VARIABLE	NAMELIST	UNITS	DEFAULT
FVENTF	TANKHX	-	1.1
FVENTO	TANKHX	-	1.1
FLTTIM	TANKHX	sec.	100
HLDTIM	TANKHX	sec.	100
MLIENV	TANKHX	-	1
PRGMLI	TANKHX	psia	2.0E-7

Figur. (cont.)

Tank Heat Transfer

	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
External tank boundary temperature (KHXOPT = 1) (°R)	df	TEXBOU	TANKHX	°R	560
Space hold heat transfer (KHXOPT = 2)					
Earth infrared heat flux (BTU/sec.in.^{2})	df	EARIR	TANKHX	BTU/sec.in.^{2}	1.35E-4
Earth reflectance (albedo)		EARREF	TANKHX	-	0.39
Average orbital altitude (miles)	250	HXALT	TANKHX	miles	125
Angle between earth-sun vector and vehicle orbital plane (deg)	df	ORBANG	TANKHX	deg	0.0
Stage absorbativity		SABSOR	TANKHX	-	0.2
Solar heat flux (BTU/sec.in.^{2})		SOLCON	TANKHX	BTU/sec.in.^{2}	8.20E-4
Ground Hold Ice formation (KHXOPT = 3)					
Relative humidity	df	RELHUM	TANKHX	-	50.
Ambient temperature (°R)		TAMICE	TANKHX	°R	560.
Wind velocity (MPH)		WNDMPH	TANKHX	mph	10.

Figure (cont.)

Positive Expulsion Bladders

		VARIABLE	NAMELIST	UNITS	DEFAULT
Space between transverse collapsing bladder and tank wall (in.)					
ox tank		BLSPOX	BLADER	in.	.01
fuel tank		BLSPFL	BLADER	in.	.01
Bond material density of bonded rolling diaphram					
ox tank	(lb/in.^{3})	DBNDOX	BLADER	lb/in.^{3}	.04
fuel tank		DBNDFL	BLADER	lb/in.^{3}	.04
Bladder thickness (for BRD only) (in.)					
ox tank		TBLDOX	BLADER	in.	.025
fuel tank		TBLDFL	BLADER	in.	.025

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
500.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
3	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
0	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
0.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.0	CPLINH	Hot bleed line loss fraction
0.0	CPLINC	Cold bleed line loss fraction
0.0	CPLINT	Turbine inlet line loss fraction
0.0	CPVLVT	Turbine throttling valve loss frac.
1	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
200.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
25.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.46	GAMGPB	GG ratio of specific heats
3.55	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
2	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
2	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
2	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.25	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.8	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
1	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
1.3	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.43	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
2.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

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                 OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

  PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
  ASSUMPTIONS:
                 TEMP       ENTHALPY
           LOX  90.18 K  -3093. CAL/MOL
           LH2  20.27 K  -2154. CAL/MOL

       ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
         C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL
TURBINE PRESSURE RATIO=   1.304726138748292
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.304726138748292
TURBINE PRESSURE RATIO=   1.316081365426303
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.316081365426303
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.316081365426303

       KEY INPUTS

   THRUST LEVEL =                        75000. (lbf)
   CYCLE TYPE =                      EXPANDER CYCLE
   REACTOR TYPE =                    ENABLER II
   FUEL SCALING FACTOR =                  0.67
   FUEL TYPE =                       COMPOSITE FUEL
   NOZZLE EXIT AREA RATIO =               200.
   PROPELLANT USED =                      LH2
   CHAMBER PRESSURE =                     500. (psia)
   CHAMBER TEMPERATURE =                 4860. (deg R)
   NUMBER OF PROPELLANT FEED LEGS =         2


                 TANKAGE SUMMARY FOR STAGE #1
                       EXPANDER CYCLE (FUEL SIDE)
                       AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                       FUEL TANK IS PRESSURIZED WITH COLD GAS
                       TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )
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.. DIMENSIONS (INCHES) ...		... WEIGHTS (POUNDS) ...	
STAGE DIAMETER	100.00	AFT TANK	78.43
TOTAL STAGE LENGTH	906.21	FORWARD TANK	1524.54
TOTAL TANK LENGTH	542.04	PRESSURE TANK	3236.41
NOZZLE LENGTH	228.51	TANK CONSTRUCTION WEIGHT	3387.56
CONVERGENT NOZZLE LENGTH	12.00		
MOUNT LENGTH	88.82	STRUCTURAL WALL	16.52
		AFT SKIRT	341.40
TANK HEAD ELLIPSE RATIO	1.38	FORWARD SKIRT	107.30

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PRESSURE TANK ELLIPSE RATIO           1.00          TANK MOUNT                           0.00
AFT TANK HEAD HEIGHT                 35.34
FORWARD TANK HEAD HEIGHT             36.04          PRESSURE TANK INSULATION             0.00
PRESSURE TANK HEAD HEIGHT            34.06          FUEL TANK INSULATION               256.20
PRESSURE TANK DIAMETER               68.12          OXIDIZER TANK INSULATION           407.04
AFT TANK CYLINDRICAL LENGTH           0.00
FORWARD TANK CYLINDRICAL LENGTH     464.68          REVERSE HEAD STIFFENER             184.69
PRESSURE TANK CYLINDRICAL LNGTH       0.00          FUEL ACQUISITION SYSTEM             11.31
                                                    OXIDIZER ACQUISITION SYSTEM          0.00
AFT LINE DIAMETER                     0.00          PRESSURANT CONTROL HARDWARE         56.81
FORWARD LINE DIAMETER                 4.16          TANK LINES                          26.07
AFT SKIRT LENGTH                    364.67
FORWARD SKIRT LENGTH                 36.04          BURNED FUEL                       8000.00
                                                    BURNED OXIDIZER                      0.00
STRUCTURAL WALL THICKNESS             0.090         FUEL RESIDUAL                        6.89
AFT TANK WALL THICKNESS               0.030         OXIDIZER RESIDUAL                    0.00
FORWARD TANK WALL THICKNESS           0.048         OXIDIZER AUTOGENOUS PRESSURANT       0.00
PRESSURE TANK WALL THICKNESS          0.837         STORED PRESSURANT                  230.76
AFT TANK DOME THICKNESS               0.030         HOLD TIME FUEL BOILOFF               0.00
FORWARD TANK DOME THICKNESS           0.033         HOLD TIME OX BOILOFF                 0.00
PRESSURE TANK DOME THICKNESS          0.837         FLIGHT FUEL BOILOFF                744.20
                                                    FLIGHT OXIDIZER BOILOFF              0.00
FUEL TANK MLI THICKNESS               0.02
FUEL TANK SOFI THICKNESS              0.50          MISC EXPENDED FUEL                   0.00
OXIDIZER TANK MLI THICKNESS           1.97          MISC EXPENDED OXIDIZER               0.00
OXIDIZER TANK SOFI THICKNESS          0.50
PRESSURE TANK INSULATION THICK        0.00          MISCELLANEOUS WEIGHT                 0.00
                                                    INTERSTAGE WEIGHT                    0.00

FUEL TNK HEAT FLUX(BTU/HR IN**2)      0.08     ... INPUT MINIMUM SAFETY FACTORS ...
OX TANK HEAT FLUX(BTU/HR IN**2)       0.00
FUEL BOILOFF RATE (LB/SEC)            0.003         STRUCTURAL WALL                      1.25
OX BOILOFF RATE (LB/SEC)              0.000         LINES                                2.00
                                                    OXIDIZER TANK                        1.25
                                                    FUEL TANK                            1.25
                                                    PRESSURE TANK                        1.50


            PROPELLANT SUMMARY FOR STAGE #1
                 PROPELLANT IS LH2


                        NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0025

.. OXIDIZER ...                                 ... FUEL ...

    NOMINAL TANK PRESSURE(PSIA)        0.0          NOMINAL TANK PRESSURE(PSIA)        35.0

    NOMINAL PROPELLANT TEMP(DEGR)      0.0          NOMINAL PROPELLANT TEMP(DEGR)      38.5
    NOMINAL DENSITY(LB/IN**3)          0.0000       NOMINAL DENSITY(LB/IN**3)           0.0025
    NOMINAL VAPOR PRESSURE(PSIA)       0.0          NOMINAL VAPOR PRESSURE(PSIA)       20.0

    MAX PROPELLANT TEMP(DEGR)          0.0          MAX PROPELLANT TEMP(DEGR)          40.0
    MAX TEMP DENSITY(LB/IN**3)         0.0000       MAX TEMP DENSITY(LB/IN**3)          0.0025
    MAX TEMP VAPOR PRESSURE(PSIA)      0.0          MAX TEMP VAPOR PRESSURE(PSIA)      25.0

    MIN PROPELLANT TEMP(DEGR)          0.0          MIN PROPELLANT TEMP(DEGR)          38.5
    MIN TEMP DENSITY(LB/IN**3)         0.0000       MIN TEMP DENSITY(LB/IN**3)          0.0025
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MIN TEMP VAPOR PRESSURE(PSIA)        0.0                    MIN TEMP VAPOR PRESSURE(PSIA)       20.0


          ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
               EXPANDER CYCLE
               CONVERGENT NOZZLE IS REGEN  COOLED   (MILLED SLOT CONSTRUCTION)
               NOZZLE IS REGEN COOLED   (TUBE CONSTRUCTION)
               PROPELLANT IS LH2

.. ENGINE DIMENSIONS (INCHES) ...                            ... PERFORMANCE ...
     THROAT DIAMETER                      10.47
     REACTOR SUPPORT DIAMETER             31.93                  DELIVERED ISP(VAC),SEC               908.58
     PRESSURE VESSEL O.D.                 44.93                  IDEAL ISP(ODE),SEC                   928.88
     NOZZLE EXIT DIAMETER                148.06
     NOZZLE EXTENSION ATTACH DIAM         25.64                  DELIVERED CSTAR,FT/SEC             16446.
     CONVERGENT NOZZLE LENGTH             12.00                  IDEAL CSTAR,FT/SEC                 16597.
     CONV. NOZZLE STRUCTURAL THICK.        0.885
     GAS SIDE WALL THICKNESS               0.073                 CHAMBER PRESSURE,PSIA                500.
     NOZZLE EXTENSION THICKNESS            0.010                 THRUST PER ENGINE(VAC),LBF         75000.
     SECOND NOZZLE EXTENSION THICKNESS     0.100                 TOTAL VAC THRUST,LBF               75000.
                                                                 BURN TIME,SEC                       3600.00
     NOZZLE EXIT AREA RATIO              200.00
     CONTRACTION RATIO                     9.11                  OVERALL EFFICIENCY                    0.978
     NOZ EXTENSION ATTCH AREA RATIO        6.00
     SECOND NOZ EXT ATTACH AREA RATI      25.00                  KINETIC EFFICIENCY                    0.999
     NOZZLE LENGTH/(MIN RAO LENGTH)        1.187                 BARRIER COOLING EFFICIENCY            0.990
     NOZZLE LENGTH                       228.51                  BOUNDARY LAYER EFFICIENCY             0.996
     FEED SYSTEM MOUNT LENGTH             88.82                  DIVERGENCE EFFICIENCY                 0.993
     REACTOR LENGTH                       34.84
                                                                 FOR   1 ENGINE
                                                                 OXIDIZER FLOWRATE,LB/SEC              0.00
                                                                 FUEL FLOWRATE,LB/SEC                 82.55
                                                                 TOTAL FLOWRATE,LB/SEC                82.55

                                                                 CORE TEMPERATURE,DEG R             4860.
                                                                 BARRIER TEMPERATURE,DEG R          1630.
                                                                 ENGINE MIXTURE RATIO                  0.00
                                                                 FUEL FILM COOLING FRACTION            0.02


THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS  1 THROUGH  6 ARE BOUNDS TO THE   5     8.375 INCH LONG NOZZLE SECTIONS
STATIONS  6 THROUGH 11 ARE BOUNDS TO THE   5     3.198 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE   0     0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS =    0.073
GAS WALL THERMAL CONDUCTIVITY  =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE=    1460. (DEG R)
```

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.104E+04	.773E+02	.652E+00	.346E+02	.261E-01	0.219E+03	.224E+03	.829E-04	.184E-03	.250E+02	.539E+03
2	.104E+04	.779E+02	.542E+00	.506E+02	.434E-01	0.256E+03	.264E+03	.122E-03	.244E-03	.176E+02	.618E+03
3	.104E+04	.789E+02	.431E+00	.809E+02	.804E-01	0.312E+03	.327E+03	.195E-03	.345E-03	.116E+02	.739E+03
4	.104E+04	.805E+02	.321E+00	.150E+03	.179E+00	0.403E+03	.436E+03	.349E-03	.553E-03	.676E+01	.948E+03
5	.104E+04	.843E+02	.210E+00	.368E+03	.573E+00	0.550E+03	.657E+03	.761E-03	.123E-02	.324E+01	.141E+04
6	.103E+04	.932E+02	.100E+00	.190E+04	.221E+01	0.520E+03	.933E+03	.317E-02	.518E-02	.100E+01	.163E+04
7	.103E+04	.950E+02	.156E+00	.804E+03	.134E+01	0.656E+03	.906E+03	.185E-02	.239E-02	.197E+01	.163E+04
8	.103E+04	.966E+02	.211E+00	.447E+03	.879E+00	0.723E+03	.887E+03	.118E-02	.140E-02	.327E+01	.163E+04
9	.103E+04	.980E+02	.267E+00	.286E+03	.621E+00	0.761E+03	.877E+03	.824E-03	.936E-03	.489E+01	.163E+04
10	.103E+04	.992E+02	.323E+00	.200E+03	.463E+00	0.785E+03	.872E+03	.610E-03	.674E-03	.684E+01	.163E+04
11	.103E+04	.100E+03	.379E+00	.148E+03	.359E+00	0.802E+03	.868E+03	.471E-03	.512E-03	.911E+01	.163E+04

DELTA T= 23.1
DELTA P= -6.9
NOZZLE DELTA T = 20.7
NOZZLE DELTA P = -6.8
ADAPTER DELTA T = 2.4
ADAPTER DELTA P = 0.0
TOTAL HEAT TRANSFER = 1810.4 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	TEMPERATURE(DEG R) OXIDIZER
... PRESSURANT ...				
MAX STORAGE	4365.0	—	550.0	—
VENT	38.5	0.0	43.2	0.0 (SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0	0.0	—	0.0
... PROPELLANT ...				
TANK PROPELLANT	35.0	0.0	38.5	0.0
BOOST PUMP OUTLET	116.1	—	40.3	—
MAIN PUMP INLET	106.0	0.0	40.3	0.0
MAIN VALVE INLET	1646.2	0.0	76.6	0.0
MAIN VALVE OUTLET	1575.7	0.0	76.6	0.0
TIE TUBE OUTLET	1325.7	—	650.7	—
REGEN OUTLET (REFL I	1032.3	—	99.7	—
REFLECTOR OUTLET	1007.3	—	324.9	—
REACTOR INLET	1007.3		539.8	
REACTOR CORE	500.0		4860.0	
TURBINE INLET	1325.7		650.7	

TURBINE OUTLET	1007.3	596.8

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

ACQUISITION DEVICE	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
ACQUISITION DEVICE	0.0	0.0		
BOOST PUMP	81.1	—	1.8	—
FEED LINE	10.1	0.0	0.0	0.0
MAIN PUMP	1540.2	0.0	36.3	0.0
MAIN VALVE	70.5	0.0	0.0	0.0
TIE TUBES	250.0	—	574.1	—
REGEN JACKET	6.9	—	23.1	—
REFLECTOR	25.0	—	225.3	—
TURBINE	318.4		53.9	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	82.546		0.000
MAIN PUMP - EACH	41.273		0.000
MAIN VALVE	82.546		0.000
TOTAL TIE TUBES	60.665		—
REGEN JACKET INFLOW	21.881		—
NOZZLE BARRIER COOLING		1.660	
REGEN/REFL OUTLET TO CORE	20.222		—
TURBINE - EACH		30.332	
TURBINE TO CORE	60.665		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.06	
CORE	80.887		—

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	80.89	LB/SEC
REACTOR POWER	1608.19	MW
CORE FLOW AREA	134.66	IN2
CORE MASS FLOW RATE	0.60	LB/IN2
FUEL ELEMENT POWER	0.80	MW/Element
FUEL ELEMENT OPERATING LIFE	1.19	HR
NUMBER OF FUEL ELEMENTS	1932.23	
NUMBER OF SUPPORT ELEMENTS	668.08	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	500.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	539.85	DEG R
CORE INLET PRESSURE	1007.30	PSIA
CORE INLET ENTHALPY	1811.04	BTU/LB
HEAT PICKUP PER TIE TUBE	0.21	MW/TUBE
HEAT PICKUP IN TIE TUBES	131543.91	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1809.19	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	

HEAT PICKUP IN REFLECTOR	18599.68	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2637.50	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	472.61	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4948.99	DEG R
PEAK FUEL TEMPERATURE	5085.42	DEG R

REACTOR DIMENSIONS

CORE LENGTH	34.84	IN
CORE DIAMETER	28.65	IN
FUEL ELEMENT CHANNEL DIAMETER	0.07	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	27.01	IN
LATERAL SUPPORT DIAMETER	31.93	IN
STRUCTURE OD	34.13	IN
REFLECTOR OD	43.70	IN
PRESSURE VESSEL ID	44.02	IN
PRESSURE VESSEL OD	44.93	IN
THICKNESS OF BATH SHIELD	14.56	IN
THICKNESS OF LEAD SHIELD	1.80	IN
PRESSURE VESSEL LENGTH	87.01	IN
FUEL VOLUME	10147.37	IN3

REACTOR MASSES

FUEL MASS	1400.34	LB
SUPPORT MASS	739.59	LB
CORE PERIPHERY MASS	214.08	LB
LATERAL SUPPORT MASS	199.43	LB
STRUCTURE MASS	437.65	LB
REFLECTOR MASS	1367.60	LB
HOT END HARDWARE MASS	90.63	LB
AFT REFLECTOR MASS	59.29	LB
CORE INLET PLENUM MASS	126.39	LB
SUPPORT PLATE MASS	440.21	LB
LATERAL SUPPORT FORWARD MASS	38.95	LB
REFLECTOR HARDWARE FORWARD MASS	105.04	LB
SUPPORT PLATE PLENUM MASS	29.59	LB
INSTRUMENTATION RING MASS	28.70	LB
FORWARD REFLECTOR HARDWARE MASS	20.81	LB
SUBTOTAL CORE A	5298.31	LB
FLOW BAFFLE MASS	0.00	LB
FLOW BAFFLE 1 MASS	0.00	LB
TOTAL CORE SUBSYSTEM MASS	5298.31	LB
PRESSURE VESSEL A MASS	348.91	LB
PRESSURE VESSEL B MASS	172.76	LB
PRESSURE VESSEL DOME MASS	71.29	LB
NOZZLE/REACTOR ADAPTER MASS	68.16	LB
TOTAL PRESSURE VESSEL MASS	661.12	LB
BATH CENTRAL SHIELD MASS	931.35	LB
BATH PERIPHERAL SHIELD MASS	778.59	LB
BATH PERIPHERAL SHIELD 2 MASS	282.03	LB
LEAD CENTRAL SHIELD MASS	398.02	LB
LEAD PERIPHERAL SHIELD MASS	0.18	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.08	LB
PERIPHERAL SHIELD PLATE MASS	36.54	LB
TOTAL SHIELD MASS	2426.80	LB
REACTOR MASS w/o SHIELD	5959.42	LB
REACTOR MASS w/ SHIELD	8386.22	LB

SAFETY RODS-FOR LAUNCH ONLY	311.34	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	6270.77	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	8697.56	LB

* * * TPA SUMMARY FOR STAGE #1 * * *
EXPANDER CYCLE
2 PROPELLANT FEED LEGS
CENTRIFUGAL PUMPS
TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	29037.
SPECIFIC SPEED	936.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	2.
NET POS SUCTION PRESSURE(PSIA)	86.00
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1646.20
VOLUMETRIC FLOWRATE(GPM)	4333.12
MASS FLOWRATE(LBM/SEC)	41.27
PUMP HORSEPOWER(HP)	5483.94
PUMP EFFICIENCY	0.709
PUMP DIAMETER(IN)	9.91
PUMP WT.(LB) - EACH PUMP	122.23

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	22692.
SPECIFIC SPEED	4050.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	15.00
OUTLET PRESSURE(PSIA)	116.08
PUMP HORSEPOWER(HP)	252.43
PUMP EFFICIENCY	0.786
PUMP DIAMETER(IN)	5.20
PUMP WT(LB) - EACH PUMP	31.42

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.691
PRESSURE RATIO	1.316
MASS FLOWRATE(LB/SEC)	30.33
DIAMETER(IN)	6.58
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52392.
ROOT STRESS SPEED LIMIT(RPM)	33998.
SPECIFIC SPEED	38.
TURBINE SPEED(RPM)	29037.
TURBINE WT(LB) - EACH TURBINE	43.67
TURBINE ANNULUS AREA(IN2)	32.879
U OVER C	0.38

INLET MACH NUMBER	0.45

... TPA ...

TPA START SYSTEM WT.	0.00
GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	0.00
GEARBOX WT.-TOTAL	0.00
BOOST PUMP WT. - EACH	31.42
MAIN TURBOPUMP WT. - EACH	165.90
TOTAL TURBOPUMP WT.	394.65
TOTAL TPA WT.	426.89

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.54
PRESSURE TANK	3236.41
TANK CONSTRUCTION WEIGHT	3387.56
TANK LINES	26.07
AFT SKIRT	341.40
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.20
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	56.81
ENGINE WEIGHTS:	
1 REACTOR	5959.42
1 REACTOR INTERNAL SHIELD	2426.80
1 NOZZLE	741.24
1 THRUST MOUNT(S)	1677.90
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	173.29
2 MAIN VALVE(S)	410.74
1 SUPPORT HARDWARE	616.19
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	0.00
2 GAS GENERATOR/PREBURNER	0.00
2 TPA ASSY(S)	394.65
1 GEARBOX(S)	0.00
2 TPA START SYSTEM(S)	0.00
1 GAS GENERATOR/PREBURNER(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	86.98
TOTAL ENGINE WEIGHT	12822.23

FLIGHT FUEL BOILOFF	744.20
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	311.34
TOTAL INERT WEIGHT	23327.36
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	6.89
OXIDIZER RESIDUAL	0.00
OXIDIZER AUTOGENOUS PRESSURANT	0.00
STORED PRESSURANT	230.76
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	31565.01
GROSS BURNOUT WEIGHT	22499.47
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	148.06
NUMBER OF NOZZLES	1
STAGE LENGTH	906.21
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	906.21
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	500.0
NOZZLE AREA RATIO	200.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	908.6

ISP EFFICIENCY	0.978
TOTAL PROP. FLOWRATE, LB/SEC	82.55
CORE PROP. FLOWRATE, LB/SEC	80.89

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...					
MAX STORAGE	4365.0	———	550.0	———	
VENT	38.5	0.0	43.2	0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0	0.0	———	0.0	
... PROPELLANT ...					
TANK PROPELLANT	35.0	0.0	38.5	0.0	
BOOST PUMP OUTLET	112.4	———	40.2	———	
MAIN PUMP INLET	102.6	0.0	40.2	0.0	
MAIN VALVE INLET	1569.5	0.0	72.5	0.0	
MAIN VALVE OUTLET	1501.1	0.0	72.5	0.0	
TIE TUBE OUTLET	1251.1	———	647.8	———	
REGEN OUTLET (REFL I	1002.0	———	97.4	———	
REFLECTOR OUTLET	977.0	———	322.8	———	
REACTOR INLET	977.0		544.8		
REACTOR CORE	400.0		4860.0		
TURBINE INLET	1251.1		647.8		
TURBINE OUTLET	977.0		599.2		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID) FUEL	PRESSURE CHANGES (PSID) OXIDIZER	TEMPERATURE CHANGES (DEG R) FUEL	TEMPERATURE CHANGES (DEG R) OXIDIZER
ACQUISITION DEVICE	0.0	0.0	1.7	———
BOOST PUMP	77.4	———	0.0	0.0
FEED LINE	9.8	0.0	32.3	0.0
MAIN PUMP	1466.9	0.0	0.0	0.0
MAIN VALVE	68.4	0.0	575.3	———
TIE TUBES	250.0	———	24.9	———
REGEN JACKET	4.5	———	225.4	———
REFLECTOR	25.0	———		
TURBINE	274.1		48.6	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL	OXIDIZER
TANK OUTFLOW	66.003	0.000

MAIN PUMP	66.003		0.000
MAIN VALVE	66.003		0.000
TOTAL TIE TUBES	48.508		——
REGEN JACKET INFLOW	17.496		——
NOZZLE BARRIER COOLING		1.326	
REGEN/REFL OUTLET TO CORE	16.169		——
TURBINE		48.508	
TURBINE TO CORE	48.508		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.06	
CORE	64.677		——

* * * TPA SUMMARY FOR STAGE #1 * * *
SUMMARY FOR TPA AT THRUST LEVEL FRACTION 0.80
EXPANDER CYCLE
SINGLE SHAFT TPA
CENTRIFUGAL PUMPS

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	28935.
SPECIFIC SPEED	1223.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	2.
NET POS SUCTION PRESSURE(PSIA)	82.61
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1569.54
VOLUMETRIC FLOWRATE(GPM)	6929.46
MASS FLOWRATE(LBM/SEC)	66.00
PUMP HORSEPOWER(HP)	7792.33
PUMP EFFICIENCY	0.760
PUMP DIAMETER(IN)	9.91
PUMP WT.(LB)	122.23

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	28935.
SPECIFIC SPEED	6773.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	15.00
OUTLET PRESSURE(PSIA)	112.39
PUMP HORSEPOWER(HP)	383.22
PUMP EFFICIENCY	0.789
PUMP DIAMETER(IN)	5.20
PUMP WT(LB)	31.42

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.700
PRESSURE RATIO	1.281
MASS FLOWRATE(LB/SEC)	48.51
DIAMETER(IN)	6.58

NUMBER OF TURBINE STAGES	2.			
BLADE ROOT STRESS LIMIT(PSI)	52388.			
ROOT STRESS SPEED LIMIT(RPM)	33997.			
SPECIFIC SPEED	88.			
TURBINE SPEED(RPM)	28935.			
TURBINE WT(LB)	43.67			
TURBINE ANNULUS AREA(IN2)	32.879			

ENGINE SUMMARY

EXPANDER CYCLE				
ENABLER II				
CENTRIFUGAL PUMPS				
THRUST LEVEL =	75000.0	lbf	333600.0	N
CHAMBER PRESSURE =	500.0	psia	3447.5	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	200.0		200.0	
NUMBER OF FEED LEGS =	2		2	
TOTAL PROPELLANT FLOWRATE =	82.5	lbm/s	37.4	kg/s
REACTOR				
COMPOSITE FUEL				
FUEL SCALING FACTOR	0.67		0.67	
REACTOR WEIGHT	5959.4	lbm	2702.7	kg
SHIELD WEIGHT	2426.8	lbm	1100.6	kg
PRESSURE VESSEL DIA.	44.9	in	114.1	cm
PRESSURE VESSEL LENGTH	87.0	in	221.0	cm
CORE PROPELLANT MASS FLOW	80.9	lbm/sec	36.7	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	175.0	lbm	79.4	kg
NOZZLE EXTENSION WEIGHT	117.9	lbm	53.5	kg
SECOND NOZZLE EXTENSION WEIGHT	448.3	lbm	203.3	kg
TOTAL NOZZLE WEIGHT	741.2	lbm	336.2	kg
AREA RATIO	200.0		200.0	
THROAT DIAMETER	10.5	in	26.6	cm
EXIT DIAMETER	148.1	in	376.1	cm
NOZZLE LENGTH	228.5	in	580.4	cm
DELIVERED VACUUM ISP	908.6	sec	8904.1	N-sec/kg
DELIVERED THRUST	75000.0	lbf	333600.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	331.8	lbm	150.5	kg
PROPELLANT BOOST PUMP WT	62.8	lbm	28.5	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	32.2	lbm	14.6	kg
BLEED LINE/VALVE WEIGHT	0.0	lbm	0.0	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1677.9	lbm	761.0	kg
SUPPORT HARDWARE	616.2	lbm	279.5	kg
ENGINE LINES	173.3	lbm	78.6	kg
MAIN VALVE	410.7	lbm	186.3	kg
GIMBAL + POWER SUPPLY	302.8	lbm	137.3	kg
MARGIN (2.0%)	87.0	lbm	39.4	kg
TOTAL NONNUCLEAR WEIGHT	4436.0	lbm	2011.8	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	12822.2	lbm	5815.1	kg

TOTAL ENGINE WEIGHT WITHOUT SHIELD	10395.4	lbm	4714.5	kg
THRUST/WEIGHT RATIO WITH SHIELD	5.8	lbf/lbm	57.4	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	7.2	lbf/lbm	70.8	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	311.3	lbm	141.2	kg
TOTAL ENGINE LAUNCH WEIGHT	13133.6	lbm	5956.3	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	10706.8	lbm	4855.7	kg
PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	60000.0	lbf	266880.0	N
PUMP-OUT CHAMBER PRESSURE	400.0	psia	2758.0	kPa
PUMP-OUT ISP	909.0	sec	8908.7	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	404.3	in	1027.0	cm
OVERALL ENGINE DIAMETER =	148.1	in	376.1	cm

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 9.110 RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM = 148.1 STAGE DIAM = 100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET
TPA CALCULATIONS TERMINATED BY ACHIEVING DESIRED ACCURACY

END NOMINAL STAGE DESIGN

Table 4-4. Sample Case No. 3

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
500.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
7	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
0	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
1400.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.07	CPLINH	Hot bleed line loss fraction
0.07	CPLINC	Cold bleed line loss fraction
0.07	CPLINT	Turbine inlet line loss fraction
0.08	CPVLVT	Turbine throttling valve loss frac.
1	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
200.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
25.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.46	GAMGPB	GG ratio of specific heats
3.51	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
2	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
2	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
2	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.25	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.8	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
0	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
1.3	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space betwden pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0038	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.3	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
20.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

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            OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

   PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
   ASSUMPTIONS:
                 TEMP      ENTHALPY
           LOX   90.18 K  -3093. CAL/MOL
           LH2   20.27 K  -2154. CAL/MOL

      ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
       C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL

      KEY INPUTS

  THRUST LEVEL =                        75000. (lbf)
  CYCLE TYPE =                       BLEED CYCLE
  REACTOR TYPE =                     ENABLER II
  FUEL SCALING FACTOR =                  0.67
  FUEL TYPE =                        COMPOSITE FUEL
  NOZZLE EXIT AREA RATIO =               200.
  PROPELLANT USED =                      LH2
  CHAMBER PRESSURE =                     500. (psia)
  CHAMBER TEMPERATURE =                 4860. (deg R)
  NUMBER OF PROPELLANT FEED LEGS =         2


            TANKAGE SUMMARY FOR STAGE #1
                  BLEED CYCLE
                                         (USER DEFINED GG)
                  AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                  FUEL TANK IS PRESSURIZED WITH COLD GAS
                  TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )  (PRESSURANT - USER DEF )

.. DIMENSIONS (INCHES) ...                          ... WEIGHTS (POUNDS) ...

     STAGE DIAMETER                    100.00          AFT TANK                       78.43
     TOTAL STAGE LENGTH                912.83          FORWARD TANK                 1524.54
     TOTAL TANK LENGTH                 542.04          PRESSURE TANK                3821.77
     NOZZLE LENGTH                     228.52          TANK CONSTRUCTION WEIGHT     3797.32
     CONVERGENT NOZZLE LENGTH           12.00
     MOUNT LENGTH                       95.43          STRUCTURAL WALL                16.52
                                                       AFT SKIRT                     347.51
     TANK HEAD ELLIPSE RATIO             1.38          FORWARD SKIRT                 107.30
     PRESSURE TANK ELLIPSE RATIO         1.00          TANK MOUNT                      0.00
     AFT TANK HEAD HEIGHT               35.34
     FORWARD TANK HEAD HEIGHT           36.04          PRESSURE TANK INSULATION        0.00
     PRESSURE TANK HEAD HEIGHT          36.00          FUEL TANK INSULATION          256.20
     PRESSURE TANK DIAMETER             72.00          OXIDIZER TANK INSULATION      407.04
     AFT TANK CYLINDRICAL LENGTH         0.00
     FORWARD TANK CYLINDRICAL LENGTH   464.68          REVERSE HEAD STIFFENER        184.69
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PRESSURE TANK CYLINDRICAL LNGTH      0.00          FUEL ACQUISITION SYSTEM           11.31
                                                   OXIDIZER ACQUISITION SYSTEM        0.00
AFT LINE DIAMETER                    0.00          PRESSURANT CONTROL HARDWARE       60.05
FORWARD LINE DIAMETER                4.16          TANK LINES                        26.07
AFT SKIRT LENGTH                   371.29
FORWARD SKIRT LENGTH                36.04          BURNED FUEL                     8000.00
                                                   BURNED OXIDIZER                    0.00
STRUCTURAL WALL THICKNESS            0.090         FUEL RESIDUAL                     10.32
AFT TANK WALL THICKNESS              0.030         OXIDIZER RESIDUAL                  0.00
FORWARD TANK WALL THICKNESS          0.048         STORED PRESSURANT                272.49
PRESSURE TANK WALL THICKNESS         0.884         HOLD TIME FUEL BOILOFF             0.00
AFT TANK DOME THICKNESS              0.030         HOLD TIME OX BOILOFF               0.00
FORWARD TANK DOME THICKNESS          0.033         FLIGHT FUEL BOILOFF              744.20
PRESSURE TANK DOME THICKNESS         0.884         FLIGHT OXIDIZER BOILOFF            0.00

FUEL TANK MLI THICKNESS              0.02          MISC EXPENDED FUEL                 0.00
FUEL TANK SOFI THICKNESS             0.50          MISC EXPENDED OXIDIZER             0.00
OXIDIZER TANK MLI THICKNESS          1.97
OXIDIZER TANK SOFI THICKNESS         0.50          MISCELLANEOUS WEIGHT               0.00
PRESSURE TANK INSULATION THICK       0.00          INTERSTAGE WEIGHT                  0.00

                                               ... INPUT MINIMUM SAFETY FACTORS ...
FUEL TNK HEAT FLUX(BTU/HR IN**2)     0.08
OX TANK HEAT FLUX(BTU/HR IN**2)      0.00          STRUCTURAL WALL                    1.25
FUEL BOILOFF RATE (LB/SEC)           0.003         LINES                              2.00
OX BOILOFF RATE (LB/SEC)             0.000         OXIDIZER TANK                      1.25
                                                   FUEL TANK                          1.25
                                                   PRESSURE TANK                      1.50


          PROPELLANT SUMMARY FOR STAGE #1
                PROPELLANT IS LH2


                      NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0025

.. OXIDIZER ...                                ... FUEL ...

   NOMINAL TANK PRESSURE(PSIA)          0.0        NOMINAL TANK PRESSURE(PSIA)         35.0

   NOMINAL PROPELLANT TEMP(DEGR)        0.0        NOMINAL PROPELLANT TEMP(DEGR)       38.5
   NOMINAL DENSITY(LB/IN**3)            0.0000     NOMINAL DENSITY(LB/IN**3)            0.0025
   NOMINAL VAPOR PRESSURE(PSIA)         0.0        NOMINAL VAPOR PRESSURE(PSIA)        20.0

   MAX PROPELLANT TEMP(DEGR)            0.0        MAX PROPELLANT TEMP(DEGR)           40.0
   MAX TEMP DENSITY(LB/IN**3)           0.0000     MAX TEMP DENSITY(LB/IN**3)           0.0025
   MAX TEMP VAPOR PRESSURE(PSIA)        0.0        MAX TEMP VAPOR PRESSURE(PSIA)       25.0

   MIN PROPELLANT TEMP(DEGR)            0.0        MIN PROPELLANT TEMP(DEGR)           38.5
   MIN TEMP DENSITY(LB/IN**3)           0.0000     MIN TEMP DENSITY(LB/IN**3)           0.0025
   MIN TEMP VAPOR PRESSURE(PSIA)        0.0        MIN TEMP VAPOR PRESSURE(PSIA)       20.0


          ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
                BLEED CYCLE
                                (USER DEFINED GG)
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CONVERGENT NOZZLE IS REGEN COOLED (MILLED SLOT CONSTRUCTION)
NOZZLE IS REGEN COOLED (TUBE CONSTRUCTION)
PROPELLANT IS LH2

.. ENGINE DIMENSIONS (INCHES) ...

THROAT DIAMETER	10.47
REACTOR SUPPORT DIAMETER	31.97
PRESSURE VESSEL O.D.	44.97
NOZZLE EXIT DIAMETER	148.06
NOZZLE EXTENSION ATTACH DIAM	25.64
CONVERGENT NOZZLE LENGTH	12.00
CONV. NOZZLE STRUCTURAL THICK.	0.884
GAS SIDE WALL THICKNESS	0.073
NOZZLE EXTENSION THICKNESS	0.010
SECOND NOZZLE EXTENSION THICKNESS	0.100
NOZZLE EXIT AREA RATIO	200.00
CONTRACTION RATIO	9.11
NOZ EXTENSION ATTCH AREA RATIO	6.00
SECOND NOZ EXT ATTACH AREA RATI	25.00
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187
NOZZLE LENGTH	228.52
FEED SYSTEM MOUNT LENGTH	95.43
REACTOR LENGTH	34.84

... PERFORMANCE ...

DELIVERED ISP(VAC),SEC	878.34
IDEAL ISP(ODE),SEC	928.88
DELIVERED CSTAR,FT/SEC	16446.
IDEAL CSTAR,FT/SEC	16597.
CHAMBER PRESSURE,PSIA	500.
THRUST PER ENGINE(VAC),LBF	75000.
TOTAL VAC THRUST,LBF	75000.
BURN TIME,SEC	3600.00
OVERALL EFFICIENCY	0.946
KINETIC EFFICIENCY	0.999
BARRIER COOLING EFFICIENCY	0.990
BOUNDARY LAYER EFFICIENCY	0.996
DIVERGENCE EFFICIENCY	0.993
GG BLEED EFFICIENCY	0.967
FOR 1 ENGINE	
OXIDIZER FLOWRATE,LB/SEC	0.00
FUEL FLOWRATE,LB/SEC	82.55
TOTAL FLOWRATE,LB/SEC	82.55
CORE TEMPERATURE,DEG R	4860.
BARRIER TEMPERATURE,DEG R	1630.
ENGINE MIXTURE RATIO	0.00
FUEL FILM COOLING FRACTION	0.02

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 8.376 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 3.197 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE 0 0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.073
GAS WALL THERMAL CONDUCTIVITY =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.104E+04	.749E+02	.652E+00	.327E+02	.259E-01	0.222E+03	.227E+03	.829E-04	.176E-03	.250E+02	.539E+03
2	.104E+04	.755E+02	.542E+00	.478E+02	.429E-01	0.260E+03	.268E+03	.122E-03	.233E-03	.176E+02	.618E+03
3	.104E+04	.765E+02	.431E+00	.764E+02	.793E-01	0.318E+03	.332E+03	.195E-03	.329E-03	.116E+02	.739E+03
4	.104E+04	.782E+02	.321E+00	.141E+03	.176E+00	0.411E+03	.444E+03	.349E-03	.527E-03	.676E+01	.948E+03
5	.104E+04	.821E+02	.210E+00	.348E+03	.564E+00	0.563E+03	.668E+03	.761E-03	.117E-02	.324E+01	.141E+04

6	.103E+04	.912E+02	.100E+00	.179E+04	.219E+01	0.532E+03	.940E+03	.317E-02	.497E-02	.100E+01	.163E+04
7	.103E+04	.930E+02	.156E+00	.760E+03	.132E+01	0.669E+03	.916E+03	.185E-02	.230E-02	.197E+01	.163E+04
8	.103E+04	.945E+02	.211E+00	.423E+03	.867E+00	0.736E+03	.897E+03	.118E-02	.135E-02	.327E+01	.163E+04
9	.103E+04	.959E+02	.267E+00	.270E+03	.611E+00	0.775E+03	.889E+03	.825E-03	.901E-03	.489E+01	.163E+04
10	.103E+04	.972E+02	.323E+00	.189E+03	.455E+00	0.799E+03	.884E+03	.610E-03	.649E-03	.683E+01	.163E+04
11	.103E+04	.983E+02	.379E+00	.140E+03	.353E+00	0.815E+03	.881E+03	.471E-03	.492E-03	.911E+01	.163E+04

DELTA T= 23.5
DELTA P= -6.3
NOZZLE DELTA T = 21.1
NOZZLE DELTA P = -6.3
ADAPTER DELTA T = 2.4
ADAPTER DELTA P = 0.0
TOTAL HEAT TRANSFER = 1786.4 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
BLEED CYCLE
(USER DEFINED GG)

	PRESSURE(PSIA)				TEMPERATURE(DEG R)			
	FUEL		OXIDIZER		FUEL		OXIDIZER	
				... PRESSURANT ...				
MAX STORAGE	4365.0		4365.0		550.0		550.0	
VENT	38.5		0.0		43.2		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0		0.0		—		—	
				... PROPELLANT ...				
TANK PROPELLANT	35.0		0.0		38.5		0.0	
BOOST PUMP OUTLET	102.0		—		40.0		—	
MAIN PUMP INLET	91.9		0.0		40.0		0.0	
MAIN VALVE INLET	1327.8		0.0		73.5		0.0	
MAIN VALVE OUTLET	1257.3		—		73.5		—	
COLD BLEED VALVE IN	1327.8		—		73.5		—	
COLD BLEED VALVE OUT	557.9		—		73.5		—	
TIE TUBE OUTLET	1007.3		—		671.8		—	
REGEN OUTLET (REFL I	1032.3		—		97.0		—	
REFLECTOR OUTLET	1007.3		—		331.3		—	
REACTOR INLET		1007.3				539.7		
REACTOR CORE		500.0				4860.0		
CHAMBER BLEED	500.0		—		4860.0		—	
MIXER OUTLET	465.0		—		1400.0		—	
TURB THROT VALVE IN		432.5				1400.0		
TURBINE INLET		397.9				1400.0		

TURBINE OUTLET	20.0	545.7

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

ACQUISITION DEVICE	PRESSURE CHANGES	(PSID)	TEMPERATURE CHANGES	(DEG R)
	0.0	0.0		
BOOST PUMP	67.0	—		
FEED LINE	10.1	0.0	1.5	—
MAIN PUMP	1235.9	0.0	0.0	0.0
MAIN VALVE	70.5	0.0	33.6	0.0
HOT BLEED LINE	35.0	—	0.0	0.0
COLD BLEED LINE	92.9	—	0.0	—
COLD BLEED VALVE	769.8	—	0.0	—
TURBINE INLET LINE	32.5	—	0.0	—
TURB THROTTLING VALV	34.6	—	0.0	—
TIE TUBES	250.0	—	0.0	—
REGEN JACKET	6.3	—	598.3	—
REFLECTOR	25.0	—	23.5	—
TURBINE			234.3	—
	377.9		854.3	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
BLEED CYCLE

(USER DEFINED GG)

	FUEL		OXIDIZER
TANK OUTFLOW	85.389		0.000
MAIN PUMP - EACH	42.694		0.000
COLD BLEED FLOW-EACH LEG	1.586		—
MAIN VALVE	82.217		0.000
TOTAL TIE TUBES	60.416		—
REGEN JACKET INFLOW	21.801		—
NOZZLE BARRIER COOLING		1.662	
REGEN/REFL OUTLET TO CORE	20.139		—
MIXER OUTLET-EACH	1.913		0.000
TURBINE - EACH		1.913	
BLEED NOZZLE - EACH		1.913	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.08	
CORE	80.555		—
CHAMBER (HOT) BLEED FLOW	0.656		—
NOZZLE OUTFLOW	79.899		—

BLEED CYCLE FLOW RATIOS

OVERALL BLEED FLOW FRACTION	0.045
OVERALL HOT BLEED FRACTION	0.008
OVERALL COLD BLEED FRACTION	0.037
HOT SIDE FRACTION OF TOTAL BLEED	0.171
COLD SIDE FRACTION OF TOTAL BLEED	0.829

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	80.56	LB/SEC
REACTOR POWER	1613.31	MW
CORE FLOW AREA	135.09	IN2
CORE MASS FLOW RATE	0.60	LB/IN2
FUEL ELEMENT POWER	0.80	MW/Element
FUEL ELEMENT OPERATING LIFE	1.19	HR
NUMBER OF FUEL ELEMENTS	1938.38	
NUMBER OF SUPPORT ELEMENTS	670.13	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	500.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	539.71	DEG R
CORE INLET PRESSURE	1007.27	PSIA
CORE INLET ENTHALPY	1810.54	BTU/LB
HEAT PICKUP PER TIE TUBE	0.21	MW/TUBE
HEAT PICKUP IN TIE TUBES	131947.36	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1786.68	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	
HEAT PICKUP IN REFLECTOR	18658.85	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2645.89	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	474.12	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4948.99	DEG R
PEAK FUEL TEMPERATURE	5085.42	DEG R

REACTOR DIMENSIONS

CORE LENGTH	34.84	IN
CORE DIAMETER	28.70	IN
FUEL ELEMENT CHANNEL DIAMETER	0.07	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	27.06	IN
LATERAL SUPPORT DIAMETER	31.97	IN
STRUCTURE OD	34.17	IN
REFLECTOR OD	43.74	IN
PRESSURE VESSEL ID	44.06	IN
PRESSURE VESSEL OD	44.97	IN
THICKNESS OF BATH SHIELD	14.56	IN
THICKNESS OF LEAD SHIELD	1.80	IN
PRESSURE VESSEL LENGTH	87.01	IN
FUEL VOLUME	10179.66	IN3

REACTOR MASSES

FUEL MASS	1404.79	LB
SUPPORT MASS	741.85	LB
CORE PERIPHERY MASS	214.41	LB
LATERAL SUPPORT MASS	199.71	LB
STRUCTURE MASS	438.22	LB
REFLECTOR MASS	1369.10	LB
HOT END HARDWARE MASS	90.92	LB
AFT REFLECTOR MASS	59.36	LB
CORE INLET PLENUM MASS	126.79	LB
SUPPORT PLATE MASS	441.30	LB
LATERAL SUPPORT FORWARD MASS	39.01	LB
REFLECTOR HARDWARE FORWARD MASS	105.15	LB
SUPPORT PLATE PLENUM MASS	29.67	LB
INSTRUMENTATION RING MASS	28.74	LB

FORWARD REFLECTOR HARDWARE MASS	20.83	LB
SUBTOTAL CORE A	5309.86	LB
FLOW BAFFLE MASS	0.00	LB
FLOW BAFFLE 1 MASS	0.00	LB
TOTAL CORE SUBSYSTEM MASS	5309.86	LB
PRESSURE VESSEL A MASS	349.58	LB
PRESSURE VESSEL B MASS	173.09	LB
PRESSURE VESSEL DOME MASS	71.49	LB
NOZZLE/REACTOR ADAPTER MASS	68.35	LB
TOTAL PRESSURE VESSEL MASS	662.51	LB
BATH CENTRAL SHIELD MASS	934.12	LB
BATH PERIPHERAL SHIELD MASS	779.52	LB
BATH PERIPHERAL SHIELD 2 MASS	282.32	LB
LEAD CENTRAL SHIELD MASS	399.21	LB
LEAD PERIPHERAL SHIELD MASS	0.18	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.08	LB
PERIPHERAL SHIELD PLATE MASS	36.58	LB
TOTAL SHIELD MASS	2432.02	LB
REACTOR MASS w/o SHIELD	5972.37	LB
REACTOR MASS w/ SHIELD	8404.40	LB
SAFETY RODS-FOR LAUNCH ONLY	312.32	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	6284.70	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	8716.72	LB

* * * TPA SUMMARY FOR STAGE #1 * * *

BLEED CYCLE (USER DEFINED GG)

2 PROPELLANT FEED LEGS

CENTRIFUGAL PUMPS

TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	27995.
SPECIFIC SPEED	633.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	71.88
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1327.78
VOLUMETRIC FLOWRATE(GPM)	4333.07
MASS FLOWRATE(LBM/SEC)	42.69
PUMP HORSEPOWER(HP)	4891.71
PUMP EFFICIENCY	0.638
PUMP DIAMETER(IN)	12.31
PUMP WT.(LB) - EACH PUMP	147.51

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	22444.
SPECIFIC SPEED	4724.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	15.00
OUTLET PRESSURE(PSIA)	101.96
PUMP HORSEPOWER(HP)	201.07

PUMP EFFICIENCY	0.792
PUMP DIAMETER(IN)	5.11
PUMP WT(LB) - EACH PUMP	30.20

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.690
PRESSURE RATIO	19.893
MASS FLOWRATE(LB/SEC)	1.91
DIAMETER(IN)	26.93
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	53286.
ROOT STRESS SPEED LIMIT(RPM)	34753.
SPECIFIC SPEED	10.
TURBINE SPEED(RPM)	27995.
TURBINE WT(LB) - EACH TURBINE	762.59
TURBINE ANNULUS AREA(IN2)	32.004
U OVER C	0.38
INLET MACH NUMBER	1.22

... TPA ...

TPA START SYSTEM WT.	0.00
GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	39.77
GEARBOX WT.-TOTAL	0.00
CHAMBER BLEED LINE WT.	73.22
COLD BLEED LINE WT.-EACH	1.29
TURBINE INLET LINE WT.-EACH	40.41
COLD BLEED VALVE WT.-EACH	1.50
TURBINE THROTTLING VALVE WT.-EA	69.31
MIXER WT.-EACH	10.96
TOTAL BLEED CYCLE LINE/VALVE WT	320.16
BOOST PUMP WT. - EACH	30.20
MAIN TURBOPUMP WT. - EACH	910.10
TOTAL TURBOPUMP WT.	1880.60
TOTAL TPA WT.	2272.77

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.54
PRESSURE TANK	3821.77
TANK CONSTRUCTION WEIGHT	3797.32
TANK LINES	26.07
AFT SKIRT	347.51
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.20
OXIDIZER TANK INSULATION	407.04

FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	60.05
ENGINE WEIGHTS:	
1 REACTOR	5972.37
1 REACTOR INTERNAL SHIELD	2432.02
1 NOZZLE	741.60
1 THRUST MOUNT(S)	1679.98
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	151.82
2 MAIN VALVE(S)	433.95
1 SUPPORT HARDWARE	616.34
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	39.77
2 GAS GENERATOR/PREBURNER	0.00
2 TPA ASSY(S)	2200.76
1 GEARBOX(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	123.98
TOTAL ENGINE WEIGHT	14727.60
FLIGHT FUEL BOILOFF	744.20
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
USER DEF. TPA DRIVE FLUID	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	312.32
TOTAL INERT WEIGHT	25905.63
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	10.32
OXIDIZER RESIDUAL	0.00
STORED PRESSURANT	272.49
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	34188.44
GROSS BURNOUT WEIGHT	25131.92
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

STAGE #1

..DIMENSIONS,IN..

STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	148.06
NUMBER OF NOZZLES	1
STAGE LENGTH	912.83
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	912.83

..PERFORMANCE..

PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	500.0
NOZZLE AREA RATIO	200.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	878.3
ISP EFFICIENCY	0.946
TOTAL PROP. FLOWRATE, LB/SEC	85.39
CORE PROP. FLOWRATE, LB/SEC	80.56

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
BLEED CYCLE

	PRESSURE(PSIA)		TEMPERATURE(DEG R)		
	FUEL	OXIDIZER	FUEL	OXIDIZER	
... PRESSURANT ...					
MAX STORAGE	4365.0	4365.0	550.0	550.0	
VENT	38.5	0.0	43.2	0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0	0.0	—	—	
... PROPELLANT ...					
TANK PROPELLANT	35.0	0.0	38.5	0.0	
BOOST PUMP OUTLET	100.2	—	40.0	—	
MAIN PUMP INLET	90.5	0.0	40.0	0.0	
MAIN VALVE INLET	1295.4	0.0	69.9	0.0	
MAIN VALVE OUTLET	1227.0	—	69.9	—	
COLD BLEED VALVE IN	1295.4	—	69.9	—	
COLD BLEED VALVE OUT	462.7	—	69.9	—	
TIE TUBE OUTLET	977.0	—	672.6	—	
REGEN OUTLET (REFL I	1002.0	—	95.2	—	
REFLECTOR OUTLET	977.0	—	329.2	—	
REACTOR INLET	977.0		544.6		

REACTOR CORE		400.0			4860.0	
CHAMBER BLEED	400.0		—	4860.0		—
MIXER OUTLET	372.0		—	1400.0		—
TURB THROT VALVE IN		346.0			1400.0	
TURBINE INLET		318.3			1400.0	
TURBINE OUTLET		20.0			585.4	

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

ACQUISITION DEVICE	PRESSURE CHANGES (PSID)			TEMPERATURE CHANGES (DEG R)		
ACQUISITION DEVICE	0.0		0.0			
BOOST PUMP	65.2		—	1.5		—
FEED LINE	9.8		0.0	0.0		0.0
MAIN PUMP	1204.9		0.0	29.9		0.0
MAIN VALVE	68.4		0.0	0.0		0.0
HOT BLEED LINE	28.0		—	0.0		—
COLD BLEED LINE	90.7		—	0.0		—
COLD BLEED VALVE	832.7		—	0.0		—
TURBINE INLET LINE	26.0		—	0.0		—
TURB THROTTLING VALV	27.7		—	0.0		—
TIE TUBES	250.0		—	0.0		—
REGEN JACKET	4.2		—	602.8		—
REFLECTOR	25.0		—	25.3		—
TURBINE		298.3		234.0	814.6	—

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
BLEED CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	68.149		0.000
MAIN PUMP	68.149		0.000
COLD BLEED FLOW	2.434		—
MAIN VALVE	65.716		0.000
TOTAL TIE TUBES	48.290		—
REGEN JACKET INFLOW	17.425		—
NOZZLE BARRIER COOLING		1.328	
REGEN/REFL OUTLET TO CORE	16.097		—
MIXER OUTLET	2.911		0.000
TURBINE		2.911	
BLEED NOZZLE		2.911	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.07	
CORE	64.387		—
CHAMBER BLEED FLOW	0.478		—
NOZZLE OUTFLOW	63.910		—

BLEED CYCLE FLOW RATIOS

OVERALL BLEED FLOW FRACTION	0.043
OVERALL HOT BLEED FRACTION	0.007
OVERALL COLD BLEED FRACTION	0.036
HOT SIDE FRACTION OF TOTAL BLEED	0.164

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COLD SIDE FRACTION OF TOTAL BLEED        0.836


            * * *   TPA SUMMARY FOR STAGE #1    * * *
            SUMMARY FOR TPA AT THRUST LEVEL FRACTION  0.80
                  BLEED CYCLE
                  SINGLE SHAFT TPA
                  CENTRIFUGAL PUMPS


... PROPELLANT PUMP ...

      PUMP SPEED (RPM)                    28792.
      SPECIFIC SPEED                        843.
      SUCTION SPECIFIC SPEED              20000.
      NUMBER OF PUMP STAGES                   1.
      NET POS SUCTION PRESSURE(PSIA)        70.46
      ACCELERATION HEAD(PSIA)                0.00
      PUMP OUTLET PRESSURE(PSIA)          1295.40
      VOLUMETRIC FLOWRATE(GPM)            6998.69
      MASS FLOWRATE(LBM/SEC)                68.15
      PUMP HORSEPOWER(HP)                 7115.81
      PUMP EFFICIENCY                       0.691
      PUMP DIAMETER(IN)                     12.31
      PUMP WT.(LB)                         147.51


... FUEL BOOST PUMP ...

      PUMP SPEED(RPM)                     28792.
      SPECIFIC SPEED                       7850.
      SUCTION SPECIFIC SPEED              20000.
      NET POS SUCTION PRESSURE(PSIA)        15.00
      OUTLET PRESSURE(PSIA)                100.24
      PUMP HORSEPOWER(HP)                  332.94
      PUMP EFFICIENCY                       0.753
      PUMP DIAMETER(IN)                      5.11
      PUMP WT(LB)                           30.20


... TURBINE ...

      ADMISSION FRACTION                    1.000
      EFFICIENCY                            0.700
      PRESSURE RATIO                       15.914
      MASS FLOWRATE(LB/SEC)                  2.91
      DIAMETER(IN)                          26.93
      NUMBER OF TURBINE STAGES                2.
      BLADE ROOT STRESS LIMIT(PSI)        53286.
      ROOT STRESS SPEED LIMIT(RPM)        34753.
      SPECIFIC SPEED                         21.
      TURBINE SPEED(RPM)                  28792.
      TURBINE WT(LB)                       762.59
      TURBINE ANNULUS AREA(IN2)            32.004

      ENGINE SUMMARY
```

BLEED CYCLE
ENABLER II
CENTRIFUGAL PUMPS

THRUST LEVEL =	75000.0	lbf	333600.0	N
CHAMBER PRESSURE =	500.0	psia	3447.5	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	200.0		200.0	
NUMBER OF FEED LEGS =	2		2	
TOTAL PROPELLANT FLOWRATE =	85.4	lbm/s	38.7	kg/s
REACTOR				
COMPOSITE FUEL				
FUEL SCALING FACTOR	0.67		0.67	
REACTOR WEIGHT	5972.4	lbm	2708.6	kg
SHIELD WEIGHT	2432.0	lbm	1103.0	kg
PRESSURE VESSEL DIA.	45.0	in	114.2	cm
PRESSURE VESSEL LENGTH	87.0	in	221.0	cm
CORE PROPELLANT MASS FLOW	80.6	lbm/sec	36.5	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	174.9	lbm	79.3	kg
NOZZLE EXTENSION WEIGHT	118.3	lbm	53.7	kg
SECOND NOZZLE EXTENSION WEIGHT	448.3	lbm	203.3	kg
TOTAL NOZZLE WEIGHT	741.6	lbm	336.3	kg
AREA RATIO	200.0		200.0	
THROAT DIAMETER	10.5	in	26.6	cm
EXIT DIAMETER	148.1	in	376.1	cm
NOZZLE LENGTH	228.5	in	580.4	cm
DELIVERED VACUUM ISP	878.3	sec	8607.7	N-sec/kg
DELIVERED THRUST	75000.0	lbf	333600.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	1820.2	lbm	825.5	kg
PROPELLANT BOOST PUMP WT	60.4	lbm	27.4	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	32.2	lbm	14.6	kg
BLEED LINE/VALVE WEIGHT	320.2	lbm	145.2	kg
GAS GENERATOR	0.0	lbm	0.0	kg
HOT GAS MANIFOLD	39.8	lbm	18.0	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1680.0	lbm	761.9	kg
SUPPORT HARDWARE	616.3	lbm	279.5	kg
ENGINE LINES	151.8	lbm	68.9	kg
MAIN VALVE	433.9	lbm	196.8	kg
GIMBAL + POWER SUPPLY	302.8	lbm	137.3	kg
MARGIN (2.0%)	124.0	lbm	56.2	kg
TOTAL NONNUCLEAR WEIGHT	6323.2	lbm	2867.7	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	14727.6	lbm	6679.2	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	12295.6	lbm	5576.2	kg
THRUST/WEIGHT RATIO WITH SHIELD	5.1	lbf/lbm	49.9	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	6.1	lbf/lbm	59.8	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	312.3	lbm	141.6	kg
TOTAL ENGINE LAUNCH WEIGHT	15039.9	lbm	6820.8	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	12607.9	lbm	5717.9	kg

PUMP-OUT CONDITIONS

PUMP-OUT THRUST	60000.0	lbf	266880.0	N
PUMP-OUT CHAMBER PRESSURE	400.0	psia	2758.0	kPa
PUMP-OUT ISP	880.4	sec	8628.1	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K

OVERALL DIMENSIONS

OVERALL ENGINE LENGTH =	411.0	in	1043.8	cm
OVERALL ENGINE DIAMETER =	148.1	in	376.1	cm

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 9.106 RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM = 148.1 STAGE DIAM = 100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET

END NOMINAL STAGE DESIGN

Table 4-5. Sample Case No. 4

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
500.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
1	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
0	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
0.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.0	CPLINH	Hot bleed line loss fraction
0.0	CPLINC	Cold bleed line loss fraction
0.0	CPLINT	Turbine inlet line loss fraction
0.0	CPVLVT	Turbine throttling valve loss frac.
1	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
200.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
25.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.75	OFGGPB	GG mixture ratio
1.378	GAMGPB	GG ratio of specific heats
2.054	CPGGPB	GG specific heat
3.53	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
2	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
2	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
2	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.25	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.8	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
0	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TCWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
1.3	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEDH	etched platelet thickness
0.1	TGEDL	platelet land thickness
0.04	TGEDS	separator platelet thickness
0.14	TGEDW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.005	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.3	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
20.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

PROPELLANTS LIQUID OXYGEN - LIQUID HYDROGEN
ASSUMPTIONS:

	TEMP	ENTHALPY
LOX	90.18 K	-3093. CAL/MOL
LH2	20.27 K	-2154. CAL/MOL

ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL

KEY INPUTS

THRUST LEVEL =	75000. (lbf)
CYCLE TYPE =	GAS GENERATOR CYCLE
REACTOR TYPE =	ENABLER II
FUEL SCALING FACTOR =	0.67
FUEL TYPE =	COMPOSITE FUEL
NOZZLE EXIT AREA RATIO =	200.
PROPELLANTS USED =	LO2/LH2
CHAMBER PRESSURE =	500. (psia)
CHAMBER TEMPERATURE =	4860. (deg R)
NUMBER OF PROPELLANT FEED LEGS =	2

TANKAGE SUMMARY FOR STAGE #1
GAS GENERATOR CYCLE
(USER DEFINED GG)
AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
FUEL TANK IS PRESSURIZED WITH COLD GAS
OXIDIZER TANK IS PRESSURIZED WITH COLD GAS
TANK MATERIALS (OX - USER DEF) (FUEL - aluminum) (PRESSURANT - USER DEF)

.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	915.89
TOTAL TANK LENGTH	542.08
NOZZLE LENGTH	228.49
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	98.49
TANK HEAD ELLIPSE RATIO	1.38
PRESSURE TANK ELLIPSE RATIO	1.00
AFT TANK HEAD HEIGHT	35.34
FORWARD TANK HEAD HEIGHT	36.04
PRESSURE TANK HEAD HEIGHT	36.03
PRESSURE TANK DIAMETER	72.07
AFT TANK CYLINDRICAL LENGTH	0.00

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.64
PRESSURE TANK	3832.31
TANK CONSTRUCTION WEIGHT	3804.77
STRUCTURAL WALL	16.52
AFT SKIRT	350.30
FORWARD SKIRT	107.30
TANK MOUNT	0.00
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.22
OXIDIZER TANK INSULATION	407.04

FORWARD TANK CYLINDRICAL LENGTH	464.72	REVERSE HEAD STIFFENER	184.69
PRESSURE TANK CYLINDRICAL LNGTH	0.00	FUEL ACQUISITION SYSTEM	11.28
		OXIDIZER ACQUISITION SYSTEM	1.46
AFT LINE DIAMETER	0.42	PRESSURANT CONTROL HARDWARE	60.98
FORWARD LINE DIAMETER	4.16	TANK LINES	27.42
AFT SKIRT LENGTH	374.31		
FORWARD SKIRT LENGTH	36.04	BURNED FUEL	7733.73
		BURNED OXIDIZER	266.27
STRUCTURAL WALL THICKNESS	0.090	FUEL RESIDUAL	10.22
AFT TANK WALL THICKNESS	0.030	OXIDIZER RESIDUAL	1.93
FORWARD TANK WALL THICKNESS	0.048	STORED PRESSURANT	273.24
PRESSURE TANK WALL THICKNESS	0.885	HOLD TIME FUEL BOILOFF	0.00
AFT TANK DOME THICKNESS	0.030	HOLD TIME OX BOILOFF	0.00
FORWARD TANK DOME THICKNESS	0.033	FLIGHT FUEL BOILOFF	745.02
PRESSURE TANK DOME THICKNESS	0.885	FLIGHT OXIDIZER BOILOFF	45.94
FUEL TANK MLI THICKNESS	0.02	MISC EXPENDED FUEL	0.00
FUEL TANK SOFI THICKNESS	0.50	MISC EXPENDED OXIDIZER	0.00
OXIDIZER TANK MLI THICKNESS	1.97		
OXIDIZER TANK SOFI THICKNESS	0.50	MISCELLANEOUS WEIGHT	0.00
PRESSURE TANK INSULATION THICK	0.00	INTERSTAGE WEIGHT	0.00

... INPUT MINIMUM SAFETY FACTORS ...

FUEL TNK HEAT FLUX(BTU/HR IN**2)	0.06	STRUCTURAL WALL	1.25
OX TANK HEAT FLUX(BTU/HR IN**2)	0.00	LINES	2.00
FUEL BOILOFF RATE (LB/SEC)	0.003	OXIDIZER TANK	1.25
OX BOILOFF RATE (LB/SEC)	0.000	FUEL TANK	1.25
		PRESSURE TANK	1.50

PROPELLANT SUMMARY FOR STAGE #1

PROPELLANT COMBINATION IS LOX/LH2

NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)= 0.0025

.. OXIDIZER ...		... FUEL ...	
NOMINAL TANK PRESSURE(PSIA)	32.9	NOMINAL TANK PRESSURE(PSIA)	35.0
NOMINAL PROPELLANT TEMP(DEGR)	160.0	NOMINAL PROPELLANT TEMP(DEGR)	38.5
NOMINAL DENSITY(LB/IN**3)	0.0473	NOMINAL DENSITY(LB/IN**3)	0.0025
NOMINAL VAPOR PRESSURE(PSIA)	12.8	NOMINAL VAPOR PRESSURE(PSIA)	20.0
MAX PROPELLANT TEMP(DEGR)	160.0	MAX PROPELLANT TEMP(DEGR)	40.0
MAX TEMP DENSITY(LB/IN**3)	0.0473	MAX TEMP DENSITY(LB/IN**3)	0.0025
MAX TEMP VAPOR PRESSURE(PSIA)	12.8	MAX TEMP VAPOR PRESSURE(PSIA)	25.0
MIN PROPELLANT TEMP(DEGR)	160.0	MIN PROPELLANT TEMP(DEGR)	38.5
MIN TEMP DENSITY(LB/IN**3)	0.0473	MIN TEMP DENSITY(LB/IN**3)	0.0025
MIN TEMP VAPOR PRESSURE(PSIA)	12.8	MIN TEMP VAPOR PRESSURE(PSIA)	20.0

ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1

GAS GENERATOR CYCLE

(USER DEFINED GG)
CONVERGENT NOZZLE IS REGEN COOLED (MILLED SLOT CONSTRUCTION)
NOZZLE IS REGEN COOLED (TUBE CONSTRUCTION)
PROPELLANT COMBINATION IS LOX/LH2

.. ENGINE DIMENSIONS (INCHES) ...

THROAT DIAMETER	10.47
REACTOR SUPPORT DIAMETER	31.63
PRESSURE VESSEL O.D.	44.63
NOZZLE EXIT DIAMETER	148.04
NOZZLE EXTENSION ATTACH DIAM	25.64
CONVERGENT NOZZLE LENGTH	12.00
CONV. NOZZLE STRUCTURAL THICK.	0.885
GAS SIDE WALL THICKNESS	0.073
NOZZLE EXTENSION THICKNESS	0.010
SECOND NOZZLE EXTENSION THICKNESS	0.100
NOZZLE EXIT AREA RATIO	200.00
CONTRACTION RATIO	9.12
NOZ EXTENSION ATTCH AREA RATIO	6.00
SECOND NOZ EXT ATTACH AREA RATI	25.00
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187
NOZZLE LENGTH	228.49
FEED SYSTEM MOUNT LENGTH	98.49
REACTOR LENGTH	34.84

... PERFORMANCE ...

DELIVERED ISP(VAC),SEC	848.01
IDEAL ISP(ODE),SEC	928.88
DELIVERED CSTAR,FT/SEC	16444.
IDEAL CSTAR,FT/SEC	16597.
CHAMBER PRESSURE,PSIA	500.
THRUST PER ENGINE(VAC),LBF	75000.
TOTAL VAC THRUST,LBF	75000.
BURN TIME,SEC	3600.00
OVERALL EFFICIENCY	0.913
KINETIC EFFICIENCY	0.999
BARRIER COOLING EFFICIENCY	0.990
BOUNDARY LAYER EFFICIENCY	0.996
DIVERGENCE EFFICIENCY	0.993
GG BLEED EFFICIENCY	0.933
FOR 1 ENGINE	
OXIDIZER FLOWRATE,LB/SEC	3.19
FUEL FLOWRATE,LB/SEC	82.55
TOTAL FLOWRATE,LB/SEC	82.55
CORE TEMPERATURE,DEG R	4860.
BARRIER TEMPERATURE,DEG R	1630.
ENGINE MIXTURE RATIO	0.00
FUEL FILM COOLING FRACTION	0.02

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 8.374 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 3.199 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE 0 0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.073
GAS WALL THERMAL CONDUCTIVITY =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.104E+04	.755E+02	.652E+00	.331E+02	.259E-01	0.221E+03	.226E+03	.829E-04	.178E-03	.250E+02	.539E+03
2	.104E+04	.762E+02	.542E+00	.484E+02	.430E-01	0.259E+03	.267E+03	.122E-03	.236E-03	.176E+02	.618E+03
3	.104E+04	.772E+02	.431E+00	.774E+02	.795E-01	0.316E+03	.331E+03	.195E-03	.333E-03	.116E+02	.739E+03
4	.104E+04	.788E+02	.321E+00	.143E+03	.176E+00	0.409E+03	.442E+03	.349E-03	.534E-03	.676E+01	.948E+03

5	.104E+04	.827E+02	.210E+00	.353E+03	.566E+00	0.560E+03	.665E+03	.762E-03	.119E-02	.324E+01	.141E+04
6	.103E+04	.917E+02	.100E+00	.181E+04	.220E+01	0.529E+03	.938E+03	.317E-02	.502E-02	.100E+01	.163E+04
7	.103E+04	.935E+02	.156E+00	.770E+03	.133E+01	0.666E+03	.913E+03	.185E-02	.232E-02	.197E+01	.163E+04
8	.103E+04	.951E+02	.212E+00	.428E+03	.889E+00	0.733E+03	.895E+03	.118E-02	.136E-02	.327E+01	.163E+04
9	.103E+04	.965E+02	.267E+00	.274E+03	.613E+00	0.772E+03	.886E+03	.824E-03	.908E-03	.489E+01	.163E+04
10	.103E+04	.978E+02	.323E+00	.191E+03	.456E+00	0.796E+03	.881E+03	.609E-03	.654E-03	.684E+01	.163E+04
11	.103E+04	.989E+02	.379E+00	.142E+03	.354E+00	0.812E+03	.878E+03	.471E-03	.496E-03	.912E+01	.163E+04

DELTA T= 23.4
DELTA P= -6.5
NOZZLE DELTA T = 21.0
NOZZLE DELTA P = -6.4
ADAPTER DELTA T = 2.4
ADAPTER DELTA P = 0.0
TOTAL HEAT TRANSFER = 1792.1 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
GAS GENERATOR CYCLE
(USER DEFINED GG)

	PRESSURE(PSIA)			TEMPERATURE(DEG R)			
	FUEL		OXIDIZER	FUEL		OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		4365.0	550.0		550.0	
VENT	38.5		36.2	43.2		179.5	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0		32.9	—		—	
... PROPELLANT ...							
TANK PROPELLANT	35.0		32.9	38.5		160.0	
BOOST PUMP OUTLET	102.0		—	40.0		—	
MAIN PUMP INLET	91.9		32.9	40.0		160.0	
MAIN VALVE INLET	1327.9		304.9	74.4		170.0	
MAIN VALVE OUTLET	1257.4		—	74.4		—	
TIE TUBE OUTLET	1007.4		—	694.8		—	
REGEN OUTLET (REFL I	1032.4		—	97.7		—	
REFLECTOR OUTLET	1007.4		—	338.8		—	
REACTOR INLET		1007.4			540.3		
REACTOR CORE		500.0			4860.0		
GG/PREBURNER INLET	304.9		304.9				
TURBINE INLET		304.9			1424.6		
TURBINE OUTLET		20.0			674.8		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
ACQUISITION DEVICE	0.0	0.0		
BOOST PUMP	67.0	——		
FEED LINE	10.1	10.1	1.5	——
MAIN PUMP	1236.0	702.4	0.0	0.0
MAIN VALVE	70.5	0.0	34.4	10.0
TIE TUBES	250.0	——	0.0	0.0
REGEN JACKET	6.5	——	620.4	——
REFLECTOR	25.0	——	23.4	——
GG/PREBURNER	0.0	0.0	241.0	——
TURBINE	284.9		749.9	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
GAS GENERATOR BLEED CYCLE
(USER DEFINED GG)

	FUEL		OXIDIZER
TANK OUTFLOW	85.156		3.286
MAIN PUMP - EACH	42.578		1.643
MAIN VALVE	80.775		0.000
TOTAL TIE TUBES	59.350		——
REGEN JACKET INFLOW	21.425		——
NOZZLE BARRIER COOLING		1.642	
REGEN/REFL OUTLET TO CORE	19.783		——
GG/PREBURNER INLET-EACH	2.191		1.643
TURBINE - EACH		3.833	
BLEED NOZZLE - EACH		3.833	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.08	
CORE	79.134		——

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	79.13	LB/SEC
REACTOR POWER	1572.80	MW
CORE FLOW AREA	131.70	IN2
CORE MASS FLOW RATE	0.60	LB/IN2
FUEL ELEMENT POWER	0.80	MW/Element
FUEL ELEMENT OPERATING LIFE	1.19	HR
NUMBER OF FUEL ELEMENTS	1889.71	
NUMBER OF SUPPORT ELEMENTS	653.90	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	500.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	540.28	DEG R
CORE INLET PRESSURE	1007.38	PSIA
CORE INLET ENTHALPY	1812.60	BTU/LB
HEAT PICKUP PER TIE TUBE	0.21	MW/TUBE
HEAT PICKUP IN TIE TUBES	128753.09	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1790.85	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	

HEAT PICKUP IN REFLECTOR	18190.37	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2579.45	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	462.21	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4948.98	DEG R
PEAK FUEL TEMPERATURE	5085.42	DEG R

REACTOR DIMENSIONS

CORE LENGTH	34.84	IN
CORE DIAMETER	28.36	IN
FUEL ELEMENT CHANNEL DIAMETER	0.07	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	26.72	IN
LATERAL SUPPORT DIAMETER	31.63	IN
STRUCTURE OD	33.83	IN
REFLECTOR OD	43.40	IN
PRESSURE VESSEL ID	43.72	IN
PRESSURE VESSEL OD	44.63	IN
THICKNESS OF BATH SHIELD	14.56	IN
THICKNESS OF LEAD SHIELD	1.80	IN
PRESSURE VESSEL LENGTH	87.01	IN
FUEL VOLUME	9924.07	IN3

REACTOR MASSES

FUEL MASS	1369.52	LB
SUPPORT MASS	723.90	LB
CORE PERIPHERY MASS	211.80	LB
LATERAL SUPPORT MASS	197.48	LB
STRUCTURE MASS	433.73	LB
REFLECTOR MASS	1357.20	LB
HOT END HARDWARE MASS	88.66	LB
AFT REFLECTOR MASS	58.84	LB
CORE INLET PLENUM MASS	123.63	LB
SUPPORT PLATE MASS	432.60	LB
LATERAL SUPPORT FORWARD MASS	38.56	LB
REFLECTOR HARDWARE FORWARD MASS	104.24	LB
SUPPORT PLATE PLENUM MASS	28.98	LB
INSTRUMENTATION RING MASS	28.43	LB
FORWARD REFLECTOR HARDWARE MASS	20.65	LB
SUBTOTAL CORE A	5218.22	LB
FLOW BAFFLE MASS	0.00	LB
FLOW BAFFLE 1 MASS	0.00	LB
TOTAL CORE SUBSYSTEM MASS	5218.22	LB
PRESSURE VESSEL A MASS	344.26	LB
PRESSURE VESSEL B MASS	170.46	LB
PRESSURE VESSEL DOME MASS	69.86	LB
NOZZLE/REACTOR ADAPTER MASS	66.80	LB
TOTAL PRESSURE VESSEL MASS	651.38	LB
BATH CENTRAL SHIELD MASS	912.16	LB
BATH PERIPHERAL SHIELD MASS	772.07	LB
BATH PERIPHERAL SHIELD 2 MASS	280.03	LB
LEAD CENTRAL SHIELD MASS	389.81	LB
LEAD PERIPHERAL SHIELD MASS	0.18	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.08	LB
PERIPHERAL SHIELD PLATE MASS	36.24	LB
TOTAL SHIELD MASS	2390.57	LB
REACTOR MASS w/o SHIELD	5869.60	LB
REACTOR MASS w/ SHIELD	8260.17	LB

SAFETY RODS-FOR LAUNCH ONLY	304.55	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	6174.16	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	8564.73	LB

* * * TPA SUMMARY FOR STAGE #1 * * *
GAS GENERATOR CYCLE (USER DEFINED GG)

2 PROPELLANT FEED LEGS
CENTRIFUGAL PUMPS
TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	26009.
SPECIFIC SPEED	588.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	71.88
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1327.89
VOLUMETRIC FLOWRATE(GPM)	4333.53
MASS FLOWRATE(LBM/SEC)	42.58
PUMP HORSEPOWER(HP)	5015.29
PUMP EFFICIENCY	0.622
PUMP DIAMETER(IN)	12.73
PUMP WT.(LB) - EACH PUMP	158.04

... OXIDIZER PUMP ...

PUMP SPEED (RPM)	26009.
SPECIFIC SPEED	1074.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	10.00
ACCELERATION HEAD	0.00
PUMP OUTLET PRESSURE(PSIA)	304.94
VOLUMETRIC FLOWRATE(GPM)	17.90
MASS FLOWRATE(LBM/SEC)	1.64
PUMP HORSEPOWER(HP)	4.83
PUMP EFFICIENCY	0.587
PUMP DIAMETER(IN)	1.54
PUMP WT(LB)	1.88

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	22443.
SPECIFIC SPEED	4724.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	15.00
OUTLET PRESSURE(PSIA)	101.97
PUMP HORSEPOWER(HP)	201.11
PUMP EFFICIENCY	0.792
PUMP DIAMETER(IN)	5.11
PUMP WT(LB) - EACH PUMP	30.20

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.687
PRESSURE RATIO	15.247
MASS FLOWRATE(LB/SEC)	3.83
DIAMETER(IN)	20.50
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	53315.
ROOT STRESS SPEED LIMIT(RPM)	27768.
SPECIFIC SPEED	17.
TURBINE SPEED(RPM)	26009.
TURBINE WT(LB) - EACH TURBINE	453.22
TURBINE ANNULUS AREA(IN2)	50.157

U OVER C	0.37
INLET MACH NUMBER	1.18

... TPA ...

TPA START SYSTEM WT.	0.00
GAS GENERATOR/PREBURNER WT.-EAC	10.07
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	62.20
GEARBOX WT.-TOTAL	0.00
BOOST PUMP WT. - EACH	30.20
MAIN TURBOPUMP WT. - EACH	611.26
TOTAL TURBOPUMP WT.	1286.69
TOTAL TPA WT.	1401.27

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.64
PRESSURE TANK	3832.31
TANK CONSTRUCTION WEIGHT	3804.77
TANK LINES	27.42
AFT SKIRT	350.30
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.22
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.28
OXIDIZER ACQUISITION SYSTEM	1.46
PRESSURANT CONTROL HARDWARE	60.98
ENGINE WEIGHTS:	
1 REACTOR	5869.60
1 REACTOR INTERNAL SHIELD	2390.57
1 NOZZLE	742.20
1 THRUST MOUNT(S)	1663.63
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	153.41
2 MAIN VALVE(S)	442.30
1 SUPPORT HARDWARE	615.17
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	62.20
2 GAS GENERATOR/PREBURNER	20.14
2 TPA ASSY(S)	1286.69
1 GEARBOX(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	106.41
TOTAL ENGINE WEIGHT	13687.34
FLIGHT FUEL BOILOFF	745.02

FLIGHT OXIDIZER BOILOFF	45.94
EXPENDABLE WEIGHT	0.00
USER DEF. TPA DRIVE FLUID	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	304.55
TOTAL INERT WEIGHT	25230.41
INTERSTAGE WEIGHT	0.00
BURNED FUEL	7733.73
BURNED OXIDIZER	266.27
FUEL RESIDUAL	10.22
OXIDIZER RESIDUAL	1.93
STORED PRESSURANT	273.24
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	33515.81
GROSS BURNOUT WEIGHT	24420.30
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	148.04
NUMBER OF NOZZLES	1
STAGE LENGTH	915.89
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	915.89
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	500.0
NOZZLE AREA RATIO	200.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	848.0
ISP EFFICIENCY	0.913

TOTAL PROP. FLOWRATE, LB/SEC 88.44
CORE PROP. FLOWRATE, LB/SEC 79.13

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
GAS GENERATOR CYCLE

	PRESSURE(PSIA) FUEL	(combined)	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	(combined)	TEMPERATURE(DEG R) OXIDIZER
... PRESSURANT ...						
MAX STORAGE	4365.0		4365.0	550.0		550.0
VENT	38.5		35.9	43.2		179.3 (SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0		32.6	——		——
... PROPELLANT ...						
TANK PROPELLANT	35.0		32.6	38.5		160.0
BOOST PUMP OUTLET	100.2		——	40.0		——
MAIN PUMP INLET	90.5		32.6	40.0		160.0
MAIN VALVE INLET	1295.5		365.9	70.1		170.3
MAIN VALVE OUTLET	1227.1		——	70.1		——
TIE TUBE OUTLET	977.1		——	691.2		——
REGEN OUTLET (REFL I	1002.1		——	95.4		——
REFLECTOR OUTLET	977.1		——	334.8		——
REACTOR INLET		977.1			545.2	
REACTOR CORE		400.0			4860.0	
GG/PREBURNER INLET	453.4		365.9			
TURBINE INLET		384.9			1424.6	
TURBINE OUTLET		20.0			674.8	

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID) FUEL	(combined)	PRESSURE CHANGES (PSID) OXIDIZER	TEMPERATURE CHANGES (DEG R) FUEL	(combined)	TEMPERATURE CHANGES (DEG R) OXIDIZER
ACQUISITION DEVICE	0.0		0.0			
BOOST PUMP	65.2		——	1.5		——
FEED LINE	9.8		9.8	0.0		0.0
MAIN PUMP	1205.1		611.2	30.2		10.3
MAIN VALVE	68.4		0.0	0.0		0.0
TIE TUBES	250.0		——	621.1		——
REGEN JACKET	4.2		——	25.2		——
REFLECTOR	25.0		——	239.5		——
GG/PREBURNER	148.5		61.0			
TURBINE		284.9			749.9	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
GAS GENERATOR BLEED CYCLE

FUEL OXIDIZER

TANK OUTFLOW	67.876		2.337
MAIN PUMP	67.876		2.337
MAIN VALVE	64.760		0.000
TOTAL TIE TUBES	47.585		———
REGEN JACKET INFLOW	17.175		———
NOZZLE BARRIER COOLING		1.314	
REGEN/REFL OUTLET TO CORE	15.862		———
GG/PREBURNER INLET	3.116		2.337
TURBINE		5.453	
BLEED NOZZLE		5.453	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.07	
CORE	63.447		———

* * * TPA SUMMARY FOR STAGE #1 * * *

SUMMARY FOR TPA AT THRUST LEVEL FRACTION 0.80

GAS GENERATOR CYCLE

SINGLE SHAFT TPA

CENTRIFUGAL PUMPS

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	27768.
SPECIFIC SPEED	813.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	70.46
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1295.52
VOLUMETRIC FLOWRATE(GPM)	6999.33
MASS FLOWRATE(LBM/SEC)	67.88
PUMP HORSEPOWER(HP)	7181.91
PUMP EFFICIENCY	0.684
PUMP DIAMETER(IN)	12.73
PUMP WT.(LB)	158.04

... OXIDIZER PUMP ...

PUMP SPEED (RPM)	27768.
SPECIFIC SPEED	834.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	1.
NET POS SUCTION PRESSURE(PSIA)	10.00
ACCELERATION HEAD	0.00
PUMP OUTLET PRESSURE(PSIA)	365.93
VOLUMETRIC FLOWRATE(GPM)	12.85
MASS FLOWRATE(LBM/SEC)	2.34
PUMP HORSEPOWER(HP)	4.54
PUMP EFFICIENCY	0.551
PUMP DIAMETER(IN)	1.54
PUMP WT(LB)	1.88

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	28790.
SPECIFIC SPEED	7850.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	15.00
OUTLET PRESSURE(PSIA)	100.25
PUMP HORSEPOWER(HP)	332.99
PUMP EFFICIENCY	0.753
PUMP DIAMETER(IN)	5.11
PUMP WT(LB)	30.20

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.700
PRESSURE RATIO	15.247

MASS FLOWRATE(LB/SEC)	5.45			
DIAMETER(IN)	20.50			
NUMBER OF TURBINE STAGES	2.			
BLADE ROOT STRESS LIMIT(PSI)	53315.			
ROOT STRESS SPEED LIMIT(RPM)	27654.			
SPECIFIC SPEED	21.			
TURBINE SPEED(RPM)	27768.			
TURBINE WT(LB)	453.22			
TURBINE ANNULUS AREA(IN2)	50.157			

ENGINE SUMMARY

GAS GENERATOR CYCLE				
ENABLER II				
CENTRIFUGAL PUMPS				
THRUST LEVEL =	75000.0	lbf	333600.0	N
CHAMBER PRESSURE =	500.0	psia	3447.5	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	200.0		200.0	
NUMBER OF FEED LEGS =	2		2	
TOTAL PROPELLANT FLOWRATE =	88.4	lbm/s	40.1	kg/s
REACTOR				
COMPOSITE FUEL				
FUEL SCALING FACTOR	0.67		0.67	
REACTOR WEIGHT	5869.6	lbm	2662.0	kg
SHIELD WEIGHT	2390.6	lbm	1084.2	kg
PRESSURE VESSEL DIA.	44.6	in	113.4	cm
PRESSURE VESSEL LENGTH	87.0	in	221.0	cm
CORE PROPELLANT MASS FLOW	79.1	lbm/sec	35.9	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	175.7	lbm	79.7	kg
NOZZLE EXTENSION WEIGHT	118.3	lbm	53.7	kg
SECOND NOZZLE EXTENSION WEIGHT	448.2	lbm	203.3	kg
TOTAL NOZZLE WEIGHT	742.2	lbm	336.6	kg
AREA RATIO	200.0		200.0	
THROAT DIAMETER	10.5	in	26.6	cm
EXIT DIAMETER	148.0	in	376.0	cm
NOZZLE LENGTH	228.5	in	580.4	cm
DELIVERED VACUUM ISP	848.0	sec	8310.5	N-sec/kg
DELIVERED THRUST	75000.0	lbf	333600.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	1222.5	lbm	554.4	kg
PROPELLANT BOOST PUMP WT	60.4	lbm	27.4	kg
MAIN OX PUMP WEIGHT	3.8	lbm	1.7	kg
TPA IGNITION WEIGHT	32.2	lbm	14.6	kg
BLEED LINE/VALVE WEIGHT	0.0	lbm	0.0	kg
GAS GENERATOR	20.1	lbm	9.1	kg
HOT GAS MANIFOLD	62.2	lbm	28.2	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1663.6	lbm	754.5	kg
SUPPORT HARDWARE	615.2	lbm	279.0	kg
ENGINE LINES	153.4	lbm	69.6	kg
MAIN VALVE	442.3	lbm	200.6	kg
GIMBAL + POWER SUPPLY	302.8	lbm	137.3	kg
MARGIN (2.0%)	106.4	lbm	48.3	kg

TOTAL NONNUCLEAR WEIGHT	5427.2	lbm	2461.3	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	13687.3	lbm	6207.4	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	11296.8	lbm	5123.2	kg
THRUST/WEIGHT RATIO WITH SHIELD	5.5	lbf/lbm	53.7	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	6.6	lbf/lbm	65.1	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	304.6	lbm	138.1	kg
TOTAL ENGINE LAUNCH WEIGHT	13991.9	lbm	6345.5	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	11601.3	lbm	5261.4	kg
PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	60000.0	lbf	266880.0	N
PUMP-OUT CHAMBER PRESSURE	400.0	psia	2758.0	kPa
PUMP-OUT ISP	854.5	sec	8374.5	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	414.0	in	1051.5	cm
OVERALL ENGINE DIAMETER =	148.0	in	376.0	cm

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

CR = 9.121 RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM = 148.0 STAGE DIAM = 100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET

END NOMINAL STAGE DESIGN

Table 4-6. Sample Case No. 5

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
1000.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
3	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
1	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
0.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.0	CPLINH	Hot bleed line loss fraction
0.0	CPLINC	Cold bleed line loss fraction
0.0	CPLINT	Turbine inlet line loss fraction
0.0	CPVLVT	Turbine throttling valve loss frac.
1	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
500.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
150.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.46	GAMGPB	GG ratio of specific heats
3.55	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
5580.	TCHAMBER	Chamber temperature
2	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
2	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
3	FTYPE	Fuel type
2	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.25	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.8	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
1	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.0001	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
5.75	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.43	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
2.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

```
                OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

      PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
      ASSUMPTIONS:
                   TEMP      ENTHALPY
              LOX  90.18 K  -3093. CAL/MOL
              LH2  20.27 K  -2154. CAL/MOL

          ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
           C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL
TURBINE PRESSURE RATIO=   1.300919930231020
TURBINE PRESSURE RATIO=   1.332538096610163
TURBINE PRESSURE RATIO=   1.348841636359766
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.348841636359766
TURBINE PRESSURE RATIO=   1.364303929320771
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.364303929320771
SUCCESSFUL CYCLE POWER BALANCE
TURBINE PRESSURE RATIO=   1.364303929320771


          KEY INPUTS

  THRUST LEVEL =                        75000. (lbf)
  CYCLE TYPE =                       EXPANDER CYCLE
  REACTOR TYPE =                     ENABLER II
  FUEL SCALING FACTOR =                  0.67
  FUEL TYPE =                        CARBIDE FUEL
  NOZZLE EXIT AREA RATIO =               500.
  PROPELLANT USED =                      LH2
  CHAMBER PRESSURE =                    1000. (psia)
  CHAMBER TEMPERATURE =                 5580. (deg R)
  NUMBER OF PROPELLANT FEED LEGS =         2


               TANKAGE SUMMARY FOR STAGE #1
                    EXPANDER CYCLE (FUEL SIDE)
                    AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                    FUEL TANK IS PRESSURIZED WITH COLD GAS
                    TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )
```

.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	996.14
TOTAL TANK LENGTH	542.45
NOZZLE LENGTH	325.97
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	80.87

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1530.39
PRESSURE TANK	3069.52
TANK CONSTRUCTION WEIGHT	3274.84
STRUCTURAL WALL	16.52

```
TANK HEAD ELLIPSE RATIO                 1.38
PRESSURE TANK ELLIPSE RATIO             1.00
AFT TANK HEAD HEIGHT                   35.34
FORWARD TANK HEAD HEIGHT               36.04
PRESSURE TANK HEAD HEIGHT              33.46
PRESSURE TANK DIAMETER                 66.93
AFT TANK CYLINDRICAL LENGTH             0.00
FORWARD TANK CYLINDRICAL LENGTH       465.10
PRESSURE TANK CYLINDRICAL LNGTH         0.00

AFT LINE DIAMETER                       0.00
FORWARD LINE DIAMETER                  11.04
AFT SKIRT LENGTH                      454.18
FORWARD SKIRT LENGTH                   36.04

STRUCTURAL WALL THICKNESS               0.090
AFT TANK WALL THICKNESS                 0.030
FORWARD TANK WALL THICKNESS             0.049
PRESSURE TANK WALL THICKNESS            0.822
AFT TANK DOME THICKNESS                 0.030
FORWARD TANK DOME THICKNESS             0.033
PRESSURE TANK DOME THICKNESS            0.822

FUEL TANK MLI THICKNESS                 0.02
FUEL TANK SOFI THICKNESS                0.50
OXIDIZER TANK MLI THICKNESS             1.97
OXIDIZER TANK SOFI THICKNESS            0.50
PRESSURE TANK INSULATION THICK          0.00

FUEL TNK HEAT FLUX(BTU/HR IN**2)        0.08
OX TANK HEAT FLUX(BTU/HR IN**2)         0.00
FUEL BOILOFF RATE (LB/SEC)              0.003
OX BOILOFF RATE (LB/SEC)                0.000
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AFT SKIRT                             424.05
FORWARD SKIRT                         107.30
TANK MOUNT                              0.00

PRESSURE TANK INSULATION                0.00
FUEL TANK INSULATION                  256.38
OXIDIZER TANK INSULATION              407.04

REVERSE HEAD STIFFENER                184.93
FUEL ACQUISITION SYSTEM                11.31
OXIDIZER ACQUISITION SYSTEM             0.00
PRESSURANT CONTROL HARDWARE           238.93
TANK LINES                             40.21

BURNED FUEL                          8000.00
BURNED OXIDIZER                         0.00
FUEL RESIDUAL                           6.89
OXIDIZER RESIDUAL                       0.00
OXIDIZER AUTOGENOUS PRESSURANT          0.00
STORED PRESSURANT                     218.86
HOLD TIME FUEL BOILOFF                  0.00
HOLD TIME OX BOILOFF                    0.00
FLIGHT FUEL BOILOFF                   744.44
FLIGHT OXIDIZER BOILOFF                 0.00

MISC EXPENDED FUEL                      0.00
MISC EXPENDED OXIDIZER                  0.00

MISCELLANEOUS WEIGHT                    0.00
INTERSTAGE WEIGHT                       0.00

... INPUT MINIMUM SAFETY FACTORS ...

STRUCTURAL WALL                         1.25
LINES                                   2.00
OXIDIZER TANK                           1.25
FUEL TANK                               1.25
PRESSURE TANK                           1.50
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PROPELLANT SUMMARY FOR STAGE #1
PROPELLANT IS LH2

NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0025

.. OXIDIZER ...

NOMINAL TANK PRESSURE(PSIA)             0.0

NOMINAL PROPELLANT TEMP(DEGR)           0.0
NOMINAL DENSITY(LB/IN**3)               0.0000
NOMINAL VAPOR PRESSURE(PSIA)            0.0

MAX PROPELLANT TEMP(DEGR)               0.0
MAX TEMP DENSITY(LB/IN**3)              0.0000
MAX TEMP VAPOR PRESSURE(PSIA)           0.0

... FUEL ...

NOMINAL TANK PRESSURE(PSIA)            35.1

NOMINAL PROPELLANT TEMP(DEGR)          38.5
NOMINAL DENSITY(LB/IN**3)               0.0025
NOMINAL VAPOR PRESSURE(PSIA)           20.0

MAX PROPELLANT TEMP(DEGR)              40.0
MAX TEMP DENSITY(LB/IN**3)              0.0025
MAX TEMP VAPOR PRESSURE(PSIA)          25.0
```

MIN PROPELLANT TEMP(DEGR)	0.0	MIN PROPELLANT TEMP(DEGR)	38.5
MIN TEMP DENSITY(LB/IN**3)	0.0000	MIN TEMP DENSITY(LB/IN**3)	0.0025
MIN TEMP VAPOR PRESSURE(PSIA)	0.0	MIN TEMP VAPOR PRESSURE(PSIA)	20.0

ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
EXPANDER CYCLE
CONVERGENT NOZZLE IS REGEN COOLED (MILLED SLOT CONSTRUCTION)
NOZZLE IS REGEN COOLED (TUBE CONSTRUCTION)
PROPELLANT IS LH2

.. ENGINE DIMENSIONS (INCHES) ...

THROAT DIAMETER	7.36
REACTOR SUPPORT DIAMETER	32.77
PRESSURE VESSEL O.D.	46.02
NOZZLE EXIT DIAMETER	164.61
NOZZLE EXTENSION ATTACH DIAM	18.03
CONVERGENT NOZZLE LENGTH	12.00
CONV. NOZZLE STRUCTURAL THICK.	1.282
GAS SIDE WALL THICKNESS	0.248
NOZZLE EXTENSION THICKNESS	0.010
SECOND NOZZLE EXTENSION THICKNESS	0.100
NOZZLE EXIT AREA RATIO	500.00
CONTRACTION RATIO	19.58
NOZ EXTENSION ATTCH AREA RATIO	6.00
SECOND NOZ EXT ATTACH AREA RATI	150.00
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187
NOZZLE LENGTH	325.97
FEED SYSTEM MOUNT LENGTH	80.87
REACTOR LENGTH	34.84

... PERFORMANCE ...

DELIVERED ISP(VAC),SEC	1003.68
IDEAL ISP(ODE),SEC	1029.24
DELIVERED CSTAR,FT/SEC	17780.
IDEAL CSTAR,FT/SEC	18053.
CHAMBER PRESSURE,PSIA	1000.
THRUST PER ENGINE(VAC),LBF	75000.
TOTAL VAC THRUST,LBF	75000.
BURN TIME,SEC	3600.00
OVERALL EFFICIENCY	0.975
KINETIC EFFICIENCY	1.000
BARRIER COOLING EFFICIENCY	0.984
BOUNDARY LAYER EFFICIENCY	0.996
DIVERGENCE EFFICIENCY	0.996
FOR 1 ENGINE	
OXIDIZER FLOWRATE,LB/SEC	0.00
FUEL FLOWRATE,LB/SEC	74.72
TOTAL FLOWRATE,LB/SEC	74.72
CORE TEMPERATURE,DEG R	5580.
BARRIER TEMPERATURE,DEG R	1666.
ENGINE MIXTURE RATIO	0.00
FUEL FILM COOLING FRACTION	0.03

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 16.560 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 3.481 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE 0 0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.248
GAS WALL THERMAL CONDUCTIVITY =.00039000 (BTU/IN SEC DEGR)

GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.131E+04	.843E+02	.158E+01	.748E+01	.292E-02	0.131E+03	.133E+03	.188E-04	.621E-04	.150E+03	.289E+03
2	.131E+04	.846E+02	.128E+01	.114E+02	.543E-02	0.150E+03	.153E+03	.302E-04	.831E-04	.100E+03	.333E+03
3	.131E+04	.851E+02	.985E+00	.193E+02	.119E-01	0.173E+03	.180E+03	.545E-04	.136E-03	.600E+02	.399E+03
4	.131E+04	.862E+02	.690E+00	.399E+02	.322E-01	0.221E+03	.241E+03	.119E-03	.239E-03	.302E+02	.512E+03
5	.131E+04	.891E+02	.395E+00	.126E+03	.137E+00	0.340E+03	.427E+03	.382E-03	.548E-03	.106E+02	.786E+03
6	.129E+04	.106E+03	.100E+00	.245E+04	.165E+01	0.320E+03	.137E+04	.561E-02	.771E-02	.100E+01	.167E+04
7	.129E+04	.107E+03	.190E+00	.692E+03	.102E+01	0.584E+03	.123E+04	.237E-02	.215E-02	.284E+01	.167E+04
8	.129E+04	.108E+03	.280E+00	.324E+03	.665E+00	0.726E+03	.115E+04	.129E-02	.108E-02	.562E+01	.167E+04
9	.129E+04	.109E+03	.370E+00	.189E+03	.460E+00	0.810E+03	.110E+04	.815E-03	.657E-03	.933E+01	.167E+04
10	.129E+04	.111E+03	.459E+00	.124E+03	.336E+00	0.860E+03	.107E+04	.566E-03	.448E-03	.140E+02	.167E+04
11	.129E+04	.112E+03	.549E+00	.876E+02	.256E+00	0.893E+03	.105E+04	.418E-03	.327E-03	.196E+02	.167E+04

DELTA T= 27.4
DELTA P= -20.4
NOZZLE DELTA T = 23.9
NOZZLE DELTA P = -20.4
ADAPTER DELTA T = 3.4
ADAPTER DELTA P = 0.0
TOTAL HEAT TRANSFER = 1585.8 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...					
MAX STORAGE	4365.0	—	550.0	—	
VENT	38.7	0.0	43.2	0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.1	0.0	—	0.0	
... PROPELLANT ...					
TANK PROPELLANT	35.1	0.0	38.5	0.0	
PUMP INLET	35.0	0.0	40.5	0.0	
MAIN VALVE INLET	2063.6	0.0	84.3	0.0	
MAIN VALVE OUTLET	1975.0	0.0	84.3	0.0	
TIE TUBE OUTLET	1725.0	—	771.4	—	
REGEN OUTLET (REFL I	1289.4	—	111.6	—	
REFLECTOR OUTLET	1264.4	—	366.9	—	
REACTOR INLET	1264.4		637.0		
REACTOR CORE	1000.0		5580.0		

TURBINE INLET	1725.0	771.4
TURBINE OUTLET	1264.4	699.5

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
ACQUISITION DEVICE	0.0	0.0		
FEED LINE	0.1	0.0	0.0	0.0
PUMP	2028.5	0.0	45.8	0.0
MAIN VALVE	88.5	0.0	0.0	0.0
TIE TUBES	250.0	—	687.1	—
REGEN JACKET	20.4	—	27.4	—
REFLECTOR	25.0	—	255.3	—
TURBINE		460.6		71.9

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	74.725		0.000
MAIN PUMP - EACH	37.382		0.000
MAIN VALVE	74.725		0.000
TOTAL TIE TUBES	54.320		—
REGEN JACKET INFLOW	20.404		—
NOZZLE BARRIER COOLING		2.298	
REGEN/REFL OUTLET TO CORE	18.107		—
TURBINE - EACH		27.160	
TURBINE TO CORE	54.320		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.06	
CORE	72.427		—

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	72.43	LB/SEC
REACTOR POWER	1710.68	MW
CORE FLOW AREA	143.25	IN2
CORE MASS FLOW RATE	0.51	LB/IN2
FUEL ELEMENT POWER	0.80	MW/Element
FUEL ELEMENT OPERATING LIFE	0.17	HR
NUMBER OF FUEL ELEMENTS	2055.36	
NUMBER OF SUPPORT ELEMENTS	709.12	
CHAMBER TEMPERATURE	5580.00	DEG R
CHAMBER PRESSURE	1000.00	PSIA
CHAMBER ENTHALPY	22306.93	BTU/LB
CORE INLET TEMPERATURE	637.00	DEG R
CORE INLET PRESSURE	1264.41	PSIA
CORE INLET ENTHALPY	2162.54	BTU/LB
HEAT PICKUP PER TIE TUBE	0.21	MW/TUBE
HEAT PICKUP IN TIE TUBES	139625.68	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1585.07	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	

HEAT PICKUP IN REFLECTOR	19784.99	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2805.58	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	502.73	BTU/S
PEAK CHANNEL WALL TEMPERATURE	5843.07	DEG R
PEAK FUEL TEMPERATURE	5899.22	DEG R

REACTOR DIMENSIONS

CORE LENGTH	34.84	IN
CORE DIAMETER	29.49	IN
FUEL ELEMENT CHANNEL DIAMETER	0.07	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	27.85	IN
LATERAL SUPPORT DIAMETER	32.77	IN
STRUCTURE OD	34.97	IN
REFLECTOR OD	44.54	IN
PRESSURE VESSEL ID	44.86	IN
PRESSURE VESSEL OD	46.02	IN
THICKNESS OF BATH SHIELD	14.57	IN
THICKNESS OF LEAD SHIELD	1.81	IN
PRESSURE VESSEL LENGTH	87.01	IN
FUEL VOLUME	10794.04	IN3

REACTOR MASSES

FUEL MASS	1856.57	LB
SUPPORT MASS	825.54	LB
CORE PERIPHERY MASS	220.54	LB
LATERAL SUPPORT MASS	204.96	LB
STRUCTURE MASS	448.78	LB
REFLECTOR MASS	1307.12	LB
HOT END HARDWARE MASS	96.35	LB
AFT REFLECTOR MASS	60.57	LB
CORE INLET PLENUM MASS	134.37	LB
SUPPORT PLATE MASS	462.14	LB
LATERAL SUPPORT FORWARD MASS	40.06	LB
REFLECTOR HARDWARE FORWARD MASS	107.30	LB
SUPPORT PLATE PLENUM MASS	31.35	LB
INSTRUMENTATION RING MASS	29.47	LB
FORWARD REFLECTOR HARDWARE MASS	21.26	LB
SUBTOTAL CORE A	5936.39	LB
FLOW BAFFLE MASS	0.00	LB
FLOW BAFFLE 1 MASS	0.00	LB
TOTAL CORE SUBSYSTEM MASS	5936.39	LB
PRESSURE VESSEL A MASS	453.75	LB
PRESSURE VESSEL B MASS	224.67	LB
PRESSURE VESSEL DOME MASS	95.19	LB
NOZZLE/REACTOR ADAPTER MASS	95.09	LB
TOTAL PRESSURE VESSEL MASS	868.70	LB
BATH CENTRAL SHIELD MASS	986.86	LB
BATH PERIPHERAL SHIELD MASS	797.06	LB
BATH PERIPHERAL SHIELD 2 MASS	287.70	LB
LEAD CENTRAL SHIELD MASS	421.79	LB
LEAD PERIPHERAL SHIELD MASS	0.19	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.08	LB
PERIPHERAL SHIELD PLATE MASS	37.40	LB
TOTAL SHIELD MASS	2531.08	LB
REACTOR MASS w/o SHIELD	6805.09	LB
REACTOR MASS w/ SHIELD	9336.17	LB

SAFETY RODS-FOR LAUNCH ONLY	331.00	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	7136.09	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	9667.17	LB

* * * TPA SUMMARY FOR STAGE #1 * * *
EXPANDER CYCLE
2 PROPELLANT FEED LEGS
AXIAL PUMPS
TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	28114.
SPECIFIC SPEED	2055.
INDUCER SPECIFIC SPEED	4024.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	8.+ INDUCER
NET POS SUCTION PRESSURE(PSIA)	109.00
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	2063.55
VOLUMETRIC FLOWRATE(GPM)	3922.47
MASS FLOWRATE(LBM/SEC)	37.36
PUMP HORSEPOWER(HP)	6263.73
PUMP EFFICIENCY	0.739
INDUCER EFFICIENCY	0.801
OVERALL PUMP EFFICIENCY	0.742
PUMP DIAMETER(IN)	5.91
PUMP WT.(LB) - EACH PUMP	244.32
INDUCER WT.(LB) - EACH	73.18
OVERALL PUMP WT.(LB) - EACH	317.49

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.627
PRESSURE RATIO	1.364
MASS FLOWRATE(LB/SEC)	27.16
DIAMETER(IN)	6.32
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52540.
ROOT STRESS SPEED LIMIT(RPM)	35566.
SPECIFIC SPEED	27.
TURBINE SPEED(RPM)	28114.
TURBINE WT(LB) - EACH TURBINE	40.09
TURBINE ANNULUS AREA(IN2)	30.128
U OVER C	0.31
INLET MACH NUMBER	0.48

... TPA ...

TPA START SYSTEM WT.	0.00

GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	0.00
GEARBOX WT.-TOTAL	0.00
MAIN TURBOPUMP WT. - EACH	357.58
TOTAL TURBOPUMP WT.	715.16
TOTAL TPA WT.	747.40

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1530.39
PRESSURE TANK	3069.52
TANK CONSTRUCTION WEIGHT	3274.84
TANK LINES	40.21
AFT SKIRT	424.05
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.38
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	238.93
ENGINE WEIGHTS:	
1 REACTOR	6805.09
1 REACTOR INTERNAL SHIELD	2531.08
1 NOZZLE	1161.52
1 THRUST MOUNT(S)	1719.90
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	172.09
2 MAIN VALVE(S)	344.76
1 SUPPORT HARDWARE	619.14
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	0.00
2 GAS GENERATOR/PREBURNER	0.00
2 TPA ASSY(S)	715.16
1 GEARBOX(S)	0.00
2 TPA START SYSTEM(S)	0.00
1 GAS GENERATOR/PREBURNER(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	101.35
TOTAL ENGINE WEIGHT	14505.10
FLIGHT FUEL BOILOFF	744.44
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	331.00

TOTAL INERT WEIGHT	25035.45
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	6.89
OXIDIZER RESIDUAL	0.00
OXIDIZER AUTOGENOUS PRESSURANT	0.00
STORED PRESSURANT	218.86
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	33261.20
GROSS BURNOUT WEIGHT	24175.76
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	164.61
NUMBER OF NOZZLES	1
STAGE LENGTH	996.14
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	996.14
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	1000.0
NOZZLE AREA RATIO	500.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	1003.7
ISP EFFICIENCY	0.975
TOTAL PROP. FLOWRATE, LB/SEC	74.72
CORE PROP. FLOWRATE, LB/SEC	72.43

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL		PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL		TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		——	550.0		——	
VENT	38.6		0.0	43.2		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.1		0.0	——		0.0	
... PROPELLANT ...							
TANK PROPELLANT	35.1		0.0	38.5		0.0	
PUMP INLET	35.0		0.0	40.2		0.0	
MAIN VALVE INLET	1712.0		0.0	73.7		0.0	
MAIN VALVE OUTLET	1633.8		0.0	73.7		0.0	
TIE TUBE OUTLET	1383.8		——	763.8		——	
REGEN OUTLET (REFL I	1143.1		——	104.6		——	
REFLECTOR OUTLET	1118.1		——	360.2		——	
REACTOR INLET		1118.1			643.5		
REACTOR CORE		800.0			5580.0		
TURBINE INLET		1383.8			763.8		
TURBINE OUTLET		1118.1			714.1		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)			TEMPERATURE CHANGES (DEG R)		
ACQUISITION DEVICE	0.0		0.0			
FEED LINE	0.1		0.0	0.0		0.0
PUMP	1677.0		0.0	35.2		0.0
MAIN VALVE	78.3		0.0	0.0		0.0
TIE TUBES	250.0		——	690.1		——
REGEN JACKET	13.4		——	30.9		——
REFLECTOR	25.0		——	255.6		——
TURBINE		265.7			49.6	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	59.559		0.000
MAIN PUMP	59.559		0.000
MAIN VALVE	59.559		0.000
TOTAL TIE TUBES	43.292		——
REGEN JACKET INFLOW	16.267		——
NOZZLE BARRIER COOLING		1.836	
REGEN/REFL OUTLET TO CORE	14.431		——
TURBINE		43.292	
TURBINE TO CORE	43.292		0.000
AUTOGENOUS PRESSURANT	0.000		0.000

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STORED PRESSURANT (AVE)                  0.05
CORE                          57.723           ____

          * * *   TPA SUMMARY FOR STAGE #1   * * *
          SUMMARY FOR TPA AT THRUST LEVEL FRACTION  0.80
                EXPANDER CYCLE
                SINGLE SHAFT TPA
                AXIAL PUMPS

... PROPELLANT PUMP ...

     PUMP SPEED (RPM)                    30460.
     SPECIFIC SPEED                       3243.
     INDUCER SPECIFIC SPEED               6349.
     SUCTION SPECIFIC SPEED              20000.
     NUMBER OF PUMP STAGES                   8.+ INDUCER
     NET POS SUCTION PRESSURE(PSIA)        92.70
     ACCELERATION HEAD(PSIA)                0.00
     PUMP OUTLET PRESSURE(PSIA)          1712.05
     VOLUMETRIC FLOWRATE(GPM)            6252.76
     MASS FLOWRATE(LBM/SEC)                59.56
     PUMP HORSEPOWER(HP)                 7641.33
     PUMP EFFICIENCY                        0.801
     INDUCER EFFICIENCY                     0.809
     OVERALL PUMP EFFICIENCY                0.802
     PUMP DIAMETER(IN)                     5.91
     PUMP WT.(LB)                        244.32
     INDUCER WT.(LB)                      73.18
     OVERALL PUMP WT.(LB)                317.49


... TURBINE ...

     ADMISSION FRACTION                     1.000
     EFFICIENCY                             0.700
     PRESSURE RATIO                         1.238
     MASS FLOWRATE(LB/SEC)                 43.29
     DIAMETER(IN)                           6.32
     NUMBER OF TURBINE STAGES               2.
     BLADE ROOT STRESS LIMIT(PSI)       52531.
     ROOT STRESS SPEED LIMIT(RPM)       35563.
     SPECIFIC SPEED                        88.
     TURBINE SPEED(RPM)                 30460.
     TURBINE WT(LB)                        40.09
     TURBINE ANNULUS AREA(IN2)             30.128

     ENGINE SUMMARY

 EXPANDER CYCLE
 ENABLER II
 AXIAL PUMPS
 THRUST LEVEL =                     75000.0  lbf      333600.0  N
 CHAMBER PRESSURE =                  1000.0  psia       6895.0  kPa
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   CHAMBER TEMPERATURE =                 5580.0  deg R       3100.0  deg K
   NOZZLE EXIT AREA RATIO =               500.0               500.0
   NUMBER OF FEED LEGS =                      2                   2
   TOTAL PROPELLANT FLOWRATE =             74.7  lbm/s         33.9  kg/s

REACTOR
   CARBIDE FUEL
   FUEL SCALING FACTOR                     0.67                0.67
   REACTOR WEIGHT                        6805.1  lbm         3086.2  kg
   SHIELD WEIGHT                         2531.1  lbm         1147.9  kg
   PRESSURE VESSEL DIA.                    46.0  in           116.9  cm
   PRESSURE VESSEL LENGTH                  87.0  in           221.0  cm
   CORE PROPELLANT MASS FLOW               72.4  lbm/sec       32.8  kg/sec

NOZZLE
   CONVERGING NOZZLE WEIGHT               180.4  lbm           81.8  kg
   NOZZLE EXTENSION WEIGHT                393.4  lbm          178.4  kg
   SECOND NOZZLE EXTENSION WEIGHT         587.7  lbm          266.5  kg
   TOTAL NOZZLE WEIGHT                   1161.5  lbm          526.8  kg
   AREA RATIO                             500.0               500.0
   THROAT DIAMETER                          7.4  in            18.7  cm
   EXIT DIAMETER                          164.6  in           418.1  cm
   NOZZLE LENGTH                          326.0  in           828.0  cm
   DELIVERED VACUUM ISP                  1003.7  sec         9836.1  N-sec/kg
   DELIVERED THRUST                     75000.0  lbf       333600.0  N

TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)
   MAIN PROP. TURBOPUMP WT                715.2  lbm          324.3  kg
   PROPELLANT BOOST PUMP WT                 0.0  lbm            0.0  kg
   MAIN OX PUMP WEIGHT                      0.0  lbm            0.0  kg
   TPA IGNITION WEIGHT                     32.2  lbm           14.6  kg
   BLEED LINE/VALVE WEIGHT                  0.0  lbm            0.0  kg

MISC. HARDWARE WEIGHTS
   THRUST MOUNT                          1719.9  lbm          780.0  kg
   SUPPORT HARDWARE                       619.1  lbm          280.8  kg
   ENGINE LINES                           172.1  lbm           78.0  kg
   MAIN VALVE                             344.8  lbm          156.4  kg
   GIMBAL + POWER SUPPLY                  302.8  lbm          137.3  kg

   MARGIN ( 2.0%)                         101.4  lbm           46.0  kg
   TOTAL NONNUCLEAR WEIGHT               5168.9  lbm         2344.2  kg

TOTAL ENGINE SYSTEM
   TOTAL ENGINE WEIGHT                  14505.1  lbm         6578.3  kg
   TOTAL ENGINE WEIGHT WITHOUT SHIELD   11974.0  lbm         5430.4  kg
   THRUST/WEIGHT RATIO WITH SHIELD          5.2  lbf/lbm       50.7  N/kg
   THRUST/WEIGHT RATIO WITHOUT SHIELD       6.3  lbf/lbm       61.4  N/kg
   REACTOR SAFETY ROD WT.-LAUNCH ONLY     331.0  lbm          150.1  kg
   TOTAL ENGINE LAUNCH WEIGHT           14836.1  lbm         6728.4  kg
   TOTAL ENGINE LAUNCH WT. W/O SHIELD   12305.0  lbm         5580.5  kg

PUMP-OUT CONDITIONS
   PUMP-OUT THRUST                      60000.0  lbf       266880.0  N
   PUMP-OUT CHAMBER PRESSURE              800.0  psia        5516.0  kPa
   PUMP-OUT ISP                          1007.4  sec         9872.6  N-sec/kg
   PUMP-OUT CHAMBER TEMPERATURE          5580.0  deg R       3100.0  deg K

OVERALL DIMENSIONS
   OVERALL ENGINE LENGTH =                493.9  in          1254.4  cm
```

```
OVERALL ENGINE DIAMETER =          164.6  in          418.1  cm
```

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

```
TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 19.577          RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM =  164.6      STAGE DIAM =  100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS  FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET
TPA CALCULATIONS TERMINATED BY ACHIEVING DESIRED ACCURACY

END NOMINAL STAGE DESIGN
```

Table 4-7. Sample Case No. 6

Input Listing

```
Nuclear Thermal Vehicle
35000.     FVAC       Vacuum thrust (lbf)
500.       PC         Chamber pressure (psia)
5          IPROP      Propellant flag
0.0        WPAYLD     Vehicle payload wt.
0.0        WMISC      Miscellaneous stage wt.
0.0        WEXPND     Expendable stage wt.
7          KCYCLE     Cycle type (1=GG,3=Expander,7=Bleed)
2          JCNFIG     Pump configuration
0          IPTYPE     Pump type (0=centr., 1=axial)
1          ISOLVE     Bleed cycle solver (see worksheet)
850.0      TURBTIN    Turbine inlet temp (ISOLVE=1)
0.0        FRACHB     Hot bleed fraction (ISOLVE=0)
0.0        FRACCB     Cold bleed fraction (ISOLVE=0)
0.07       CPLINH     Hot bleed line loss fraction
0.07       CPLINC     Cold bleed line loss fraction
0.07       CPLINT     Turbine inlet line loss fraction
0.08       CPVLVT     Turbine throttling valve loss frac.
1          JBPFL      Use fuel boost pump?
0          JBPOX      Use ox boost pump?
1          NTPA       Number of identical turbopumps
0          IDBLRUN    Double run flag
0.8        FFRAC      Thrust fraction
0          ITRATE     Double run solver
1          IUSRBRN    Input engine burn time?
3600.0     TUSRBRN    Engine burn time
0.02       FMARG      Margin weight fraction
1.0        XLFL       Barrier liquid film length
0.15       ALFMIX     Barrier mixing angle
200.       EPS        Engine area ratio
1          KEXNOZ     Use a nozzle extension?
1          NOZTYP     Use a 3-portion nozzle?
6.         EPSATT     Nozzle extension 1 attach area ratio
25.        EPSAT2     Nozzle extension 2 attach area ratio
12.0       XLN        Convergent nozzle length
2          KNOZ       Type of nozzle
0          IPLUG      Use plug nozzle?
1.1868     RATMLR     Nozzle length ratio
0.0        OFGGPB     GG mixture ratio
1.46       GAMGPB     GG ratio of specific heats
3.51       CPGGPB     GG specific heat
2.016      WMGGPB     GG molecular weight
4860.      TCHAMBER   Chamber temperature
1          IREACTR    Reactor model flag (1=enabler1,2=enabler2)
2          CONFIG     Flow path flag (1=old,2=new)
0.11       DC         Fuel element chamber diameter
0.173      SC         Spacing between holes
1.2        PAC        Peak to average channel factor
19.0       HOLES      Number of holes per element
2          FTYPE      Fuel type
2          SPAT       Support pattern
35.0       LC         Core length
1.2        PMW        Power in each element (MW per 52 inches)
0.25       NFF        Nozzle flow fraction
0.31       QTT        Heat pickup per tie tube
-106.0     HTANK      Enthalpy of coolant entering system
0.0122     FREF       Fractional heat pickup in reflector
0.00031    FES        Fractional heat pickup in ext shield
0.00173    FCS        Fractional heat pickup in cent shield
0.67       FALPHA     Fuel scaling fraction
```

0.750	HEX	Uncoated fuel hex flat dimension
35.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
1.0	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
0	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
1.3	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
15.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.3	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
20.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

Nuclear Thermal Vehicle

KEY INPUTS

THRUST LEVEL =	35000.	(lbf)
CYCLE TYPE =	BLEED CYCLE	
REACTOR TYPE =	ENABLER I	
FUEL TYPE =	COMPOSITE FUEL	
NOZZLE EXIT AREA RATIO =	200.	
PROPELLANT USED =	LH2	
CHAMBER PRESSURE =	500.	(psia)
CHAMBER TEMPERATURE =	4860.	(deg R)
NUMBER OF PROPELLANT FEED LEGS =	1	

TANKAGE SUMMARY FOR STAGE #1
BLEED CYCLE
AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
FUEL TANK IS PRESSURIZED WITH COLD GAS
TANK MATERIALS (OX - USER DEF) (FUEL - aluminum) (PRESSURANT - USER DEF)

.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	831.89
TOTAL TANK LENGTH	542.02
NOZZLE LENGTH	156.82
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	86.06
TANK HEAD ELLIPSE RATIO	1.38
PRESSURE TANK ELLIPSE RATIO	1.00
AFT TANK HEAD HEIGHT	35.34
FORWARD TANK HEAD HEIGHT	36.04
PRESSURE TANK HEAD HEIGHT	28.95
PRESSURE TANK DIAMETER	57.89
AFT TANK CYLINDRICAL LENGTH	0.00
FORWARD TANK CYLINDRICAL LENGTH	464.66
PRESSURE TANK CYLINDRICAL LNGTH	0.00
AFT LINE DIAMETER	0.00
FORWARD LINE DIAMETER	3.33
AFT SKIRT LENGTH	290.21
FORWARD SKIRT LENGTH	36.04
STRUCTURAL WALL THICKNESS	0.061
AFT TANK WALL THICKNESS	0.030
FORWARD TANK WALL THICKNESS	0.048
PRESSURE TANK WALL THICKNESS	0.711
AFT TANK DOME THICKNESS	0.030
FORWARD TANK DOME THICKNESS	0.033
PRESSURE TANK DOME THICKNESS	0.711
FUEL TANK MLI THICKNESS	0.02
FUEL TANK SOFI THICKNESS	0.50
OXIDIZER TANK MLI THICKNESS	1.97
OXIDIZER TANK SOFI THICKNESS	0.50
PRESSURE TANK INSULATION THICK	0.00
FUEL TNK HEAT FLUX(BTU/HR IN**2)	0.08
OX TANK HEAT FLUX(BTU/HR IN**2)	0.00
FUEL BOILOFF RATE (LB/SEC)	0.003
OX BOILOFF RATE (LB/SEC)	0.000

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.49
PRESSURE TANK	1986.42
TANK CONSTRUCTION WEIGHT	2512.54
STRUCTURAL WALL	11.29
AFT SKIRT	272.64
FORWARD SKIRT	75.76
TANK MOUNT	0.00
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.20
OXIDIZER TANK INSULATION	407.04
REVERSE HEAD STIFFENER	184.69
FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	33.44
TANK LINES	18.99
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	9.09
OXIDIZER RESIDUAL	0.00
STORED PRESSURANT	141.63
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00
FLIGHT FUEL BOILOFF	744.20
FLIGHT OXIDIZER BOILOFF	0.00
MISC EXPENDED FUEL	0.00
MISC EXPENDED OXIDIZER	0.00
MISCELLANEOUS WEIGHT	0.00
INTERSTAGE WEIGHT	0.00

... INPUT MINIMUM SAFETY FACTORS ...

STRUCTURAL WALL	1.25
LINES	2.00
OXIDIZER TANK	1.25
FUEL TANK	1.25
PRESSURE TANK	1.50

PROPELLANT SUMMARY FOR STAGE #1
PROPELLANT IS LH2

NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)= 0.0025

.. OXIDIZER ...

NOMINAL TANK PRESSURE(PSIA)	0.0
NOMINAL PROPELLANT TEMP(DEGR)	0.0
NOMINAL DENSITY(LB/IN**3)	0.0000
NOMINAL VAPOR PRESSURE(PSIA)	0.0
MAX PROPELLANT TEMP(DEGR)	0.0
MAX TEMP DENSITY(LB/IN**3)	0.0000
MAX TEMP VAPOR PRESSURE(PSIA)	0.0
MIN PROPELLANT TEMP(DEGR)	0.0
MIN TEMP DENSITY(LB/IN**3)	0.0000
MIN TEMP VAPOR PRESSURE(PSIA)	0.0

... FUEL ...

NOMINAL TANK PRESSURE(PSIA)	35.0
NOMINAL PROPELLANT TEMP(DEGR)	38.5
NOMINAL DENSITY(LB/IN**3)	0.0025
NOMINAL VAPOR PRESSURE(PSIA)	20.0
MAX PROPELLANT TEMP(DEGR)	40.0
MAX TEMP DENSITY(LB/IN**3)	0.0025
MAX TEMP VAPOR PRESSURE(PSIA)	25.0
MIN PROPELLANT TEMP(DEGR)	38.5
MIN TEMP DENSITY(LB/IN**3)	0.0025
MIN TEMP VAPOR PRESSURE(PSIA)	20.0

ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
BLEED CYCLE
CONVERGENT NOZZLE IS REGEN COOLED (MILLED SLOT CONSTRUCTION)
NOZZLE IS REGEN COOLED (TUBE CONSTRUCTION)
PROPELLANT IS LH2

.. ENGINE DIMENSIONS (INCHES) ...

THROAT DIAMETER	7.18
REACTOR SUPPORT DIAMETER	32.55
PRESSURE VESSEL O.D.	45.20
NOZZLE EXIT DIAMETER	101.60
NOZZLE EXTENSION ATTACH DIAM	17.60
CONVERGENT NOZZLE LENGTH	12.00
CONV. NOZZLE STRUCTURAL THICK.	0.617
GAS SIDE WALL THICKNESS	0.072
NOZZLE EXTENSION THICKNESS	0.010
SECOND NOZZLE EXTENSION THICKNESS	0.100
NOZZLE EXIT AREA RATIO	200.00
CONTRACTION RATIO	9.69
NOZ EXTENSION ATTCH AREA RATIO	6.00
SECOND NOZ EXT ATTACH AREA RATI	25.00
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187
NOZZLE LENGTH	156.82
FEED SYSTEM MOUNT LENGTH	86.06
REACTOR LENGTH	35.00

... PERFORMANCE ...

DELIVERED ISP(VAC),SEC	874.53
IDEAL ISP(ODE),SEC	928.88
DELIVERED CSTAR,FT/SEC	16377.
IDEAL CSTAR,FT/SEC	16597.
CHAMBER PRESSURE,PSIA	500.
THRUST PER ENGINE(VAC),LBF	35000.
TOTAL VAC THRUST,LBF	35000.
BURN TIME,SEC	3600.00
OVERALL EFFICIENCY	0.941
KINETIC EFFICIENCY	1.000
BARRIER COOLING EFFICIENCY	0.986
BOUNDARY LAYER EFFICIENCY	0.996
DIVERGENCE EFFICIENCY	0.993
GG BLEED EFFICIENCY	0.967
FOR 1 ENGINE	
OXIDIZER FLOWRATE,LB/SEC	0.00
FUEL FLOWRATE,LB/SEC	40.33
TOTAL FLOWRATE,LB/SEC	40.33
CORE TEMPERATURE,DEG R	4860.
BARRIER TEMPERATURE,DEG R	1630.
ENGINE MIXTURE RATIO	0.00
FUEL FILM COOLING FRACTION	0.03

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 5.748 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 2.840 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE 0 0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.072
GAS WALL THERMAL CONDUCTIVITY =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.630E+03	.586E+02	.649E+00	.207E+02	.215E-01	0.296E+03	.300E+03	.897E-04	.905E-04	.250E+02	.539E+03
2	.630E+03	.592E+02	.539E+00	.302E+02	.351E-01	0.347E+03	.353E+03	.132E-03	.122E-03	.176E+02	.618E+03
3	.630E+03	.600E+02	.429E+00	.481E+02	.641E-01	0.423E+03	.435E+03	.211E-03	.177E-03	.116E+02	.739E+03
4	.630E+03	.615E+02	.320E+00	.887E+02	.142E+00	0.545E+03	.571E+03	.377E-03	.294E-03	.676E+01	.948E+03
5	.630E+03	.647E+02	.210E+00	.217E+03	.478E+00	0.741E+03	.829E+03	.824E-03	.707E-03	.324E+01	.141E+04
6	.628E+03	.714E+02	.100E+00	.110E+04	.194E+01	0.704E+03	.106E+04	.343E-02	.307E-02	.100E+01	.163E+04
7	.628E+03	.730E+02	.158E+00	.461E+03	.111E+01	0.858E+03	.106E+04	.196E-02	.141E-02	.202E+01	.163E+04
8	.628E+03	.744E+02	.216E+00	.256E+03	.710E+00	0.923E+03	.105E+04	.123E-02	.836E-03	.341E+01	.163E+04
9	.628E+03	.755E+02	.274E+00	.164E+03	.495E+00	0.957E+03	.105E+04	.852E-03	.562E-03	.514E+01	.163E+04
10	.628E+03	.765E+02	.332E+00	.115E+03	.367E+00	0.977E+03	.105E+04	.627E-03	.407E-03	.724E+01	.163E+04
11	.628E+03	.775E+02	.390E+00	.857E+02	.283E+00	0.990E+03	.104E+04	.482E-03	.311E-03	.969E+01	.163E+04

DELTA T= 18.9
DELTA P= -1.9
NOZZLE DELTA T = 16.9
NOZZLE DELTA P = -1.9
ADAPTER DELTA T = 1.9
ADAPTER DELTA P = 0.0
TOTAL HEAT TRANSFER = 811.9 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
BLEED CYCLE

	PRESSURE(PSIA) FUEL		PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL		TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		4365.0	550.0		550.0	
VENT	38.5		0.0	43.2		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.0		0.0	—		—	
... PROPELLANT ...							
TANK PROPELLANT	35.0		0.0	38.5		0.0	
BOOST PUMP OUTLET	78.9		—	39.7		—	
MAIN PUMP INLET	72.9		0.0	39.7		0.0	
MAIN VALVE INLET	894.9		0.0	58.3		0.0	
MAIN VALVE OUTLET	852.7		—	58.3		—	
COLD BLEED VALVE IN	894.9		—	58.3		—	
COLD BLEED VALVE OUT	527.6		—	58.3		—	
TIE TUBE OUTLET	602.7		—	688.1		—	
REGEN OUTLET (REFL I	627.7		—	77.1		—	
REFLECTOR OUTLET	602.7		—	305.0		—	
REACTOR INLET		602.7			558.7		
REACTOR CORE		500.0			4860.0		
CHAMBER BLEED	500.0		—	4860.0		—	
MIXER OUTLET	465.0		—	850.0		—	
TURB THROT VALVE IN		432.5			850.0		
TURBINE INLET		397.9			850.0		
TURBINE OUTLET		15.0			302.6		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)			TEMPERATURE CHANGES (DEG R)		
ACQUISITION DEVICE	0.0		0.0			
BOOST PUMP	43.9		—	1.2		—
FEED LINE	6.0		0.0	0.0		0.0
MAIN PUMP	822.0		0.0	18.6		0.0
MAIN VALVE	42.2		0.0	0.0		0.0
HOT BLEED LINE	35.0		—	0.0		—
COLD BLEED LINE	62.6		—	0.0		—
COLD BLEED VALVE	367.3		—	0.0		—
TURBINE INLET LINE	32.5		—	0.0		—
TURB THROTTLING VALV	34.6		—	0.0		—
TIE TUBES	250.0		—	629.8		—
REGEN JACKET	1.9		—	18.9		—
REFLECTOR	25.0		—	227.8		—
TURBINE		382.9			547.4	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
BLEED CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	40.022		0.000
MAIN PUMP	40.022		0.000
COLD BLEED FLOW	1.474		——
MAIN VALVE	38.548		0.000
TOTAL TIE TUBES	28.059		——
REGEN JACKET INFLOW	10.489		——
NOZZLE BARRIER COOLING		1.136	
REGEN/REFL OUTLET TO CORE	9.353		——
MIXER OUTLET	1.647		0.000
TURBINE		1.647	
BLEED NOZZLE		1.647	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.04	
CORE	37.412		——
CHAMBER BLEED FLOW	0.173		——
NOZZLE OUTFLOW	37.239		——

BLEED CYCLE FLOW RATIOS

OVERALL BLEED FLOW FRACTION	0.041
OVERALL HOT BLEED FRACTION	0.004
OVERALL COLD BLEED FRACTION	0.037
HOT SIDE FRACTION OF TOTAL BLEED	0.105
COLD SIDE FRACTION OF TOTAL BLEED	0.895

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	37.41	LB/SEC
REACTOR POWER	750.83	MW
CORE FLOW AREA	139.42	IN2
CORE MASS FLOW RATE	0.27	LB/IN2
FUEL ELEMENT POWER	0.81	MW/Element
FUEL ELEMENT OPERATING LIFE	1.47	HR
NUMBER OF FUEL ELEMENTS	898.00	
NUMBER OF SUPPORT ELEMENTS	323.33	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	500.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	558.67	DEG R
CORE INLET PRESSURE	602.72	PSIA
CORE INLET ENTHALPY	1877.55	BTU/LB
HEAT PICKUP PER TIE TUBE	0.21	MW/TUBE
HEAT PICKUP IN TIE TUBES	63956.48	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	812.06	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	
HEAT PICKUP IN REFLECTOR	8683.86	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	1231.40	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	220.66	BTU/S
PEAK CHANNEL WALL TEMPERATURE	5024.13	DEG R
PEAK FUEL TEMPERATURE	5191.86	DEG R

REACTOR DIMENSIONS

CORE LENGTH	35.00	IN
CORE DIAMETER	29.27	IN
FUEL ELEMENT CHANNEL DIAMETER	0.11	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	27.63	IN
LATERAL SUPPORT DIAMETER	32.55	IN
STRUCTURE OD	34.75	IN
REFLECTOR OD	44.32	IN
PRESSURE VESSEL ID	44.64	IN
PRESSURE VESSEL OD	45.20	IN
THICKNESS OF BATH SHIELD	12.03	IN
THICKNESS OF LEAD SHIELD	1.22	IN
PRESSURE VESSEL LENGTH	84.04	IN
FUEL VOLUME	10553.86	IN3

REACTOR MASSES

FUEL MASS	1456.43	LB
SUPPORT MASS	861.33	LB
CORE PERIPHERY MASS	219.84	LB
LATERAL SUPPORT MASS	204.44	LB
STRUCTURE MASS	447.57	LB
REFLECTOR MASS	1395.72	LB
HOT END HARDWARE MASS	94.83	LB
AFT REFLECTOR MASS	60.24	LB
CORE INLET PLENUM MASS	132.24	LB
SUPPORT PLATE MASS	456.30	LB

LATERAL SUPPORT FORWARD MASS	39.77	LB
REFLECTOR HARDWARE FORWARD MASS	106.71	LB
SUPPORT PLATE PLENUM MASS	30.88	LB
INSTRUMENTATION RING MASS	29.27	LB
FORWARD REFLECTOR HARDWARE MASS	21.14	LB
SUBTOTAL CORE A	5556.70	LB
FLOW BAFFLE MASS	0.00	LB
FLOW BAFFLE 1 MASS	0.00	LB
TOTAL CORE SUBSYSTEM MASS	5556.70	LB
PRESSURE VESSEL A MASS	217.92	LB
PRESSURE VESSEL B MASS	107.59	LB
PRESSURE VESSEL DOME MASS	44.49	LB
NOZZLE/REACTOR ADAPTER MASS	0.00	LB
TOTAL PRESSURE VESSEL MASS	370.00	LB
BATH CENTRAL SHIELD MASS	813.62	LB
BATH PERIPHERAL SHIELD MASS	654.19	LB
BATH PERIPHERAL SHIELD 2 MASS	230.63	LB
LEAD CENTRAL SHIELD MASS	279.80	LB
LEAD PERIPHERAL SHIELD MASS	0.18	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.08	LB
PERIPHERAL SHIELD PLATE MASS	37.18	LB
TOTAL SHIELD MASS	2015.68	LB
REACTOR MASS w/o SHIELD	5926.70	LB
REACTOR MASS w/ SHIELD	7942.38	LB
SAFETY RODS-FOR LAUNCH ONLY	327.26	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	6253.96	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	8269.63	LB

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* * *   TPA SUMMARY FOR STAGE #1   * * *
        BLEED CYCLE
        SINGLE SHAFT TPA
        CENTRIFUGAL PUMPS

... PROPELLANT PUMP ...

    PUMP SPEED (RPM)                     37607.
    SPECIFIC SPEED                        1123.
    SUCTION SPECIFIC SPEED               20000.
    NUMBER OF PUMP STAGES                    1.
    NET POS SUCTION PRESSURE(PSIA)       52.86
    ACCELERATION HEAD(PSIA)               0.00
    PUMP OUTLET PRESSURE(PSIA)          894.91
    VOLUMETRIC FLOWRATE(GPM)           4102.10
    MASS FLOWRATE(LBM/SEC)               40.02
    PUMP HORSEPOWER(HP)                2642.95
    PUMP EFFICIENCY                      0.744
    PUMP DIAMETER(IN)                     8.00
    PUMP WT.(LB)                         59.91

... FUEL BOOST PUMP ...

    PUMP SPEED(RPM)                      37607.
    SPECIFIC SPEED                       10458.
    SUCTION SPECIFIC SPEED               20000.
    NET POS SUCTION PRESSURE(PSIA)       15.00
    OUTLET PRESSURE(PSIA)                78.90
    PUMP HORSEPOWER(HP)                 155.26
    PUMP EFFICIENCY                      0.646
    PUMP DIAMETER(IN)                     3.77
    PUMP WT(LB)                          15.88

... TURBINE ...

    ADMISSION FRACTION                   1.000
    EFFICIENCY                           0.700
    PRESSURE RATIO                      26.524
    MASS FLOWRATE(LB/SEC)                 1.65
    DIAMETER(IN)                         16.90
    NUMBER OF TURBINE STAGES                2.
    BLADE ROOT STRESS LIMIT(PSI)        52636.
    ROOT STRESS SPEED LIMIT(RPM)        48000.
    SPECIFIC SPEED                         15.
    TURBINE SPEED(RPM)                  37607.
    TURBINE WT(LB)                      309.37
    TURBINE ANNULUS AREA(IN2)           16.571

... TPA ...

    TPA START SYSTEM WT.                  0.00
```

GAS GENERATOR/PREBURNER WT.	0.00
IGNITION SYSTEM WT.-TOTAL	16.12
HOT GAS MANIFOLD WT.-TOTAL	10.79
GEARBOX WT.-TOTAL	0.00
CHAMBER BLEED LINE WT.	15.66
COLD BLEED LINE WT.	1.21
TURBINE INLET LINE WT.	16.83
COLD BLEED VALVE WT.	1.95
TURBINE THROTTLING VALVE WT.	46.61
MIXER WT.	3.68
TOTAL BLEED CYCLE LINE/VALVE WT	85.93
BOOST PUMP WT. - EACH	15.88
MAIN TURBOPUMP WT. - EACH	369.28
TOTAL TURBOPUMP WT.	385.17
TOTAL TPA WT.	498.00

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1524.49
PRESSURE TANK	1986.42
TANK CONSTRUCTION WEIGHT	2512.54
TANK LINES	18.99
AFT SKIRT	272.64
FORWARD SKIRT	75.76
TANK MOUNT	0.00
STRUCTURAL WALL	11.29
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	256.20
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	33.44
ENGINE WEIGHTS:	
1 REACTOR	5926.70
1 REACTOR INTERNAL SHIELD	2015.68
1 NOZZLE	344.87
1 THRUST MOUNT(S)	1366.15
1 GIMBAL SYSTEM(S)	76.63
1 ENGINE BAY LINE(S)	34.90
1 MAIN VALVE(S)	157.77
1 SUPPORT HARDWARE	591.27
1 GIMBAL POWER SUPPLY	96.49
1 IGNITION SYSTEM(S)	16.12
1 HOT GAS MANIFOLD(S)	10.79
1 GAS GENERATOR/PREBURNER	0.00
1 TPA ASSY(S)	471.10
1 GEARBOX(S)	0.00
1 TPA START SYSTEM(S)	0.00
1 GAS GENERATOR/PREBURNER(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	63.32
TOTAL ENGINE WEIGHT	11171.79
FLIGHT FUEL BOILOFF	744.20
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	327.26
TOTAL INERT WEIGHT	19349.32
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00

BURNED OXIDIZER	0.00
FUEL RESIDUAL	9.09
OXIDIZER RESIDUAL	0.00
STORED PRESSURANT	141.63
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	27500.03
GROSS BURNOUT WEIGHT	18418.58
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	101.60
NUMBER OF NOZZLES	1
STAGE LENGTH	831.89
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	831.89
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	35000.0
PC,PSIA	500.0
NOZZLE AREA RATIO	200.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	874.5
ISP EFFICIENCY	0.941
TOTAL PROP. FLOWRATE, LB/SEC	40.02
CORE PROP. FLOWRATE, LB/SEC	37.41

ENGINE SUMMARY

BLEED CYCLE				
ENABLER I				
CENTRIFUGAL PUMPS				
THRUST LEVEL =	35000.0	lbf	155680.0	N
CHAMBER PRESSURE =	500.0	psia	3447.5	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	200.0		200.0	
NUMBER OF FEED LEGS =	1		1	
TOTAL PROPELLANT FLOWRATE =	40.0	lbm/s	18.2	kg/s
REACTOR				
COMPOSITE FUEL				
REACTOR WEIGHT	5926.7	lbm	2687.8	kg
SHIELD WEIGHT	2015.7	lbm	914.1	kg
PRESSURE VESSEL DIA.	45.2	in	114.8	cm
PRESSURE VESSEL LENGTH	84.0	in	213.5	cm
CORE PROPELLANT MASS FLOW	37.4	lbm/sec	17.0	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	77.7	lbm	35.3	kg
NOZZLE EXTENSION WEIGHT	56.0	lbm	25.4	kg
SECOND NOZZLE EXTENSION WEIGHT	211.1	lbm	95.8	kg
TOTAL NOZZLE WEIGHT	344.9	lbm	156.4	kg
AREA RATIO	200.0		200.0	
THROAT DIAMETER	7.2	in	18.2	cm
EXIT DIAMETER	101.6	in	258.1	cm
NOZZLE LENGTH	156.8	in	398.3	cm
DELIVERED VACUUM ISP	874.5	sec	8570.3	N-sec/kg
DELIVERED THRUST	35000.0	lbf	155680.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	369.3	lbm	167.5	kg
PROPELLANT BOOST PUMP WT	15.9	lbm	7.2	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	16.1	lbm	7.3	kg
BLEED LINE/VALVE WEIGHT	85.9	lbm	39.0	kg
GAS GENERATOR	0.0	lbm	0.0	kg
HOT GAS MANIFOLD	10.8	lbm	4.9	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1366.2	lbm	619.6	kg
SUPPORT HARDWARE	591.3	lbm	268.2	kg
ENGINE LINES	34.9	lbm	15.8	kg
MAIN VALVE	157.8	lbm	71.6	kg
GIMBAL + POWER SUPPLY	173.1	lbm	78.5	kg
MARGIN (2.0%)	63.3	lbm	28.7	kg
TOTAL NONNUCLEAR WEIGHT	3229.4	lbm	1464.6	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	11171.8	lbm	5066.6	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	9156.1	lbm	4152.4	kg
THRUST/WEIGHT RATIO WITH SHIELD	3.1	lbf/lbm	30.7	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	3.8	lbf/lbm	37.5	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	327.3	lbm	148.4	kg
TOTAL ENGINE LAUNCH WEIGHT	11499.0	lbm	5215.0	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	9483.4	lbm	4300.8	kg

PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	0.0	lbf	0.0	N
PUMP-OUT CHAMBER PRESSURE	0.0	psia	0.0	kPa
PUMP-OUT ISP	0.0	sec	0.0	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	0.0	deg R	0.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	326.9	in	830.4	cm
OVERALL ENGINE DIAMETER =	101.6	in	258.1	cm

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 9.693 RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM = 101.6 STAGE DIAM = 100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET

END NOMINAL STAGE DESIGN

Table 4-8. Sample Case No. 7

Input Listing

Nuclear Thermal Vehicle

250000.	FVAC	Vacuum thrust (lbf)
500.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
7	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
1	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
1400.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.07	CPLINH	Hot bleed line loss fraction
0.07	CPLINC	Cold bleed line loss fraction
0.07	CPLINT	Turbine inlet line loss fraction
0.08	CPVLVT	Turbine throttling valve loss frac.
1	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
3	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
1.0	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
200.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
25.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.46	GAMGPB	GG ratio of specific heats
3.51	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
1	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
2	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
3	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.7	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dimension
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.0	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
0	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.0001	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCHM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplier
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
15.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier: all tanks
15*1.0	CXNCT1	Weight multiplier: non-conv. tanks
1.7	CXWFLT	Weight multiplier: fuel tank
1.7	CXWOXT	Weight multiplier: ox tank
1.7	CXWPTN	Weight multiplier: pres. tank
1.0	CXWSTR	Weight multiplier: structure
1.0	CXWATL	Weight multiplier: aft tank lines
1.0	CXWFTL	Weight multiplier: forward tank lines
1.0	CXWPTL	Weight multiplier: pres. tank lines
1.0	CXWENG	Weight multiplier: nozzle + hardware
2.8	CXVALV	Weight multiplier: valves
1.0	CXWCHM	Weight multiplier: convergent nozzle
1.1	CXWNZE	Weight multiplier: nozzle extension
3.5	CXWDUC	Weight multiplier: hot gas ducts
1.4	CXWGIM	Weight multiplier: gimbal
0.9	CXWTHM	Weight multiplier: thrust mount
1.4	CXWIGG	Weight multiplier: GG injector
1.3	CXWTPA	Weight multiplier: turbines
6.0	CXWPMP	Weight multiplier: pumps
2.5	CXWLIN	Weight multiplier: engine bay lines
0.25	CXWPNEU	Weight multiplier: pneumatic system
1.0	CXWINST	Weight multiplier: instrumentation
0.9	CXWTNKAS	Weight multiplier: reactor cooldown
1.3	CXWIGN	Weight multiplier: ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly weights?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

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1           MTNKOX    ox tank material
2           MATPT     pressure tank material
11          MATSTR    structure and skirts material
15*11       MATNK1    tank materials (non-conventional tanks)
0.29        RHO       user defined tank material density
29.0E6      YMOD      user defined tank material elastic mod.
112300.0    SIGMAX    user defined tank material strength
0.12        SPHEAT    user defined tank material specific heat
0.00023     CONDCT    user defined tank material conductivity
0.035       TMING     user defined tank material min gauge
0.035       TMINGS    user defined material structural min gauge
1.25        SFFLTK    fuel tank safety factor
1.25        SFOXTK    ox tank safety factor
1.5         SFPRTK    pressure tank safety factor
1.25        SFSTRC    structure safety factor
2.0         SFLINE    lines safety factor
15*1.5      SFTNK1    tank safety factors - non-conv. tanks
0.0         XMOUNT    engine mounting length adjustment
0           INPEXF    fuel expulsion efficiency flag
0           INPEXO    ox expulsion efficiency flag
0.995       EXPLFL    fuel expulsion efficiency
0.995       EXPLOX    ox expulsion efficiency
0.1         DACQFL    fuel acquisition device density
0.1         DACQOX    ox acquisition device density
0.152       AESSR     forward shroud cross-sect. area
0.25        AFSSR     aft shroud cross-sect. area
1           IPUTMP    Input propellant temperatures?
38.5        TPMINF    fuel min temp
38.5        TPNOMF    fuel nominal temp
40.0        TPMAXF    fuel max temp
0.0         TPMINO    ox min temp
0.0         TPNOMO    ox nominal temp
0.0         TPMAXO    ox max temp
1           LNFULL    Lines full at burnout?
0.0         WMISFL    miscellaneous fuel on-board
0.0         WMISOX    miscellaneous ox on-board
2           NTMPIT    number of temp schedule iterations
0.0         TSPCA     space between aft suspended tank & wall
0.0         TSPCF     space between for. suspended tank & wall
0.0         TSPCP     space between pres. suspended tank & wall
0.0414      RHOINS    pressure tank insulation density
0           KLINEA    propellant feed line flag
0.0         CBM       stage critical bending moment
0.0         CMMAX     max carry moment
0.0         CLRAF     space between aft and forward tank
0.0         CLRFP     space between forward and pressure tanks
0.04        RHPTIN    pressure tank insulation density
0.0         TINSUL    insulation thickness for pressure tank
15*1.0      RATNK1    non-conv. tank usable volume ratios
2.0         CLRTNK    min clearance between non-conv tanks
2.0         ENGSPC    min clearance between nozzles
3           KNEST     non-conv model engine nesting mode
15*1        KTHCK1    non-conv tank thickness mode
5.0         FLKFCT    velocity heads lost in fuel lines
5.0         OXKFCT    velocity heads lost in ox lines
0.0001      RUFFFL    fuel line surface roughness
0.0001      RUFFOX    ox line surface roughness
1.66        GAMICG    pressurant ratio of specific heats (isen)
1.0         GAMPCG    pressurant ratio of specific heats (poly)
240.0       TIMPCG    time at which polytropic ratio is 1.1
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4.0	WTMCG	molecular weight of press. .nt
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.005	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0038	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.3	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
20.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

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              OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

  PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
  ASSUMPTIONS:
              TEMP       ENTHALPY
         LOX  90.18 K   -3093. CAL/MOL
         LH2  20.27 K   -2154. CAL/MOL

     ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
      C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL

     KEY INPUTS

 THRUST LEVEL =                          250000. (lbf)
 CYCLE TYPE =                         BLEED CYCLE
 REACTOR TYPE =                       ENABLER I
 FUEL TYPE =                          COMPOSITE FUEL
 NOZZLE EXIT AREA RATIO =                200.
 PROPELLANT USED =                       LH2
 CHAMBER PRESSURE =                      500. (psia)
 CHAMBER TEMPERATURE =                  4860. (deg R)
 NUMBER OF PROPELLANT FEED LEGS =          3

              TANKAGE SUMMARY FOR STAGE #1
                   BLEED CYCLE
                                            (USER DEFINED GG)
                   AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                   FUEL TANK IS PRESSURIZED WITH COLD GAS
                   TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )  (PRESSURANT - USER DEF )
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.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	1122.72
TOTAL TANK LENGTH	544.20
NOZZLE LENGTH	415.47
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	99.04
TANK HEAD ELLIPSE RATIO	1.38
PRESSURE TANK ELLIPSE RATIO	1.00
AFT TANK HEAD HEIGHT	35.34
FORWARD TANK HEAD HEIGHT	36.04
PRESSURE TANK HEAD HEIGHT	40.04
PRESSURE TANK DIAMETER	80.08
AFT TANK CYLINDRICAL LENGTH	0.00
FORWARD TANK CYLINDRICAL LENGTH	466.84
PRESSURE TANK CYLINDRICAL LNGTH	0.00

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1532.78
PRESSURE TANK	5258.60
TANK CONSTRUCTION WEIGHT	4808.87
STRUCTURAL WALL	30.13
AFT SKIRT	523.47
FORWARD SKIRT	189.41
TANK MOUNT	0.00
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	257.11
OXIDIZER TANK INSULATION	407.04
REVERSE HEAD STIFFENER	184.83
FUEL ACQUISITION SYSTEM	11.31

AFT LINE DIAMETER	0.00	OXIDIZER ACQUISITION SYSTEM	0.00
FORWARD LINE DIAMETER	25.76	PRESSURANT CONTROL HARDWARE	1068.10
AFT SKIRT LENGTH	581.88	TANK LINES	80.37
FORWARD SKIRT LENGTH	38.04		
STRUCTURAL WALL THICKNESS	0.164	BURNED FUEL	8000.00
AFT TANK WALL THICKNESS	0.030	BURNED OXIDIZER	0.00
FORWARD TANK WALL THICKNESS	0.048	FUEL RESIDUAL	138.02
PRESSURE TANK WALL THICKNESS	0.984	OXIDIZER RESIDUAL	0.00
AFT TANK DOME THICKNESS	0.030	STORED PRESSURANT	374.94
FORWARD TANK DOME THICKNESS	0.033	HOLD TIME FUEL BOILOFF	0.00
PRESSURE TANK DOME THICKNESS	0.984	HOLD TIME OX BOILOFF	0.00
		FLIGHT FUEL BOILOFF	744.34
		FLIGHT OXIDIZER BOILOFF	0.00
FUEL TANK MLI THICKNESS	0.02	MISC EXPENDED FUEL	0.00
FUEL TANK SOFI THICKNESS	0.50	MISC EXPENDED OXIDIZER	0.00
OXIDIZER TANK MLI THICKNESS	1.97	MISCELLANEOUS WEIGHT	0.00
OXIDIZER TANK SOFI THICKNESS	0.50	INTERSTAGE WEIGHT	0.00
PRESSURE TANK INSULATION THICK	0.00		

... INPUT MINIMUM SAFETY FACTORS ...

FUEL TNK HEAT FLUX(BTU/HR IN**2)	0.00	STRUCTURAL WALL	1.25
OX TANK HEAT FLUX(BTU/HR IN**2)	0.00	LINES	2.00
FUEL BOILOFF RATE (LB/SEC)	0.003	OXIDIZER TANK	1.25
OX BOILOFF RATE (LB/SEC)	0.000	FUEL TANK	1.25
		PRESSURE TANK	1.50

PROPELLANT SUMMARY FOR STAGE #1
PROPELLANT IS LH2

NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)= 0.0025

.. OXIDIZER ...		... FUEL ...	
NOMINAL TANK PRESSURE(PSIA)	0.0	NOMINAL TANK PRESSURE(PSIA)	35.1
NOMINAL PROPELLANT TEMP(DEGR)	0.0	NOMINAL PROPELLANT TEMP(DEGR)	38.5
NOMINAL DENSITY(LB/IN**3)	0.0000	NOMINAL DENSITY(LB/IN**3)	0.0025
NOMINAL VAPOR PRESSURE(PSIA)	0.0	NOMINAL VAPOR PRESSURE(PSIA)	20.0
MAX PROPELLANT TEMP(DEGR)	0.0	MAX PROPELLANT TEMP(DEGR)	40.0
MAX TEMP DENSITY(LB/IN**3)	0.0000	MAX TEMP DENSITY(LB/IN**3)	0.0025
MAX TEMP VAPOR PRESSURE(PSIA)	0.0	MAX TEMP VAPOR PRESSURE(PSIA)	25.0
MIN PROPELLANT TEMP(DEGR)	0.0	MIN PROPELLANT TEMP(DEGR)	38.5
MIN TEMP DENSITY(LB/IN**3)	0.0000	MIN TEMP DENSITY(LB/IN**3)	0.0025
MIN TEMP VAPOR PRESSURE(PSIA)	0.0	MIN TEMP VAPOR PRESSURE(PSIA)	20.0

ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
BLEED CYCLE
(USER DEFINED GG)
CONVERGENT NOZZLE IS REGEN COOLED (MILLED SLOT CONSTRUCTION)

NOZZLE IS REGEN COOLED (TUBE CONSTRUCTION)
PROPELLANT IS LH2

.. ENGINE DIMENSIONS (INCHES) ...

THROAT DIAMETER	19.03
REACTOR SUPPORT DIAMETER	61.44
PRESSURE VESSEL O.D.	74.65
NOZZLE EXIT DIAMETER	269.19
NOZZLE EXTENSION ATTACH DIAM	46.63
CONVERGENT NOZZLE LENGTH	12.00
CONV. NOZZLE STRUCTURAL THICK.	1.353
GAS SIDE WALL THICKNESS	0.073
NOZZLE EXTENSION THICKNESS	0.010
SECOND NOZZLE EXTENSION THICKNESS	0.100
NOZZLE EXIT AREA RATIO	200.00
CONTRACTION RATIO	7.12
NOZ EXTENSION ATTCH AREA RATIO	6.00
SECOND NOZ EXT ATTACH AREA RATI	25.00
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187
NOZZLE LENGTH	415.47
FEED SYSTEM MOUNT LENGTH	99.04
REACTOR LENGTH	52.00

... PERFORMANCE ...

DELIVERED ISP(VAC),SEC	888.66
IDEAL ISP(ODE),SEC	928.88
DELIVERED CSTAR,FT/SEC	16514.
IDEAL CSTAR,FT/SEC	16597.
CHAMBER PRESSURE,PSIA	500.
THRUST PER ENGINE(VAC),LBF	250000.
TOTAL VAC THRUST,LBF	250000.
BURN TIME,SEC	3600.00
OVERALL EFFICIENCY	0.957
KINETIC EFFICIENCY	0.998
BARRIER COOLING EFFICIENCY	0.995
BOUNDARY LAYER EFFICIENCY	0.996
DIVERGENCE EFFICIENCY	0.993
GG BLEED EFFICIENCY	0.975
FOR 1 ENGINE	
OXIDIZER FLOWRATE,LB/SEC	0.00
FUEL FLOWRATE,LB/SEC	274.17
TOTAL FLOWRATE,LB/SEC	274.17
CORE TEMPERATURE,DEG R	4860.
BARRIER TEMPERATURE,DEG R	1630.
ENGINE MIXTURE RATIO	0.00
FUEL FILM COOLING FRACTION	0.01

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 15.228 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 3.981 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE 0 0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.073
GAS WALL THERMAL CONDUCTIVITY =.00039000 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.113E+04	.632E+02	.656E+00	.138E+03	.306E-01	0.116E+03	.121E+03	.733E-04	.585E-03	.250E+02	.539E+03
2	.113E+04	.636E+02	.545E+00	.201E+03	.517E-01	0.131E+03	.141E+03	.108E-03	.768E-03	.176E+02	.618E+03
3	.113E+04	.641E+02	.433E+00	.319E+03	.974E-01	0.156E+03	.174E+03	.172E-03	.106E-02	.116E+02	.739E+03
4	.113E+04	.651E+02	.322E+00	.582E+03	.219E+00	0.197E+03	.238E+03	.309E-03	.166E-02	.676E+01	.948E+03
5	.112E+04	.673E+02	.211E+00	.139E+04	.684E+00	0.264E+03	.393E+03	.673E-03	.347E-02	.324E+01	.141E+04
6	.773E+03	.712E+02	.100E+00	.723E+04	.254E+01	0.250E+03	.726E+03	.281E-02	.142E-01	.100E+01	.163E+04

7	.765E+03	.718E+02	.146E+00	.342E+04	.177E+01	0.314E+03	.645E+03	.179E-02	.730E-02	.178E+01	.163E+04
8	.763E+03	.723E+02	.193E+00	.199E+04	.126E+01	0.351E+03	.587E+03	.121E-02	.452E-02	.278E+01	.163E+04
9	.763E+03	.728E+02	.239E+00	.131E+04	.939E+00	0.376E+03	.552E+03	.872E-03	.310E-02	.401E+01	.163E+04
10	.762E+03	.732E+02	.285E+00	.926E+03	.727E+00	0.393E+03	.529E+03	.661E-03	.227E-02	.545E+01	.163E+04
11	.762E+03	.736E+02	.332E+00	.691E+03	.580E+00	0.405E+03	.514E+03	.520E-03	.175E-02	.712E+01	.163E+04

DELTA T= 10.4
DELTA P= -364.9
NOZZLE DELTA T = 9.6
NOZZLE DELTA P = -364.5
ADAPTER DELTA T = 0.8
ADAPTER DELTA P = -0.4
TOTAL HEAT TRANSFER = 6250.4 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
BLEED CYCLE
(USER DEFINED GG)

	PRESSURE(PSIA) FUEL		PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL		TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		4365.0	550.0		550.0	
VENT	38.6		0.0	43.2		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.1		0.0	——		——	
... PROPELLANT ...							
TANK PROPELLANT	35.1		0.0	38.5		0.0	
PUMP INLET	35.0		0.0	39.6		0.0	
MAIN VALVE INLET	1178.7		0.0	63.5		0.0	
MAIN VALVE OUTLET	1127.1		——	63.5		——	
COLD BLEED VALVE IN	1178.7		——	63.5		——	
COLD BLEED VALVE OUT	547.5		——	63.5		——	
TIE TUBE OUTLET	737.1		——	826.4		——	
REGEN OUTLET (REFL I	762.1		——	73.9		——	
REFLECTOR OUTLET	737.1		——	157.8		——	
REACTOR INLET		737.1			325.3		
REACTOR CORE		500.0			4860.0		
CHAMBER BLEED	500.0		——	4860.0		——	
MIXER OUTLET	465.0		——	1400.0		——	
TURB THROT VALVE IN		432.5			1400.0		
TURBINE INLET		397.9			1400.0		
TURBINE OUTLET		20.0			545.7		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
ACQUISITION DEVICE	0.0	0.0		
FEED LINE	0.1	0.0	0.0	0.0
PUMP	1143.6	0.0	25.0	0.0
MAIN VALVE	51.6	0.0	0.0	0.0
HOT BLEED LINE	35.0	——	0.0	——
COLD BLEED LINE	82.5	——	0.0	——
COLD BLEED VALVE	631.1	——	0.0	——
TURBINE INLET LINE	32.5	——	0.0	——
TURB THROTTLING VALV	34.6	——	0.0	——
TIE TUBES	250.0	——	762.9	——
REGEN JACKET	364.9	——	10.4	——
REFLECTOR	25.0	——	83.9	——
TURBINE				
	377.9		854.3	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
BLEED CYCLE

(USER DEFINED GG)

	FUEL		OXIDIZER
TANK OUTFLOW	281.321		0.000
MAIN PUMP - EACH	93.774		0.000
COLD BLEED FLOW-EACH LEG	2.657		——
MAIN VALVE	273.350		0.000
TOTAL TIE TUBES	81.093		——
REGEN JACKET INFLOW	192.256		——
NOZZLE BARRIER COOLING		3.038	
REGEN/REFL OUTLET TO CORE	189.218		——
MIXER OUTLET-EACH	3.232		0.000
TURBINE - EACH		3.232	
BLEED NOZZLE - EACH		3.232	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.10	
CORE	270.312		——
CHAMBER (HOT) BLEED FLOW	1.725		——
NOZZLE OUTFLOW	268.586		——

BLEED CYCLE FLOW RATIOS

OVERALL BLEED FLOW FRACTION	0.034
OVERALL HOT BLEED FRACTION	0.006
OVERALL COLD BLEED FRACTION	0.028
HOT SIDE FRACTION OF TOTAL BLEED	0.178
COLD SIDE FRACTION OF TOTAL BLEED	0.822

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	270.31	LB/SEC
REACTOR POWER	5403.12	MW

CORE FLOW AREA	675.28	IN2
CORE MASS FLOW RATE	0.40	LB/IN2
FUEL ELEMENT POWER	1.20	MW/Element
FUEL ELEMENT OPERATING LIFE	1.79	HR
NUMBER OF FUEL ELEMENTS	4349.52	
NUMBER OF SUPPORT ELEMENTS	760.92	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	500.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	325.29	DEG R
CORE INLET PRESSURE	737.14	PSIA
CORE INLET ENTHALPY	1008.20	BTU/LB
HEAT PICKUP PER TIE TUBE	0.31	MW/TUBE
HEAT PICKUP IN TIE TUBES	223618.92	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	6244.61	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	
HEAT PICKUP IN REFLECTOR	62490.37	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	8861.34	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	1587.87	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4944.82	DEG R
PEAK FUEL TEMPERATURE	5077.92	DEG R

REACTOR DIMENSIONS

CORE LENGTH	52.00	IN
CORE DIAMETER	58.16	IN
FUEL ELEMENT CHANNEL DIAMETER	0.11	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	56.53	IN
LATERAL SUPPORT DIAMETER	61.44	IN
STRUCTURE OD	63.64	IN
REFLECTOR OD	73.21	IN
PRESSURE VESSEL ID	73.53	IN
PRESSURE VESSEL OD	74.65	IN
THICKNESS OF BATH SHIELD	12.49	IN
THICKNESS OF LEAD SHIELD	1.32	IN
PRESSURE VESSEL LENGTH	101.61	IN
FUEL VOLUME	75947.19	IN3

REACTOR MASSES

FUEL MASS	10480.71	LB
SUPPORT MASS	1957.53	LB
CORE PERIPHERY MASS	658.29	LB
LATERAL SUPPORT MASS	587.65	LB
STRUCTURE MASS	1170.99	LB
REFLECTOR MASS	3589.08	LB
HOT END HARDWARE MASS	396.80	LB
AFT REFLECTOR MASS	104.26	LB
CORE INLET PLENUM MASS	553.34	LB
SUPPORT PLATE MASS	1530.53	LB
LATERAL SUPPORT FORWARD MASS	77.95	LB
REFLECTOR HARDWARE FORWARD MASS	184.69	LB
SUPPORT PLATE PLENUM MASS	121.92	LB
INSTRUMENTATION RING MASS	55.69	LB
FORWARD REFLECTOR HARDWARE MASS	36.59	LB
SUBTOTAL CORE A	21506.01	LB
FLOW BAFFLE MASS	0.00	LB

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FLOW BAFFLE 1 MASS                               0.00  LB
TOTAL CORE SUBSYSTEM MASS                    21506.01  LB
PRESSURE VESSEL A MASS                         938.30  LB
PRESSURE VESSEL B MASS                         354.93  LB
PRESSURE VESSEL DOME MASS                      242.70  LB
NOZZLE/REACTOR ADAPTER MASS                    120.12  LB
TOTAL PRESSURE VESSEL MASS                    1656.04  LB
BATH CENTRAL SHIELD MASS                      3325.20  LB
BATH PERIPHERAL SHIELD MASS                   1221.05  LB
BATH PERIPHERAL SHIELD 2 MASS                  403.49  LB
LEAD CENTRAL SHIELD MASS                      1201.26  LB
LEAD PERIPHERAL SHIELD MASS                      0.33  LB
LEAD PERIPHERAL SHIELD 2 MASS                    0.13  LB
PERIPHERAL SHIELD PLATE MASS                    66.85  LB
TOTAL SHIELD MASS                             6218.31  LB
REACTOR MASS w/o SHIELD                      23162.05  LB
REACTOR MASS w/ SHIELD                       29380.36  LB
SAFETY RODS-FOR LAUNCH ONLY                   2034.45  LB
REACTOR MASS w/o SHIELD-LAUNCH WT.           25196.50  LB
REACTOR MASS w/ SHIELD-LAUNCH WT.            31414.81  LB


        * * *   TPA SUMMARY FOR STAGE #1    * * *
            BLEED CYCLE
                                          (USER DEFINED GG)
              3 PROPELLANT FEED LEGS
            AXIAL PUMPS
            TPA SIZE/WT/PERFORMANCE IS USER DEFINED


 ... PROPELLANT PUMP ...

     PUMP SPEED (RPM)                   17065.
     SPECIFIC SPEED                      2417.
     INDUCER SPECIFIC SPEED              5871.
     SUCTION SPECIFIC SPEED             20000.
     NUMBER OF PUMP STAGES                  6.+ INDUCER
     NET POS SUCTION PRESSURE(PSIA)        67.99
     ACCELERATION HEAD(PSIA)                0.00
     PUMP OUTLET PRESSURE(PSIA)          1178.65
     VOLUMETRIC FLOWRATE(GPM)            9594.67
     MASS FLOWRATE(LBM/SEC)                93.77
     PUMP HORSEPOWER(HP)                 8192.84
     PUMP EFFICIENCY                        0.780
     INDUCER EFFICIENCY                     0.832
     OVERALL PUMP EFFICIENCY                0.782
     PUMP DIAMETER(IN)                      8.91
     PUMP WT.(LB) - EACH PUMP             490.56
     INDUCER WT.(LB) - EACH               157.58
     OVERALL PUMP WT.(LB) - EACH          648.15


 ... TURBINE ...

     ADMISSION FRACTION                     1.000
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EFFICIENCY	0.663
PRESSURE RATIO	19.893
MASS FLOWRATE(LB/SEC)	3.23
DIAMETER(IN)	39.75
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	53286.
ROOT STRESS SPEED LIMIT(RPM)	29154.
SPECIFIC SPEED	8.
TURBINE SPEED(RPM)	17065.
TURBINE WT(LB) - EACH TURBINE	1503.12
TURBINE ANNULUS AREA(IN2)	45.477
U OVER C	0.34
INLET MACH NUMBER	1.22

... TPA ...

TPA START SYSTEM WT.	0.00
GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	48.36
HOT GAS MANIFOLD WT.-TOTAL	86.71
GEARBOX WT.-TOTAL	0.00
CHAMBER BLEED LINE WT.	255.36
COLD BLEED LINE WT.-EACH	2.62
TURBINE INLET LINE WT.-EACH	94.63
COLD BLEED VALVE WT.-EACH	2.68
TURBINE THROTTLING VALVE WT.-EA	117.08
MIXER WT.-EACH	26.91
TOTAL BLEED CYCLE LINE/VALVE WT	987.10
MAIN TURBOPUMP WT. - EACH	2151.27
TOTAL TURBOPUMP WT.	6453.80
TOTAL TPA WT.	7575.97

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	1532.78
PRESSURE TANK	5258.60
TANK CONSTRUCTION WEIGHT	4808.87
TANK LINES	80.37
AFT SKIRT	523.47
FORWARD SKIRT	189.41
TANK MOUNT	0.00
STRUCTURAL WALL	30.13
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	257.11
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.31
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	1068.10
ENGINE WEIGHTS:	
1 REACTOR	23162.05
1 REACTOR INTERNAL SHIELD	6218.31
1 NOZZLE	2519.96
1 THRUST MOUNT(S)	3907.32

1 GIMBAL SYSTEM(S)	126.59
3 ENGINE BAY LINE(S)	810.09
3 MAIN VALVE(S)	2941.39
1 SUPPORT HARDWARE	721.18
1 GIMBAL POWER SUPPLY	689.24
3 IGNITION SYSTEM(S)	48.36
3 HOT GAS MANIFOLD(S)	86.71
3 GAS GENERATOR/PREBURNER	0.00
3 TPA ASSY(S)	7440.90
1 GEARBOX(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	385.83
TOTAL ENGINE WEIGHT	49057.93
FLIGHT FUEL BOILOFF	744.34
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
USER DEF. TPA DRIVE FLUID	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	2034.45
TOTAL INERT WEIGHT	65055.02
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	138.02
OXIDIZER RESIDUAL	0.00
STORED PRESSURANT	374.94
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00
GROSS IGNITION WEIGHT	73567.98
GROSS BURNOUT WEIGHT	62789.19
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

STAGE #1

..DIMENSIONS,IN..

STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	269.19

NUMBER OF NOZZLES	1
STAGE LENGTH	1122.72
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	1122.72

..PERFORMANCE..

PROPELLANT	LOX/LH2
THRUST, VACUUM DELIVERED, LBF	250000.0
PC, PSIA	500.0
NOZZLE AREA RATIO	200.00
BURN TIME, SEC	3600.00
ISP, VACUUM DELIVERED, SEC	888.7
ISP EFFICIENCY	0.957
TOTAL PROP. FLOWRATE, LB/SEC	281.32
CORE PROP. FLOWRATE, LB/SEC	270.31

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 250000.
BLEED CYCLE

	PRESSURE(PSIA) FUEL		PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL		TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...							
MAX STORAGE	4365.0		4365.0	550.0		550.0	
VENT	38.6		0.0	43.2		0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	35.1		0.0	—		—	
... PROPELLANT ...							
TANK PROPELLANT	35.1		0.0	38.5		0.0	
PUMP INLET	35.0		0.0	39.7		0.0	
MAIN VALVE INLET	1170.9		0.0	61.8		0.0	
MAIN VALVE OUTLET	1119.3		—	61.8		—	
COLD BLEED VALVE IN	1170.9		—	61.8		—	
COLD BLEED VALVE OUT	547.0		—	61.8		—	
TIE TUBE OUTLET	737.1		—	822.5		—	
REGEN OUTLET (REFL I	762.1		—	72.5		—	
REFLECTOR OUTLET	737.1		—	156.0		—	
REACTOR INLET		737.1			325.3		
REACTOR CORE		500.0			4860.0		
CHAMBER BLEED	500.0		—	4860.0		—	
MIXER OUTLET	465.0		—	1400.0		—	
TURB THROT VALVE IN		432.5			1400.0		
TURBINE INLET		397.9			1400.0		
TURBINE OUTLET		20.0			545.7		

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID)			TEMPERATURE CHANGES (DEG R)		
ACQUISITION DEVICE	0.0	0.0				
FEED LINE	0.1	0.0		0.0	0.0	
PUMP	1135.9	0.0		23.3	0.0	
MAIN VALVE	51.6	0.0		0.0	0.0	
HOT BLEED LINE	35.0	—		0.0	—	
COLD BLEED LINE	82.0	—		0.0	—	
COLD BLEED VALVE	624.0	—		0.0	—	
TURBINE INLET LINE	32.5	—		0.0	—	
TURB THROTTLING VALV	34.6	—		0.0	—	
TIE TUBES	250.0	—		760.6	—	
REGEN JACKET	357.2	—		10.6	—	
REFLECTOR	25.0	—		83.5	—	
TURBINE			377.9			854.3

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
BLEED CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	280.732		0.000
MAIN PUMP - EACH	140.366		0.000
COLD BLEED FLOW—EACH LEG	3.599		—
MAIN VALVE	273.534		0.000
TOTAL TIE TUBES	81.149		—
REGEN JACKET INFLOW	192.385		—
NOZZLE BARRIER COOLING		3.038	
REGEN/REFL OUTLET TO CORE	189.347		—
MIXER OUTLET-EACH	4.384		0.000
TURBINE - EACH		4.384	
BLEED NOZZLE - EACH		4.384	
TURBINE TO CORE	0.000		0.000
STORED PRESSURANT (AVE)		0.10	
CORE	270.495		—
CHAMBER (HOT) BLEED FLOW	1.569		—
NOZZLE OUTFLOW	268.927		—

BLEED CYCLE FLOW RATIOS

OVERALL BLEED FLOW FRACTION	0.031
OVERALL HOT BLEED FRACTION	0.006
OVERALL COLD BLEED FRACTION	0.026
HOT SIDE FRACTION OF TOTAL BLEED	0.179
COLD SIDE FRACTION OF TOTAL BLEED	0.821

* * * TPA SUMMARY FOR STAGE #1 * * *
SUMMARY FOR TPA AT THRUST LEVEL FRACTION 1.00
BLEED CYCLE
2 PROPELLANT FEED LEGS
AXIAL PUMPS

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	19978.
SPECIFIC SPEED	3500.
INDUCER SPECIFIC SPEED	8503.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	6.+ INDUCER
NET POS SUCTION PRESSURE(PSIA)	67.63
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1170.93
VOLUMETRIC FLOWRATE(GPM)	14535.93
MASS FLOWRATE(LBM/SEC)	140.37
PUMP HORSEPOWER(HP)	11660.17
PUMP EFFICIENCY	0.830
INDUCER EFFICIENCY	0.766
OVERALL PUMP EFFICIENCY	0.827
PUMP DIAMETER(IN)	8.91
PUMP WT.(LB) - EACH PUMP	490.56
INDUCER WT.(LB) - EACH	157.58
OVERALL PUMP WT.(LB) - EACH	648.15

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.700
PRESSURE RATIO	19.893
MASS FLOWRATE(LB/SEC)	4.38
DIAMETER(IN)	39.75
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	53286.
ROOT STRESS SPEED LIMIT(RPM)	29154.
SPECIFIC SPEED	10.
TURBINE SPEED(RPM)	19978.
TURBINE WT(LB) - EACH TURBINE	1503.12
TURBINE ANNULUS AREA(IN2)	45.477

ENGINE SUMMARY

BLEED CYCLE				
ENABLER I				
AXIAL PUMPS				
THRUST LEVEL =	250000.0	lbf	1112000.0	N
CHAMBER PRESSURE =	500.0	psia	3447.5	kPa
CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	200.0		200.0	
NUMBER OF FEED LEGS =	3		3	
TOTAL PROPELLANT FLOWRATE =	281.3	lbm/s	127.6	kg/s
REACTOR				
COMPOSITE FUEL				
REACTOR WEIGHT	23162.0	lbm	10504.3	kg
SHIELD WEIGHT	6218.3	lbm	2820.1	kg
PRESSURE VESSEL DIA.	74.7	in	189.6	cm
PRESSURE VESSEL LENGTH	101.6	in	258.1	cm
CORE PROPELLANT MASS FLOW	270.3	lbm/sec	122.6	kg/sec

NOZZLE				
CONVERGING NOZZLE WEIGHT	646.1	lbm	293.0	kg
NOZZLE EXTENSION WEIGHT	391.8	lbm	177.7	kg
SECOND NOZZLE EXTENSION WEIGHT	1482.0	lbm	672.1	kg
TOTAL NOZZLE WEIGHT	2520.0	lbm	1142.8	kg
AREA RATIO	200.0		200.0	
THROAT DIAMETER	19.0	in	48.3	cm
EXIT DIAMETER	269.2	in	683.7	cm
NOZZLE LENGTH	415.5	in	1055.3	cm
DELIVERED VACUUM ISP	888.7	sec	8708.9	N-sec/kg
DELIVERED THRUST	250000.0	lbf	1112000.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	6453.8	lbm	2926.9	kg
PROPELLANT BOOST PUMP WT	0.0	lbm	0.0	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	48.4	lbm	21.9	kg
BLEED LINE/VALVE WEIGHT	987.1	lbm	447.7	kg
GAS GENERATOR	0.0	lbm	0.0	kg
HOT GAS MANIFOLD	86.7	lbm	39.3	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	3907.3	lbm	1772.0	kg
SUPPORT HARDWARE	721.2	lbm	327.1	kg
ENGINE LINES	810.1	lbm	367.4	kg
MAIN VALVE	2941.4	lbm	1334.0	kg
GIMBAL + POWER SUPPLY	815.8	lbm	370.0	kg
MARGIN (2.0%)	385.8	lbm	175.0	kg
TOTAL NONNUCLEAR WEIGHT	19677.6	lbm	8924.1	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	49057.9	lbm	22248.5	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	42839.6	lbm	19428.4	kg
THRUST/WEIGHT RATIO WITH SHIELD	5.1	lbf/lbm	50.0	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	5.8	lbf/lbm	57.2	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	2034.5	lbm	922.7	kg
TOTAL ENGINE LAUNCH WEIGHT	51092.4	lbm	23171.1	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	44874.1	lbm	20351.0	kg
PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	250000.0	lbf	1112000.0	N
PUMP-OUT CHAMBER PRESSURE	500.0	psia	3447.5	kPa
PUMP-OUT ISP	890.5	sec	8727.2	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	616.1	in	1565.0	cm
OVERALL ENGINE DIAMETER =	269.2	in	683.7	cm

WARNING

```
                    THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR =  7.123          RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM =  269.2     STAGE DIAM =  100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS  FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET

END NOMINAL STAGE DESIGN
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Table 4-9. Sample Case No. 8

Input Listing

Nuclear Thermal Vehicle

75000.	FVAC	Vacuum thrust (lbf)
1000.	PC	Chamber pressure (psia)
5	IPROP	Propellant flag
0.0	WPAYLD	Vehicle payload wt.
0.0	WMISC	Miscellaneous stage wt.
0.0	WEXPND	Expendable stage wt.
3	KCYCLE	Cycle type (1=GG,3=Expander,7=Bleed)
2	JCNFIG	Pump configuration
1	IPTYPE	Pump type (0=centr., 1=axial)
1	ISOLVE	Bleed cycle solver (see worksheet)
0.0	TURBTIN	Turbine inlet temp (ISOLVE=1)
0.0	FRACHB	Hot bleed fraction (ISOLVE=0)
0.0	FRACCB	Cold bleed fraction (ISOLVE=0)
0.0	CPLINH	Hot bleed line loss fraction
0.0	CPLINC	Cold bleed line loss fraction
0.0	CPLINT	Turbine inlet line loss fraction
0.0	CPVLVT	Turbine throttling valve loss frac.
0	JBPFL	Use fuel boost pump?
0	JBPOX	Use ox boost pump?
2	NTPA	Number of identical turbopumps
1	IDBLRUN	Double run flag
0.8	FFRAC	Thrust fraction
0	ITRATE	Double run solver
1	IUSRBRN	Input engine burn time?
3600.0	TUSRBRN	Engine burn time
0.02	FMARG	Margin weight fraction
1.0	XLFL	Barrier liquid film length
0.15	ALFMIX	Barrier mixing angle
500.	EPS	Engine area ratio
1	KEXNOZ	Use a nozzle extension?
1	NOZTYP	Use a 3-portion nozzle?
6.	EPSATT	Nozzle extension 1 attach area ratio
150.	EPSAT2	Nozzle extension 2 attach area ratio
12.0	XLN	Convergent nozzle length
2	KNOZ	Type of nozzle
0	IPLUG	Use plug nozzle?
1.1868	RATMLR	Nozzle length ratio
0.0	OFGGPB	GG mixture ratio
1.48	GAMGPB	GG ratio of specific heats
4.2	CPGGPB	GG specific heat
2.016	WMGGPB	GG molecular weight
4860.	TCHAMBER	Chamber temperature
1	IREACTR	Reactor model flag (1=enabler1,2=enabler2)
1	CONFIG	Flow path flag (1=old,2=new)
0.11	DC	Fuel element chamber diameter
0.173	SC	Spacing between holes
1.2	PAC	Peak to average channel factor
19.0	HOLES	Number of holes per element
2	FTYPE	Fuel type
3	SPAT	Support pattern
52.0	LC	Core length
1.2	PMW	Power in each element (MW per 52 inches)
0.7	NFF	Nozzle flow fraction
0.31	QTT	Heat pickup per tie tube
-106.0	HTANK	Enthalpy of coolant entering system
0.0122	FREF	Fractional heat pickup in reflector
0.00031	FES	Fractional heat pickup in ext shield
0.00173	FCS	Fractional heat pickup in cent shield
0.67	FALPHA	Fuel scaling fraction

0.750	HEX	Uncoated fuel hex flat dim...sion
52.0	LEL	Scalable fuel element (overrides LC)
0.002	ZRCI	Channel coating thickness at inlet
0.006	ZRCO	Channel coating thickness at outlet
0.0015	ZRCH	Element external coating thickness
2.74	PVSG	Pressure vessel material specific grav.
50000.	PVSA	Pressure vessel mat. allowable stress
4.785	TREFL	Beryllium reflector thickness
0.0	FZRH	Fraction of max ZrH loading in tie tubes
8000.	WTLPRP	Burned propellant wt.
0.02	ULLFOX	Ox ullage fraction
0.02	ULLFFL	Fuel ullage fraction
6	KACQOX	Ox acquisition device
6	KACQFL	Fuel acquisition device
1	KGASOX	Ox tank pressurization
0	KGASFL	Fuel tank pressurization
2	KGAS	Type of non-autogenous pressurization
4365.	PICG	Cold helium storage pressure
0.8	FPULCG	Helium tank final pressure fraction
2	KHXOPT	Propellant tank heat transfer
0.5	TSOFIF	Fuel tank SOFI thickness
0.018	TMLIF	Fuel tank MLI thickness
0.5	TSOFIO	Ox tank SOFI thickness
1.97	TMLIO	Ox tank MLI thickness
60.0	TMIN	Minimum stage operating temperature
75.0	TOP	Nominal stage operating temperature
90.0	TMAX	Maximum stage operating temperature
2	KOOLNZ	Nozzle cooling method
1460.0	TGWNOM	Nominal conv. wall material temp.
1	IRPRNT	Output a regen summary?
0.01275	GWMING	Gas wall minimum gauge
0.00039	WALLK	Gas wall thermal conductivity
0.05	DIFTBF	see worksheet
2000.0	TNENOM	Nominal nozzle material temp
0.07	CPVLVO	Pressure drop across ox valve
0.07	CPVLVF	Pressure drop across fuel valve
0.01	CPLINO	Pressure drop across ox lines
0.01	CPLINF	Pressure drop across fuel lines
0	KTRNOZ	Translating nozzle?
150.	EPTRAT	Translating nozzle attach area ratio
1	NGIMB	Number of gimballing engines
6.0	GMBANG	Gimbal angle
0.322	RHCSTR	Convergent nozzle density
25000.0	SIGCNM	Convergent nozzle strength
0.322	RHOCLS	Regen closeout material density
25000.0	SIGCLS	Regen closeout material strength
0.322	RHOGW	Regen gas wall density
0.298	RHOVLV	Valve material density
0.298	RHONZE	Nozzle extension 1 density
37000.0	SIGNZE	Nozzle extension 1 strength
0.01	TNZMIN	Nozzle extension 1 minimum thickness
0.061	RHONZ2	Nozzle extension 2 density
50000.0	SIGNZ2	Nozzle extension 2 strength
0.1	TNZMN2	Nozzle extension 2 minimum thickness
0.28	ROTRNZ	Translating nozzle density
1	KWTMOD	Engine weight model
0.0	XLNOZ	Input nozzle length
0.0	WTLTCA	Input engine weight
1.0	THDUSR	Input nozzle throat diameter
0.71	BYPTUR	Turbine bypass fraction

1.0	CHMULT	Cooling channel multiplie.
0.00008	EPIPE	Regen channel surface roughness
3.2	HOWMAX	Max depth to width ratio
5	NCON	Number of regen segments in conv. sec.
5	NNZL	Number of regen segments in nozzle
1.0	SAMULT	surface area multiplier
0.04	WLTHR	Cooling channel land width
0.10	WTHR	Cooling channel width
0	INDPDT	Input regen delta T and P?
0.0	DELTAT	Input regen total delta T
0.0	DELTAP	Input regen total delta P
25.0	FLNPSP	Fuel NPSP
10.0	OXNPSP	Ox NPSP
1.0	ADJGGB	GG bleed efficiency adjustment
0.2	ADJBL	Boundary layer efficiency adjustment
1.0	ADJDIV	Divergence efficiency adjustment
1.0	ADJMRD	Barrier cooling efficiency adjustment
1.7	CXWTNK	Weight multiplier; all tanks
15*1.0	CXNCT1	Weight multiplier; non-conv. tanks
1.7	CXWFLT	Weight multiplier; fuel tank
1.7	CXWOXT	Weight multiplier; ox tank
1.7	CXWPTN	Weight multiplier; pres. tank
1.0	CXWSTR	Weight multiplier; structure
1.0	CXWATL	Weight multiplier; aft tank lines
1.0	CXWFTL	Weight multiplier; forward tank lines
1.0	CXWPTL	Weight multiplier; pres. tank lines
1.0	CXWENG	Weight multiplier; nozzle + hardware
2.8	CXVALV	Weight multiplier; valves
1.0	CXWCHM	Weight multiplier; convergent nozzle
1.1	CXWNZE	Weight multiplier; nozzle extension
3.5	CXWDUC	Weight multiplier; hot gas ducts
1.4	CXWGIM	Weight multiplier; gimbal
0.9	CXWTHM	Weight multiplier; thrust mount
1.4	CXWIGG	Weight multiplier; GG injector
1.3	CXWTPA	Weight multiplier; turbines
5.75	CXWPMP	Weight multiplier; pumps
2.5	CXWLIN	Weight multiplier; engine bay lines
0.25	CXWPNEU	Weight multiplier; pneumatic system
1.0	CXWINST	Weight multiplier; instrumentation
0.9	CXWTNKAS	Weight multiplier; reactor cooldown
1.3	CXWIGN	Weight multiplier; ignition system
0	ISTSET	Input turbomachinery characteristics?
1	PSTAGF	number of fuel pump stages
1	PSTAGO	number of ox pump stages
0.0	PDIAFL	fuel pump diameter
0.0	PDIAOX	ox pump diameter
0.0	BPDIAF	fuel boost pump diameter
0.0	BPDIAO	ox boost pump diameter
1	TSTGES	number of turbine stages
1	TSTAGF	number of fuel turbine stages
1	TSTAGO	number of ox turbine stages
0.0	TDIAM	turbine diameter
0.0	TDIAFL	fuel turbine diameter
0.0	TDIAOX	ox turbine diameter
1.0	ADMFR	turbine admission fraction
1.0	ADMFRF	fuel turbine admission fraction
1.0	ADMFRO	ox turbine admission fraction
0.0	ANAREA	turbine annulus area
0.0	ANARFL	fuel turbine annulus area
0.0	ANAROX	ox turbine annulus area

0	INPTPA	Input turbopump assembly w ghts?
0.0	TPAWT	total TPa weight
0.0	WSTART	TPA start system weight
0.0	WIGNIT	Ignition system weight
0.0	WHGMF	hot gas manifold weight
0.0	WGBOX	gear box weight
0.0	WTHTX	heat exchanger weight
0.0	WGGPB	GG/preburner weight
0	IUSRGG	Have user-defined gas generator?
0.1	WDBLNZ	bleed nozzle flowrate
0.99	ETAGGB	GG bleed efficiency
5000.0	TTLIMT	max turbine temperature
0.0	TUSRGG	turbine/GG inlet temp.
0.0	WDUSRG	turbine flowrate
0.0	USRGGI	Isp of GG bleed
0.0	PUSRTI	turbine inlet pressure
10.0	WPUSRG	user defined drive fluid weight
10.0	WIUSRG	user defined drive fluid tank weight
0.01	ROUSRG	density of drive fluid
25000.0	SYUSRG	yield stress of drive fluid tank
0.098	ROUSMT	density of drive fluid tank material
2	IDTRAN	transpiration cooling criteria
1.0	QMAXTR	max heat flux before transp. cooling
2.0	EPSTRU	upstream area ratio for transp.
1.2	EPSTRD	downstream area ratio for transp.
0.08	TGEOH	etched platelet thickness
0.1	TGEOL	platelet land thickness
0.04	TGEOS	separator platelet thickness
0.14	TGEOW	flow passage widths
0.28	RHTRIN	transp. cooling insert density
0.3	TRINST	transp. cooling insert thickness
0.0004	TRANKM	transp. cooling insert conductivity
0	NCTNK	Use non-conventional tanks?
1	MNCQA	Aft tank monocoque?
1	MNCQF	Forward tank monocoque?
0	KDOME	tank dome types
0	KPRESS	pressure tank geometry
1	NPRB	number of pressure bottles
1.38	ELDOME	propellant tank head ellipse ratio
1.0	ELRP	pressurant tank head ellipse ratio
1	KXATAH	propellant tank dome orientation
-1	KXATFH	propellant tank dome orientation
-1	KXFTAH	propellant tank dome orientation
-1	KXFTFH	propellant tank dome orientation
0	KPRPA	propellant location
0	NTANKS	number of non-conventional tanks
15*1.0	ELTNK1	tank ellipse ratios
15*1	KTANK1	tank types
15*1	INTNK1	tank contents
15*0.0	TANGL1	tank angular location
15*1.0	RADLO1	tank radial location
0	KALMOD	kind of dimensional input
15*2.0	RDIM1	Lcyl/D
15*0.0	RMAJ1	tank radius
5*0.0	ENGAN1	engine angular location
5*0.0	ENGRD1	engine radial location
100.0	DMOTOR	stage diameter
1.0	FFSKTL	forward skirt length
1.0	FASKTL	aft skirt length
11	MTNKFL	fuel tank material

1	MTNKOX	ox tank material
2	MATPT	pressure tank material
11	MATSTR	structure and skirts material
15*11	MATNK1	tank materials (non-conventional tanks)
0.29	RHO	user defined tank material density
29.0E6	YMOD	user defined tank material elastic mod.
112300.0	SIGMAX	user defined tank material strength
0.12	SPHEAT	user defined tank material specific heat
0.00023	CONDCT	user defined tank material conductivity
0.035	TMING	user defined tank material min gauge
0.035	TMINGS	user defined material structural min gauge
1.25	SFFLTK	fuel tank safety factor
1.25	SFOXTK	ox tank safety factor
1.5	SFPRTK	pressure tank safety factor
1.25	SFSTRC	structure safety factor
2.0	SFLINE	lines safety factor
15*1.5	SFTNK1	tank safety factors - non-conv. tanks
0.0	XMOUNT	engine mounting length adjustment
0	INPEXF	fuel expulsion efficiency flag
0	INPEXO	ox expulsion efficiency flag
0.995	EXPLFL	fuel expulsion efficiency
0.995	EXPLOX	ox expulsion efficiency
0.1	DACQFL	fuel acquisition device density
0.1	DACQOX	ox acquisition device density
0.152	AESSR	forward shroud cross-sect. area
0.25	AFSSR	aft shroud cross-sect. area
1	IPUTMP	Input propellant temperatures?
38.5	TPMINF	fuel min temp
38.5	TPNOMF	fuel nominal temp
40.0	TPMAXF	fuel max temp
0.0	TPMINO	ox min temp
0.0	TPNOMO	ox nominal temp
0.0	TPMAXO	ox max temp
1	LNFULL	Lines full at burnout?
0.0	WMISFL	miscellaneous fuel on-board
0.0	WMISOX	miscellaneous ox on-board
2	NTMPIT	number of temp schedule iterations
0.0	TSPCA	space between aft suspended tank & wall
0.0	TSPCF	space between for. suspended tank & wall
0.0	TSPCP	space between pres. suspended tank & wall
0.0414	RHOINS	pressure tank insulation density
0	KLINEA	propellant feed line flag
0.0	CBM	stage critical bending moment
0.0	CMMAX	max carry moment
0.0	CLRAF	space between aft and forward tank
0.0	CLRFP	space between forward and pressure tanks
0.04	RHPTIN	pressure tank insulation density
0.0	TINSUL	insulation thickness for pressure tank
15*1.0	RATNK1	non-conv. tank usable volume ratios
2.0	CLRTNK	min clearance between non-conv tanks
2.0	ENGSPC	min clearance between nozzles
3	KNEST	non-conv model engine nesting mode
15*1	KTHCK1	non-conv tank thickness mode
5.0	FLKFCT	velocity heads lost in fuel lines
5.0	OXKFCT	velocity heads lost in ox lines
0.0001	RUFFFL	fuel line surface roughness
0.0001	RUFFOX	ox line surface roughness
1.66	GAMICG	pressurant ratio of specific heats (isen)
1.0	GAMPCG	pressurant ratio of specific heats (poly)
240.0	TIMPCG	time at which polytropic ratio is 1.1

4.0	WTMCG	molecular weight of pressurant
3.0	APATGG	solid GG min port to throat area ratio
1.5	BTEQGG	solid GG equilibrium temp ratio
0.095	CBRGG	solid GG burn rate coefficient
1.25	CDESGG	solid GG design complexity multiplier
3932.0	CSGG	solid GG grain characteristic velocity
3.0	DMINSG	solid GG min allowable grain diameter
0.64	EBRGG	solid GG grain burn rate exponent
0.2662	FH2OGG	solid GG combustion product water fract.
1.1	FPULGG	solid GG ullage pressure multiplier
1.27	GAMGG	combustion product specific heat ratio
0.0036	PIPKGG	temperature sensitivity of GG pressure
0.056	RHOGG	solid GG grain density
0.0013	SIGGG	solid grain burn rate temp sensitivity
2130.0	TCMBGG	solid GG combustion temperature
100.0	TDCYGG	solid GG temp decay time constant
80.0	TREFGG	solid GG ref temp for burn rate coef.
19.0	WTMGG	solid GG molecular weight of comb. prod.
0.0464	BPFRFL	boost pump fraction of total head rise
0.0464	BPFROX	boost pump fraction of total head rise
0.65	CVMLTF	GG control valve pressure drop multiplier
1.2	PBPRF	fuel pressure ratio across GG
1.2	PBPRO	ox pressure ratio across GG
20.0	PTURBO	turbine outlet pressure (for GG)
2	KPUMP	TPA/engine assignments
100.0	TULLFL	autogenous fuel pressurant temp
0.0	TULLOX	autogenous ox pressurant temp
20000.0	SSSFL	fuel pump suction specific speed
20000.0	SSSOX	ox pump suction specific speed
20000.0	SSSBPF	fuel boost pump suction specific speed
20000.0	SSSBPO	ox boost pump suction specific speed
1.2	TURBPR	initial value of turbine pressure ratio
0.4	UOVERC	turbine velocity ratio
2.0	EPSGGB	bleed nozzle area ratio
12.0	GGCR	GG contraction ratio
0.3	ROINGG	GG injector density
30000.0	SYINGG	GG injector strength
0.298	ROSTAK	hot gas duct material density
30000.0	SYDUCT	hot gas duct material strength
0	ISTART	TPA start system design
1.0	CV	TPA start valve complexity multiplier
1.0	CVACUM	TPA accumulator valve complexity mult.
0.14	BURNRA	TPA solid grain burn rate
28.0	GASMW	molecular wt. of pres. gas for TPA start
60	NR	number of engine restarts
0.16	RHOBOT	TPA start bottle material density
3.3	RHOCYL	TPA start cylinder material density
0.1	RHOSPH	TPA start sphere material density
0.3	ROCART	TPA start cartridge material density
0.07	ROGRAN	TPA start cartridge grain density
75000.0	SYBOT	TPA start bottle yield strength
100000.0	SYCART	TPA start cartridge yield strength
30000.0	SYCYL	TPA start cylinder yield strength
47000.0	SYSPH	TPA start sphere yield strength
530.0	TBOGAS	TPA start bottle gas temp.
210.0	TSPH	TPA start sphere temp.
0.3	RHOTFL	fuel turbine blade density
0.3	RHOTOX	ox turbine blade density
0.305	RHOTUR	turbine blade density
0.298	RHOTPA	TPA effective material density

134000.0	US	turbine blade ultimate strength
120000.0	YS	turbine blade yield strength
0.298	ROLINE	engine bay line density
30000.0	SYLIN	engine bay line yield strength
0.3	ROSPVL	cold gas valve material density
0.3	ROACVL	accumulator valve material density
1	KALCON	tank insulation conductivity flag
2.5917E-9	CNMLI	thermal conductivity of MLI
9.5647E-8	CNSOFI	thermal conductivity of SOFI
3.935E-8	SOFIA	SOFI thermal conductivity constants
5.676E-10	SOFIB	SOFI thermal conductivity constants
0.002	DNMLI	MLI density
0.00127	DNSOFI	SOFI density
40.0	RADPIN	MLI radiation shields per inch
2.0	SACCEL	average stage acceleration
8	NITHX	iteration counter in heat transfer calcs
1.1	FVENTF	fuel tank ullage pressure fraction-vent.
1.1	FVENTO	ox tank ullage pressure fraction-vent.
259200.0	FLTTIM	stage action time
0.	HLDTIM	stage hold time
4	MLIENV	MLI environment flag
2.0E-7	PRGMLI	MLI purge gas pressure at space hold
560.0	TEXBOU	external tank boundary temperature
1.35E-4	EARIR	Earth infrared heat flux
0.39	EARREF	Earth reflectance (albedo)
250.0	HXALT	average orbital altitude
0.0	ORBANG	orbital angle
0.2	SABSOR	stage absorbativity
8.28E-4	SOLCON	solar heat flux
50.0	RELHUM	relative humidity
560.0	TAMICE	ambient temperature
10.0	WNDMPH	wind velocity
0.01	BLSPOX	space between ox bladder and wall
0.01	BLSPFL	space between fuel bladder and wall
0.04	DBNDOX	ox bonded rolling diaphragm density
0.04	DBNDFL	fuel bonded rolling diaphragm density
0.025	TBLDOX	ox bladder thickness
0.025	TBLDFL	fuel bladder thickness

Output Listing

```
              OUTPUT FOR MULTIPLE PUMPS AT FULL THRUST LEVEL

    PROPELLANTS  LIQUID OXYGEN - LIQUID HYDROGEN
    ASSUMPTIONS:
                  TEMP       ENTHALPY
             LOX  90.18 K  -3093. CAL/MOL
             LH2  20.27 K  -2154. CAL/MOL

        ODK VALUES CORRESPOND TO THROAT RADIUS=2.289 IN.
         C-STAR & CHAMBER TEMP DATA EVALUATED AT ODE PC & ODE MR VAL
 TURBINE PRESSURE RATIO=   1.501013860388780
 TURBINE PRESSURE RATIO=   1.591221774110766
 TURBINE PRESSURE RATIO=   1.655783786901820
 TURBINE PRESSURE RATIO=   1.703389461871302
 TURBINE PRESSURE RATIO=   1.739229791011710
 SUCCESSFUL CYCLE POWER BALANCE
 TURBINE PRESSURE RATIO=   1.739229791011710
 SUCCESSFUL CYCLE POWER BALANCE
 TURBINE PRESSURE RATIO=   1.739229791011710
 SUCCESSFUL CYCLE POWER BALANCE
 TURBINE PRESSURE RATIO=   1.739229791011710


        KEY INPUTS

   THRUST LEVEL =                       75000. (lbf)
   CYCLE TYPE =                     EXPANDER CYCLE
   REACTOR TYPE =                   ENABLER I
   FUEL TYPE =                      COMPOSITE FUEL
   NOZZLE EXIT AREA RATIO =               500.
   PROPELLANT USED =                      LH2
   CHAMBER PRESSURE =                    1000. (psia)
   CHAMBER TEMPERATURE =                 4860. (deg R)
   NUMBER OF PROPELLANT FEED LEGS =        2


              TANKAGE SUMMARY FOR STAGE #1
                   EXPANDER CYCLE (FUEL SIDE)
                   AFT TANK CONTAINS OXIDIZER ... FORWARD TANK CONTAINS FUEL
                   FUEL TANK IS PRESSURIZED WITH COLD GAS
                   TANK MATERIALS  (OX - USER DEF )  (FUEL - aluminum )
```

.. DIMENSIONS (INCHES) ...

STAGE DIAMETER	100.00
TOTAL STAGE LENGTH	1013.63
TOTAL TANK LENGTH	541.46
NOZZLE LENGTH	328.85
CONVERGENT NOZZLE LENGTH	12.00
MOUNT LENGTH	79.32

... WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	2317.37
PRESSURE TANK	4540.87
TANK CONSTRUCTION WEIGHT	4855.67
STRUCTURAL WALL	16.52

TANK HEAD ELLIPSE RATIO	1.38
PRESSURE TANK ELLIPSE RATIO	1.00
AFT TANK HEAD HEIGHT	35.34
FORWARD TANK HEAD HEIGHT	36.04
PRESSURE TANK HEAD HEIGHT	38.13
PRESSURE TANK DIAMETER	76.26
AFT TANK CYLINDRICAL LENGTH	0.00
FORWARD TANK CYLINDRICAL LENGTH	464.10
PRESSURE TANK CYLINDRICAL LNGTH	0.00
AFT LINE DIAMETER	0.00
FORWARD LINE DIAMETER	4.03
AFT SKIRT LENGTH	455.51
FORWARD SKIRT LENGTH	36.04
STRUCTURAL WALL THICKNESS	0.000
AFT TANK WALL THICKNESS	0.030
FORWARD TANK WALL THICKNESS	0.078
PRESSURE TANK WALL THICKNESS	0.937
AFT TANK DOME THICKNESS	0.030
FORWARD TANK DOME THICKNESS	0.054
PRESSURE TANK DOME THICKNESS	0.937
FUEL TANK MLI THICKNESS	0.02
FUEL TANK SOFI THICKNESS	0.50
OXIDIZER TANK MLI THICKNESS	1.97
OXIDIZER TANK SOFI THICKNESS	0.50
PRESSURE TANK INSULATION THICK	0.00
FUEL TNK HEAT FLUX(BTU/HR IN**2)	0.07
OX TANK HEAT FLUX(BTU/HR IN**2)	0.00
FUEL BOILOFF RATE (LB/SEC)	0.003
OX BOILOFF RATE (LB/SEC)	0.000

AFT SKIRT	425.27
FORWARD SKIRT	107.30
TANK MOUNT	0.00
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	255.96
OXIDIZER TANK INSULATION	407.04
REVERSE HEAD STIFFENER	217.00
FUEL ACQUISITION SYSTEM	11.30
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	60.79
TANK LINES	25.81
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	6.90
OXIDIZER RESIDUAL	0.00
OXIDIZER AUTOGENOUS PRESSURANT	0.00
STORED PRESSURANT	323.76
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00
FLIGHT FUEL BOILOFF	754.19
FLIGHT OXIDIZER BOILOFF	0.00
MISC EXPENDED FUEL	0.00
MISC EXPENDED OXIDIZER	0.00
MISCELLANEOUS WEIGHT	0.00
INTERSTAGE WEIGHT	0.00

... INPUT MINIMUM SAFETY FACTORS ...

STRUCTURAL WALL	1.25
LINES	2.00
OXIDIZER TANK	1.25
FUEL TANK	1.25
PRESSURE TANK	1.50

PROPELLANT SUMMARY FOR STAGE #1
PROPELLANT IS LH2

NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)= 0.0025

.. OXIDIZER ...

NOMINAL TANK PRESSURE(PSIA)	0.0
NOMINAL PROPELLANT TEMP(DEGR)	0.0
NOMINAL DENSITY(LB/IN**3)	0.0000
NOMINAL VAPOR PRESSURE(PSIA)	0.0
MAX PROPELLANT TEMP(DEGR)	0.0
MAX TEMP DENSITY(LB/IN**3)	0.0000
MAX TEMP VAPOR PRESSURE(PSIA)	0.0

... FUEL ...

NOMINAL TANK PRESSURE(PSIA)	56.3
NOMINAL PROPELLANT TEMP(DEGR)	38.5
NOMINAL DENSITY(LB/IN**3)	0.0025
NOMINAL VAPOR PRESSURE(PSIA)	20.0
MAX PROPELLANT TEMP(DEGR)	40.0
MAX TEMP DENSITY(LB/IN**3)	0.0025
MAX TEMP VAPOR PRESSURE(PSIA)	25.0

```
MIN PROPELLANT TEMP(DEGR)              0.0          MIN PROPELLANT TEMP(DEGR)              38.5
MIN TEMP DENSITY(LB/IN**3)             0.0000       MIN TEMP DENSITY(LB/IN**3)              0.0025
MIN TEMP VAPOR PRESSURE(PSIA)          0.0          MIN TEMP VAPOR PRESSURE(PSIA)          20.0


          ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
                EXPANDER CYCLE
                CONVERGENT NOZZLE IS REGEN  COOLED   (MILLED SLOT CONSTRUCTION)
                NOZZLE IS REGEN COOLED   (TUBE CONSTRUCTION)
                PROPELLANT IS LH2


.. ENGINE DIMENSIONS (INCHES) ...                          ... PERFORMANCE ...
      THROAT DIAMETER                       7.43
      REACTOR SUPPORT DIAMETER             35.81                DELIVERED ISP(VAC),SEC          912.78
      PRESSURE VESSEL O.D.                 40.81                IDEAL ISP(ODE),SEC              933.79
      NOZZLE EXIT DIAMETER                166.06
      NOZZLE EXTENSION ATTACH DIAM         18.19                DELIVERED CSTAR,FT/SEC        16491.
      CONVERGENT NOZZLE LENGTH             12.00                IDEAL CSTAR,FT/SEC            16709.
      CONV. NOZZLE STRUCTURAL THICK.        1.216
      GAS SIDE WALL THICKNESS               0.248               CHAMBER PRESSURE,PSIA          1000.
      NOZZLE EXTENSION THICKNESS            0.010               THRUST PER ENGINE(VAC),LBF    75000.
      SECOND NOZZLE EXTENSION THICKNESS     0.100               TOTAL VAC THRUST,LBF          75000.
                                                                BURN TIME,SEC                  3600.00
      NOZZLE EXIT AREA RATIO              500.00
      CONTRACTION RATIO                    15.13                OVERALL EFFICIENCY                0.977
      NOZ EXTENSION ATTCH AREA RATIO        6.00
      SECOND NOZ EXT ATTACH AREA RATI     150.00                KINETIC EFFICIENCY                1.000
      NOZZLE LENGTH/(MIN RAO LENGTH)        1.187               BARRIER COOLING EFFICIENCY        0.986
      NOZZLE LENGTH                       328.85                BOUNDARY LAYER EFFICIENCY         0.996
      FEED SYSTEM MOUNT LENGTH             79.32                DIVERGENCE EFFICIENCY             0.996
      REACTOR LENGTH                       52.00
                                                                FOR   1 ENGINE
                                                                OXIDIZER FLOWRATE,LB/SEC          0.00
                                                                FUEL FLOWRATE,LB/SEC             82.17
                                                                TOTAL FLOWRATE,LB/SEC            82.17

                                                                CORE TEMPERATURE,DEG R         4860.
                                                                BARRIER TEMPERATURE,DEG R      1630.
                                                                ENGINE MIXTURE RATIO              0.00
                                                                FUEL FILM COOLING FRACTION        0.03


THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1


THE ENGINE IS A FUEL COOLED
CONVENTIONAL EXPANSION NOZZLE

STATIONS  1 THROUGH  6 ARE BOUNDS TO THE   5     16.706 INCH LONG NOZZLE SECTIONS
STATIONS  6 THROUGH 11 ARE BOUNDS TO THE   5      3.220 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 11 ARE BOUNDS TO THE   0      0.000 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS =     0.248
GAS WALL THERMAL CONDUCTIVITY  =.00039000 (BTU/IN SEC DEGR)
```

GAS WALL MAXIMUM OPERATING TEMPERATURE= 1460. (DEG R)

STATION	P	TB	W	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.220E+04	.907E+02	.158E+01	.187E+02	.338E-02	0.109E+03	.111E+03	.197E-04	.187E-03	.150E+03	.283E+03
2	.220E+04	.908E+02	.128E+01	.283E+02	.651E-02	0.116E+03	.120E+03	.316E-04	.263E-03	.100E+03	.326E+03
3	.220E+04	.911E+02	.986E+00	.479E+02	.145E-01	0.127E+03	.136E+03	.570E-04	.402E-03	.600E+02	.390E+03
4	.220E+04	.916E+02	.690E+00	.980E+02	.405E-01	0.150E+03	.176E+03	.125E-03	.690E-03	.302E+02	.501E+03
5	.220E+04	.932E+02	.395E+00	.303E+03	.177E+00	0.213E+03	.326E+03	.401E-03	.148E-02	.106E+02	.769E+03
6	.200E+04	.100E+03	.100E+00	.519E+04	.177E+01	0.204E+03	.133E+04	.591E-02	.171E-01	.100E+01	.163E+04
7	.199E+04	.101E+03	.176E+00	.169E+04	.130E+01	0.338E+03	.117E+04	.280E-02	.549E-02	.249E+01	.163E+04
8	.199E+04	.102E+03	.252E+00	.828E+03	.949E+00	0.436E+03	.104E+04	.160E-02	.284E-02	.465E+01	.163E+04
9	.199E+04	.102E+03	.328E+00	.492E+03	.708E+00	0.505E+03	.955E+03	.105E-02	.176E-02	.747E+01	.163E+04
10	.199E+04	.103E+03	.403E+00	.326E+03	.544E+00	0.552E+03	.897E+03	.742E-03	.121E-02	.110E+02	.163E+04
11	.199E+04	.103E+03	.479E+00	.232E+03	.429E+00	0.585E+03	.858E+03	.555E-03	.891E-03	.151E+02	.163E+04

DELTA T= 12.8
DELTA P= -204.3
NOZZLE DELTA T = 11.0
NOZZLE DELTA P = -204.2
ADAPTER DELTA T = 1.8
ADAPTER DELTA P = -0.1
TOTAL HEAT TRANSFER = 1854.0 (BTU/SEC)

P - COOLANT PRESSURE (PSIA)
TB - COOLANT BULK TEMPERATURE (DEGR)
W - COOLANT CHANNEL WIDTH (IN)
V - COOLANT VELOCITY (IN/SEC)
Q - HEAT FLUX (BTU/IN**2 SEC)
TCW - TEMPERATURE OF COOLANT WALL (DEGR)
TGW - TEMPERATURE OF GAS WALL (DEGR)
HG - GAS SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
HC - COOLANT SIDE HEAT TRANSFER COEFF (BTU/IN**2 SEC DEGR)
E - LOCAL AREA RATIO (-)
TGAS - COMBUSTION GAS TEMPERATURE (DEGR)

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	PRESSURE(PSIA) OXIDIZER	TEMPERATURE(DEG R) FUEL	TEMPERATURE(DEG R) OXIDIZER	
... PRESSURANT ...					
MAX STORAGE	4365.0	——	550.0	——	
VENT	62.0	0.0	47.2	0.0	(SATURATION TEMP OF PROPELLANT)
ULLAGE	56.3	0.0	——	0.0	
... PROPELLANT ...					
TANK PROPELLANT	56.3	0.0	38.5	0.0	
PUMP INLET	45.0	0.0	40.7	0.0	
MAIN VALVE INLET	2298.3	0.0	90.2	0.0	
MAIN VALVE OUTLET	2219.0	0.0	90.2	0.0	
TIE TUBE OUTLET	1969.0	——	915.0	——	
REGEN OUTLET (REFL I	1994.0	——	103.0	——	
REFLECTOR OUTLET	1969.0	——	193.2	——	
REACTOR INLET	1132.1		349.0		
REACTOR CORE	1000.0		4860.0		

TURBINE INLET	1969.0	622.3
TURBINE OUTLET	1132.1	520.1

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

ACQUISITION DEVICE	PRESSURE CHANGES (PSID)		TEMPERATURE CHANGES (DEG R)	
	0.0	0.0		
FEED LINE	11.3	0.0	0.0	0.0
PUMP	2253.3	0.0	51.7	0.0
MAIN VALVE	79.2	0.0	0.0	0.0
TIE TUBES	250.0	—	824.8	—
REGEN JACKET	204.3	—	12.8	—
REFLECTOR	25.0	—	90.2	—
TURBINE	836.9		102.3	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL		OXIDIZER
TANK OUTFLOW	82.167		0.000
MAIN PUMP - EACH	41.083		0.000
MAIN VALVE	82.167		0.000
TOTAL TIE TUBES	23.947		—
REGEN JACKET INFLOW	58.219		—
NOZZLE BARRIER COOLING		2.342	
REGEN/REFL OUTLET TO CORE	39.673		—
TURBINE - EACH		20.076	
TURBINE TO CORE	40.152		0.000
AUTOGENOUS PRESSURANT	0.000		0.000
STORED PRESSURANT (AVE)		0.09	
CORE	79.825		—

REACTOR OPERATING CHARACTERISTICS AND MASSES

REACTOR OPERATING CHARACTERISTICS

TOTAL COOLANT FLOW	79.82	LB/SEC
REACTOR POWER	1587.01	MW
CORE FLOW AREA	198.34	IN2
CORE MASS FLOW RATE	0.40	LB/IN2
FUEL ELEMENT POWER	1.20	MW/Element
FUEL ELEMENT OPERATING LIFE	1.78	HR
NUMBER OF FUEL ELEMENTS	1277.54	
NUMBER OF SUPPORT ELEMENTS	248.92	
CHAMBER TEMPERATURE	4860.00	DEG R
CHAMBER PRESSURE	1000.00	PSIA
CHAMBER ENTHALPY	18764.53	BTU/LB
CORE INLET TEMPERATURE	348.97	DEG R
CORE INLET PRESSURE	1132.13	PSIA
CORE INLET ENTHALPY	1102.04	BTU/LB
HEAT PICKUP PER TIE TUBE	0.31	MW/TUBE
HEAT PICKUP IN TIE TUBES	73153.64	BTU/S
FRACTIONAL HEAT PICKUP IN NOZZLE	0.00	
HEAT PICKUP IN NOZZLE	1854.04	BTU/S
FRACTIONAL HEAT PICKUP IN REFLECTOR	0.01	

HEAT PICKUP IN REFLECTOR	18354.69	BTU/S
FRACTIONAL CENTRAL SHIELD HEAT PICKUP	0.00	
CENTRAL SHIELD HEAT PICKUP	2602.76	BTU/S
FRACTIONAL EXTENSION SHIELD HEAT PICKUP	0.00	
EXTENSION SHIELD HEAT PICKUP	466.39	BTU/S
PEAK CHANNEL WALL TEMPERATURE	4948.22	DEG R
PEAK FUEL TEMPERATURE	5077.55	DEG R

REACTOR DIMENSIONS

CORE LENGTH	52.00	IN
CORE DIAMETER	32.53	IN
FUEL ELEMENT CHANNEL DIAMETER	0.11	IN
VOID FRACTION OF FUEL ELEMENTS	0.32	
PEAK TO AVERAGE CHANNEL FACTOR	1.20	
CORE EFFECTIVE DIAMETER	30.89	IN
LATERAL SUPPORT DIAMETER	35.81	IN
STRUCTURE OD	38.01	IN
REFLECTOR OD	47.58	IN
PRESSURE VESSEL ID	47.90	IN
PRESSURE VESSEL OD	49.81	IN
THICKNESS OF BATH SHIELD	12.43	IN
THICKNESS OF LEAD SHIELD	1.31	IN
PRESSURE VESSEL LENGTH	101.54	IN
FUEL VOLUME	22307.24	IN3

REACTOR MASSES

FUEL MASS	3078.40	LB
SUPPORT MASS	640.38	LB
CORE PERIPHERY MASS	364.04	LB
LATERAL SUPPORT MASS	335.77	LB
STRUCTURE MASS	691.06	LB
REFLECTOR MASS	2244.61	LB
HOT END HARDWARE MASS	118.52	LB
AFT REFLECTOR MASS	65.20	LB
CORE INLET PLENUM MASS	165.28	LB
SUPPORT PLATE MASS	545.93	LB
LATERAL SUPPORT FORWARD MASS	44.08	LB
REFLECTOR HARDWARE FORWARD MASS	115.50	LB
SUPPORT PLATE PLENUM MASS	38.14	LB
INSTRUMENTATION RING MASS	32.25	LB
FORWARD REFLECTOR HARDWARE MASS	22.88	LB
SUBTOTAL CORE A	8502.03	LB
FLOW BAFFLE MASS	105.13	LB
FLOW BAFFLE 1 MASS	195.02	LB
TOTAL CORE SUBSYSTEM MASS	8802.19	LB
PRESSURE VESSEL A MASS	1054.44	LB
PRESSURE VESSEL B MASS	398.86	LB
PRESSURE VESSEL DOME MASS	184.14	LB
NOZZLE/REACTOR ADAPTER MASS	105.91	LB
TOTAL PRESSURE VESSEL MASS	1743.36	LB
BATH CENTRAL SHIELD MASS	1036.13	LB
BATH PERIPHERAL SHIELD MASS	737.10	LB
BATH PERIPHERAL SHIELD 2 MASS	257.78	LB
LEAD CENTRAL SHIELD MASS	372.31	LB
LEAD PERIPHERAL SHIELD MASS	0.20	LB
LEAD PERIPHERAL SHIELD 2 MASS	0.09	LB
PERIPHERAL SHIELD PLATE MASS	40.52	LB
TOTAL SHIELD MASS	2444.13	LB
REACTOR MASS w/o SHIELD	10545.55	LB
REACTOR MASS w/ SHIELD	12989.67	LB

SAFETY RODS-FOR LAUNCH ONLY	607.68	LB
REACTOR MASS w/o SHIELD-LAUNCH WT.	11153.23	LB
REACTOR MASS w/ SHIELD-LAUNCH WT.	13597.36	LB

* * * TPA SUMMARY FOR STAGE #1 * * *
EXPANDER CYCLE
2 PROPELLANT FEED LEGS
AXIAL PUMPS
TPA SIZE/WT/PERFORMANCE IS USER DEFINED

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	39582.
SPECIFIC SPEED	1973.
INDUCER SPECIFIC SPEED	5495.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	5.+ INDUCER
NET POS SUCTION PRESSURE(PSIA)	118.23
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	2298.29
VOLUMETRIC FLOWRATE(GPM)	4297.88
MASS FLOWRATE(LBM/SEC)	41.08
PUMP HORSEPOWER(HP)	7753.93
PUMP EFFICIENCY	0.726
INDUCER EFFICIENCY	0.805
OVERALL PUMP EFFICIENCY	0.729
PUMP DIAMETER(IN)	5.52
PUMP WT.(LB) - EACH PUMP	131.07
INDUCER WT.(LB) - EACH	64.90
OVERALL PUMP WT.(LB) - EACH	195.97

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.617
PRESSURE RATIO	1.739
MASS FLOWRATE(LB/SEC)	20.08
DIAMETER(IN)	5.66
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52357.
ROOT STRESS SPEED LIMIT(RPM)	46995.
SPECIFIC SPEED	21.
TURBINE SPEED(RPM)	39582.
TURBINE WT(LB) - EACH TURBINE	31.78
TURBINE ANNULUS AREA(IN2)	17.196
U OVER C	0.30
INLET MACH NUMBER	0.69

... TPA ...

TPA START SYSTEM WT.	0.00

GAS GENERATOR/PREBURNER WT.-EAC	0.00
IGNITION SYSTEM WT.-TOTAL	32.24
HOT GAS MANIFOLD WT.-TOTAL	0.00
GEARBOX WT.-TOTAL	0.00
MAIN TURBOPUMP WT. - EACH	227.75
TOTAL TURBOPUMP WT.	455.49
TOTAL TPA WT.	487.73

.. STAGE #1 WEIGHTS (POUNDS) ...

AFT TANK	78.43
FORWARD TANK	2317.37
PRESSURE TANK	4540.87
TANK CONSTRUCTION WEIGHT	4855.67
TANK LINES	25.81
AFT SKIRT	425.27
FORWARD SKIRT	107.30
TANK MOUNT	0.00
STRUCTURAL WALL	16.52
PRESSURE TANK INSULATION	0.00
FUEL TANK INSULATION	255.96
OXIDIZER TANK INSULATION	407.04
FUEL ACQUISITION SYSTEM	11.30
OXIDIZER ACQUISITION SYSTEM	0.00
PRESSURANT CONTROL HARDWARE	60.79
ENGINE WEIGHTS:	
1 REACTOR	10545.55
1 REACTOR INTERNAL SHIELD	2444.13
1 NOZZLE	1178.87
1 THRUST MOUNT(S)	1069.35
1 GIMBAL SYSTEM(S)	96.00
2 ENGINE BAY LINE(S)	197.39
2 MAIN VALVE(S)	409.18
1 SUPPORT HARDWARE	615.58
1 GIMBAL POWER SUPPLY	206.77
2 IGNITION SYSTEM(S)	32.24
2 HOT GAS MANIFOLD(S)	0.00
2 GAS GENERATOR/PREBURNER	0.00
2 TPA ASSY(S)	455.49
1 GEARBOX(S)	0.00
2 TPA START SYSTEM(S)	0.00
1 GAS GENERATOR/PREBURNER(S)	0.00
NON-NUCLEAR WEIGHT MARGIN	97.22
TOTAL ENGINE WEIGHT	17947.77
FLIGHT FUEL BOILOFF	754.19
FLIGHT OXIDIZER BOILOFF	0.00
EXPENDABLE WEIGHT	0.00
MISCELLANEOUS WEIGHT	0.00
USER DEFINED WEIGHT	0.00
REACTOR SAFETY ROD WT.	607.68

TOTAL INERT WEIGHT	32411.97
INTERSTAGE WEIGHT	0.00
BURNED FUEL	8000.00
BURNED OXIDIZER	0.00
FUEL RESIDUAL	6.90
OXIDIZER RESIDUAL	0.00
OXIDIZER AUTOGENOUS PRESSURANT	0.00
STORED PRESSURANT	323.76
MISC ON-BOARD FUEL	0.00
MISC ON-BOARD OXIDIZER	0.00

GROSS IGNITION WEIGHT	40742.63
GROSS BURNOUT WEIGHT	31370.76
HOLD TIME FUEL BOILOFF	0.00
HOLD TIME OX BOILOFF	0.00

Nuclear Thermal Vehicle

**** VEHICLE SUMMARY ****

	STAGE #1
..DIMENSIONS,IN..	
STAGE DIAMETER	100.00
NOZZLE EXIT DIAMETER	166.06
NUMBER OF NOZZLES	1
STAGE LENGTH	1013.63
PAYLOAD LENGTH	0.00
TOTAL VEH LENGTH	1013.63
..PERFORMANCE..	
PROPELLANT	LOX/LH2
THRUST,VACUUM DELIVERED,LBF	75000.0
PC,PSIA	1000.0
NOZZLE AREA RATIO	500.00
BURN TIME,SEC	3600.00
ISP,VACUUM DELIVERED,SEC	912.8
ISP EFFICIENCY	0.977
TOTAL PROP. FLOWRATE, LB/SEC	82.17
CORE PROP. FLOWRATE, LB/SEC	79.82

OUTPUT FOR SINGLE PUMP AT REDUCED THRUST

PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
FOR ONE PUMP AT REDUCED THRUST LEVEL 60000.
EXPANDER CYCLE

	PRESSURE(PSIA) FUEL	OXIDIZER	TEMPERATURE(DEG R) FUEL	OXIDIZER
... PRESSURANT ...				
MAX STORAGE	4365.0	——	550.0	——
VENT	60.1	0.0	46.9	0.0 (SATURATION TEMP OF PROPELLANT)
ULLAGE	54.6	0.0	——	0.0
... PROPELLANT ...				
TANK PROPELLANT	54.6	0.0	38.5	0.0
PUMP INLET	45.0	0.0	40.3	0.0
MAIN VALVE INLET	1633.8	0.0	72.2	0.0
MAIN VALVE OUTLET	1566.5	0.0	72.2	0.0
TIE TUBE OUTLET	1316.5	——	926.9	——
REGEN OUTLET (REFL I	1341.5	——	86.5	——
REFLECTOR OUTLET	1316.5	——	175.0	——
REACTOR INLET	962.5		358.4	
REACTOR CORE	800.0		4860.0	
TURBINE INLET	1316.5		618.7	
TURBINE OUTLET	962.5		559.0	

.. COMPONENT PRESSURE/TEMPERATURE CHANGES ..

	PRESSURE CHANGES (PSID) FUEL	OXIDIZER	TEMPERATURE CHANGES (DEG R) FUEL	OXIDIZER
ACQUISITION DEVICE	0.0	0.0		
FEED LINE	9.6	0.0	0.0	0.0
PUMP	1588.8	0.0	33.7	0.0
MAIN VALVE	67.4	0.0	0.0	0.0
TIE TUBES	250.0	——	854.7	——
REGEN JACKET	133.6	——	14.3	——
REFLECTOR	25.0	——	88.5	——
TURBINE	354.0		59.8	

FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
EXPANDER CYCLE

	FUEL	OXIDIZER
TANK OUTFLOW	65.663	0.000
MAIN PUMP	65.663	0.000
MAIN VALVE	65.663	0.000
TOTAL TIE TUBES	19.138	——
REGEN JACKET INFLOW	46.525	——
NOZZLE BARRIER COOLING	1.871	
REGEN/REFL OUTLET TO CORE	31.705	——
TURBINE	32.087	
TURBINE TO CORE	32.087	0.000
AUTOGENOUS PRESSURANT	0.000	0.000

STORED PRESSURANT (AVE)		0.08
CORE	63.792	——

* * * TPA SUMMARY FOR STAGE #1 * * *
SUMMARY FOR TPA AT THRUST LEVEL FRACTION 0.80
EXPANDER CYCLE
SINGLE SHAFT TPA
AXIAL PUMPS

... PROPELLANT PUMP ...

PUMP SPEED (RPM)	40583.
SPECIFIC SPEED	3323.
INDUCER SPECIFIC SPEED	9256.
SUCTION SPECIFIC SPEED	20000.
NUMBER OF PUMP STAGES	5.+ INDUCER
NET POS SUCTION PRESSURE(PSIA)	89.10
ACCELERATION HEAD(PSIA)	0.00
PUMP OUTLET PRESSURE(PSIA)	1633.85
VOLUMETRIC FLOWRATE(GPM)	6871.14
MASS FLOWRATE(LBM/SEC)	65.66
PUMP HORSEPOWER(HP)	8051.56
PUMP EFFICIENCY	0.796
INDUCER EFFICIENCY	0.717
OVERALL PUMP EFFICIENCY	0.792
PUMP DIAMETER(IN)	5.52
PUMP WT.(LB)	131.07
INDUCER WT.(LB)	64.90
OVERALL PUMP WT.(LB)	195.97

... TURBINE ...

ADMISSION FRACTION	1.000
EFFICIENCY	0.700
PRESSURE RATIO	1.368
MASS FLOWRATE(LB/SEC)	32.09
DIAMETER(IN)	5.66
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS LIMIT(PSI)	52353.
ROOT STRESS SPEED LIMIT(RPM)	46993.
SPECIFIC SPEED	74.
TURBINE SPEED(RPM)	40583.
TURBINE WT(LB)	31.78
TURBINE ANNULUS AREA(IN2)	17.196

ENGINE SUMMARY

EXPANDER CYCLE
ENABLER I
AXIAL PUMPS

THRUST LEVEL =	75000.0	lbf	333600.0	N
CHAMBER PRESSURE =	1000.0	psia	6895.0	kPa

CHAMBER TEMPERATURE =	4860.0	deg R	2700.0	deg K
NOZZLE EXIT AREA RATIO =	500.0		500.0	
NUMBER OF FEED LEGS =	2		2	
TOTAL PROPELLANT FLOWRATE =	82.2	lbm/s	37.3	kg/s
REACTOR				
COMPOSITE FUEL				
REACTOR WEIGHT	10545.5	lbm	4782.6	kg
SHIELD WEIGHT	2444.1	lbm	1108.4	kg
PRESSURE VESSEL DIA.	49.8	in	126.5	cm
PRESSURE VESSEL LENGTH	101.5	in	257.9	cm
CORE PROPELLANT MASS FLOW	79.8	lbm/sec	36.2	kg/sec
NOZZLE				
CONVERGING NOZZLE WEIGHT	181.6	lbm	82.3	kg
NOZZLE EXTENSION WEIGHT	399.2	lbm	181.0	kg
SECOND NOZZLE EXTENSION WEIGHT	598.1	lbm	271.3	kg
TOTAL NOZZLE WEIGHT	1178.9	lbm	534.6	kg
AREA RATIO	500.0		500.0	
THROAT DIAMETER	7.4	in	18.9	cm
EXIT DIAMETER	166.1	in	421.8	cm
NOZZLE LENGTH	328.8	in	835.3	cm
DELIVERED VACUUM ISP	912.8	sec	8945.2	N-sec/kg
DELIVERED THRUST	75000.0	lbf	333600.0	N
TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)				
MAIN PROP. TURBOPUMP WT	455.5	lbm	206.6	kg
PROPELLANT BOOST PUMP WT	0.0	lbm	0.0	kg
MAIN OX PUMP WEIGHT	0.0	lbm	0.0	kg
TPA IGNITION WEIGHT	32.2	lbm	14.6	kg
BLEED LINE/VALVE WEIGHT	0.0	lbm	0.0	kg
MISC. HARDWARE WEIGHTS				
THRUST MOUNT	1669.3	lbm	757.1	kg
SUPPORT HARDWARE	615.6	lbm	279.2	kg
ENGINE LINES	197.4	lbm	89.5	kg
MAIN VALVE	409.2	lbm	185.6	kg
GIMBAL + POWER SUPPLY	302.8	lbm	137.3	kg
MARGIN (2.0%)	97.2	lbm	44.1	kg
TOTAL NONNUCLEAR WEIGHT	4958.1	lbm	2248.6	kg
TOTAL ENGINE SYSTEM				
TOTAL ENGINE WEIGHT	17947.8	lbm	8139.6	kg
TOTAL ENGINE WEIGHT WITHOUT SHIELD	15503.6	lbm	7031.1	kg
THRUST/WEIGHT RATIO WITH SHIELD	4.2	lbf/lbm	41.0	N/kg
THRUST/WEIGHT RATIO WITHOUT SHIELD	4.8	lbf/lbm	47.4	N/kg
REACTOR SAFETY ROD WT.-LAUNCH ONLY	607.7	lbm	275.6	kg
TOTAL ENGINE LAUNCH WEIGHT	18555.5	lbm	8415.2	kg
TOTAL ENGINE LAUNCH WT. W/O SHIELD	16111.3	lbm	7306.7	kg
PUMP-OUT CONDITIONS				
PUMP-OUT THRUST	60000.0	lbf	266880.0	N
PUMP-OUT CHAMBER PRESSURE	800.0	psia	5516.0	kPa
PUMP-OUT ISP	913.8	sec	8954.8	N-sec/kg
PUMP-OUT CHAMBER TEMPERATURE	4860.0	deg R	2700.0	deg K
OVERALL DIMENSIONS				
OVERALL ENGINE LENGTH =	509.7	in	1294.7	cm
OVERALL ENGINE DIAMETER =	166.1	in	421.8	cm

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TWO PHASE FLUID ENCOUNTERED IN REGEN

CR = 15.130 RECOMMENDED RANGE = 1.5 TO 4

NOZZLE EXIT DIAM = 166.1 STAGE DIAM = 100.0

AXIAL BUCKLING DESIGNS STRUCTURAL WALL THICKNESS
MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

HOOP STRESS DESIGNS FORWARD TANK WALL THICKNESS
AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

GAS PHASE ENCOUNTERED IN REGEN JACKET
TPA CALCULATIONS TERMINATED BY ACHIEVING DESIRED ACCURACY

END NOMINAL STAGE DESIGN

5.0 MODEL VERIFICATION/COMPARISON

NESS NTP engine system design, Sample Case No. 8 presented in Section 4.0, was compared to past preliminary engine system designs to support in verification of the models. Since no past detailed ENABLER-based NTP engine system designs are available that incorporate state-of-the-art engine system technologies, a comparison to similar, but not exact, engine system designs was undertaken. The 75,000 lbf thrust, 1000 psia chamber pressure, composite fueled, 2700 °K (4860 °R) chamber temperature, 500:1 area ratio nozzle sample case was compared to a similar Rocketdyne NTP engine system design and a past ELES-NTP engine system design that are described in Refs. 2-3 and 5-1. The past ELES-NTP engine system design example did not incorporate an integrated ENABLER reactor system design, but included a reactor system design that only approximated in matching engine system cycle parameters.

Tables 5-1 and 5-2 compare the NESS sample design case to similar Rocketdyne and past ELES-NTP engine system designs. Tables 5-1 and 5-2 compare key engine cycle parameters and major engine subsystem weights of the NESS sample case design to the Rocketdyne and ELES-NTP designs, respectively. One key observation is that the NESS design exhibits a delivered Isp of approximately 1% lower than that associated with the other designs. This is because the integrated NESS model more accurately calculates nozzle cooling losses. It was found that film cooling of the nozzle wall was required to keep its maximum wall temperature at or under the acceptable limit of 1460 °R. Table 5-3 shows the effect of wall temperature on engine system performance as predicted by NESS. The ELES-NTP did not properly model this effect. It is unknown if the Rocketdyne engine design properly represents this integrated design effect. The reduced Isp also increased the engine system flow rate slightly to offset this effect.

The NESS program also more accurately models the pressure and temperature drops associated with cooling the nozzle and reactor system. This corresponds to the difference in the cycle pressures, temperatures, and turbopump operating parameters compared to the other referenced designs.

It is believed that the NESS weights (and size) more accurately represents the reactor system because its model of the reactor is sized to take advantage of heat captured by the coolant before it enters the reactor. Likewise, the NESS integrated ENABLER reactor system module more accurately determines the reactor system weight and size for a given design point, when compared to past modeling methods, see Refs. 2-3 and 5-1.

Table 5-1 Engine Cycle Parameter Comparison*

Parameter	Rocketdyne	SAIC - ELES NTP	SAIC NESS
Total Flowrate (kg/s)	36.7	36.9	37.27
Pump Discharge Pres. (psia)	1,544	1,538.3	2,298.3
Turbine Flowrate, % Pump	50	50	50
Turbine Inlet Temp. (°K)	555.6	555.3	622.3
Turbine Inlet Pres. (psia)	1,412	1,416.8	1,969.0
Turbine Pressure Ratio	1.25	1.295	1.739
Reactor Inlet Pres. (psia)	1,130	1,255.4	1,132.1
Reactor Power, (MW)	1,645	-	1,587
Reactor Core Flowrate (kg/s)	36.7	36.9	36.2
Nozzle Chamber Temp (°K)	2,700	2,700	2,700
Nozzle Chamber Pres. (psia)	1,000	1,000	1,000
Nozzle Exit Diameter (m)	4.15	4.15	4.22
Nozzle Expansion Ratio	500	500	500
Specific Impulse-Vac (sec)	923	922.8	912.9
Pump Speed (rpm)	37,500	34,913	40,583

* Rocketdyne uses their Mark 25 type axial turbopump (4 stages); SAIC ELES-NTP used a single-stage centrifugal pump; SAIC NESS, Sample Case No. 8, uses a 5-stage axial pump.

Table 5-2. Engine Component Weight Comparison*

Parameter	Rocketdyne	SAIC ELES-NTP	SAIC NESS
Specific Impulse - Vac (sec)	923	922.8	912.9
Reactor (kg)	5,824	5,823	4,783
Internal Shield (kg)	—	1,523	1,108
Nozzle Assembly (kg)	440	421	535
Turbopump Assembly (kg)	304	104	221
Nonnuclear Support Hardware (kg) - Lines, Values, Actuators, Instrumentation Thrust Structure	1,815	1,264	1,493

* Rocketdyne uses their Mark 25 type axial turbopump (4 stages); SAIC ELES-NTP used a single-stage centrifugal pump; SAIC NESS, Sample Case No. 8, uses a 5-stage axial pump.

Table 5-3. Effect of Wall Temperature on Performance*

Wall Temperature (°R)	Barrier Temperature (°R)	Isp (Sec.)	Fuel Film Cooling Fraction
1460	1630	912.9	0.03
1800	2106	915.9	0.03
2000	2429	917.5	0.02
2400	2892	919.4	0.02
2800	3418	921.2	0.02
3000	3651	921.9	0.02
3200	3864	922.4	0.02

* Core Temperature = 4860°R (2700°K)

The ELES-NTP reactor system weight was approximated by reading off a reactor power versus weight graph that can have some inherent inconsistencies. The increase in the NESS weight for the TPA is due to the more stressing operating conditions under which the turbopumps must perform to meet the increased pumping requirements of the NESS design. Likewise, the NESS design comparison example includes axial turbopumps, which are not used in the ELES-NTP design example. The increase in the NESS design nozzle weight is attributed to a more accurate nozzle weight calculation that has been embedded in the NESS program. The ELES-NTP design approach only estimated nozzle weight by using multiple program runs to represent the various design portions of the nozzle. These results were then summed together which approximated the engine weight. NESS now calculates nozzle weight using exact geometric equations from which weight is determined.

The nonnuclear support hardware weight is somewhat higher for the NESS design than the ELES-NTP design. The NESS design weight is believed to be more accurate than the ELES-NTP design weight because it uses true design calculations derived by TRW, see Ref. 1-1, during the past NERVA program effort that have been adjusted for today's technologies, as discussed in Section 2.2.5. Additionally, the NESS nonnuclear support hardware weight calculations are more representative of an NTP engine system because they include options, such as those associated with a gimbal power supply, that can be a significant weight factor for long NTP engine burns and a weight allocation associated with a lower pressure cooldown propellant coolant feed leg. The past ELES-NTP nonnuclear weight was estimated, based on a percentage of the reactor weight typical of the NERVA flight engine. This method has a greater degree of uncertainty. It is felt that the NESS program accurately models representative designs of solid core NERVA-type NTP engine systems to support preliminary design and mission studies.

6.0 CONCLUDING REMARKS

The NESS preliminary design analysis program characterizes, in detail, complete near-term and next-generation solid core NERVA-type NTP engine system in terms of performance, weight and size, and key operating parameters for the overall system and its associated subsystem. The NESS program incorporates numerous state-of-the-art engine system technology design options and design features unique to NTP systems such as a multiple leg turbopump propellant feed system assembly and a low pressure cooldown propellant coolant feed system. The NESS program is easy to use and is flexible to address various NTP engine system design options efficiently. Though an initial validation effort, the NESS program is deemed accurate to support preliminary engine and vehicle system design and mission analysis efforts.

Development of the NESS program is considered to be one of many key first steps required to support NTP development. Because of the modular nature of the NESS program, it has great potential for further upgrades in its design/technology option and analysis capabilities. Recommended future upgrade activities include: incorporation of other representative reactor system design modules such as for a particle bed and/or a pellet bed and/or cermet system; upgrade performance prediction correlations; include and upgrade materials option capability which considers radiation effects/compatibility; include a radiation heating model; integration of an efficient design optimization capability and perform more detailed analysis code verification. It is envisioned that NESS program could be a key design tool element when integrated into an advanced NTP engine system design workstation.

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13. ABSTRACT ***(Maximum 200 words)***

This Program User's Guide discusses the Nuclear Thermal Propulsion (NTP) engine system design features and capabilities modeled in the Nuclear Engine System Simulation (NESS): Version 2.0 program (referred to as NESS throughout the remainder of this document), as well as its operation. NESS has been upgraded to include many new modeling capabilities not available in the original version delivered to the NASA Lewis Research Center in December 1991, see Ref. 1-0. Ness's new features include:

- An improved input format
- An advanced solid-core NERVA-type reactor system model (ENABLER II)
- A bleed-cycle engine system option
- An axial-turbopump design option
- An automated pump-out turbopump assembly sizing option
- An off-design gas generator engine cycle design option
- Updated hydrogen properties
- An improved output format
- Personal computer operation capability

Sample design cases are presented in the user's guide that demonstrate many of the new features associated with this upgraded version of NESS, as well as design modeling features associated with the original version of NESS, discussed in Ref. 1-0.

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