ID # 11183

84D31Y

ELES-1984

June 1984

EXPANDED LIQUID ENGINE SIMULATION COMPUTER PROGRAM

NEW USERS GUIDE

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ACKNOWLEDGEMENTS

The mathematical models used in ELES-1984 are the result of many analysts committing their knowledge and experience to the task of producing simplified, preliminary-design algorithms. The following is a list of contributors:

Roger Anderson
Ed Barth (AFRPL)
Randy Bickford
Kirk Christensen
Don Culver
Jack Dever
Al Epes
Fred Fischietto
Keith Hamlyn (MMDA)
Ross Hewitt
John Hidahl
Bob Holman (SEA)
Jack Ito
Joe Jellison
Craig Judd
Tom Lee
Don Lemke
Bruce Lindley
Barbara Loch/Bicknell (MMDA)
Rich Matlock (AFRPL)
Gregg Meagher
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INTRODUCTION

The ELES-1984 computer code is a landmark development in the preliminary systems analysis of liquid rocket vehicles. It is capable of revealing subsystem interactions and design choice impacts on total vehicle performance. Its use enables very rapid determinations of optimum vehicle designs.

The liquid propulsion system models in ELES have been developed by Aerojet TechSystems Company under the auspices of AFRPL during the past few years (1980-1984). The main purpose of ELES is to find optimum vehicle designs for specified mission requirements. Toward that end it is capable of evaluating the size, weight, and performance of system components over a range of design configurations, materials of construction, and operating points. These capabilities allow the code to act as an excellent propulsion system preliminary design training tool.

The objective of this manual is to explain the basic use of the ELES-1984 computer code. The main topics to be covered by this manual include defining a problem statement and formulating an input set for liquid stages in a rocket vehicle.

Use of the non-liquid portions of ELES (solid stage design, trajectory simulation, method of multipliers optimization, etc.) are documented by other sources available through AFRPL.

There are four manuals which describe the operation of the ELES-1984 Computer Program.

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
New Users Guide, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Technical Information Manual, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Programmers Manual, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Advanced Users Manual, Aerojet TechSystems Company, 1984

Introduction (cont.)

Both users guides are concerned with proper formulation and input of a problem statement. The new users guide does so in a more basic manor than the advanced users guide. The technical information manual describes the mathematical algorithms used in ELES to model the various propulsion subsystems. The programmers manual deals with the internal structure of the FORTRAN code, its file structure, and internal communication.

For more information regarding the ELES-1984 computer program contact

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1. EXPANDED LIQUID ENGINE SIMULATION (ELES-1984) OVERVIEW

There are three main sections of the ELES computer code (see Figure 1a): a stage design section, a trajectory model, and a multivariable optimizer. The stage design section calculates the size, weight and engine performance of liquid or solid stages (see Figure 1b). The trajectory model uses a 2D round non-rotating earth, 1962 standard atmospheric data, Adams-Moulton/Runge-Kutta integration, and Kepler orbital mechanics. The optimizer provides optima for both stage design and vehicle guidance with design and guidance parameter sensitivities included. Mixed solid and liquid stage vehicles of up to 4 stages can be modeled by ELES.

The liquid stage design section of ELES was developed by Aerojet under contracts FO4611-79-C-0054 and FO4611-82-C-0062. That portion of the code performs size, weight, and performance analyses on liquid stage designs of interest.

The liquid engine feed system power cycles modeled by ELES are illustrated in Figure 1c. The list includes pressure fed engines and pump fed engines with the following turbopump power cycles: gas generator bleed, single preburner staged combustion, staged reaction, and expander. The ELES engine analysis outputs engine size, weight, and performance, as well as turbopump assembly (TPA) size, weight and performance.

Engine performance is based on the standard JANNAF method. It begins with ideal one dimensional equilibrium (ODE) performance and degrades that ideal performance with loss multipliers. The calculation of these multipliers is performed by standard JANNAF procedures or by Aerojet derived methods. The analysis includes the effect of injector design, thrust chamber material, operating temperatures, propellant inlet temperatures, and thrust chamber geometry.

TPA design options are shown in Figure 1c as gearbox, single shaft, and twin TPA. As required, the code will stage the pumps and turbines. The TPA is designed by considering system power requirements and drive fluid characteristics. Pump and turbine efficiencies are based on industry standards (Ref. NASA SP-8109, Figure 6; AFRPL TR 72-45, Figure 4).

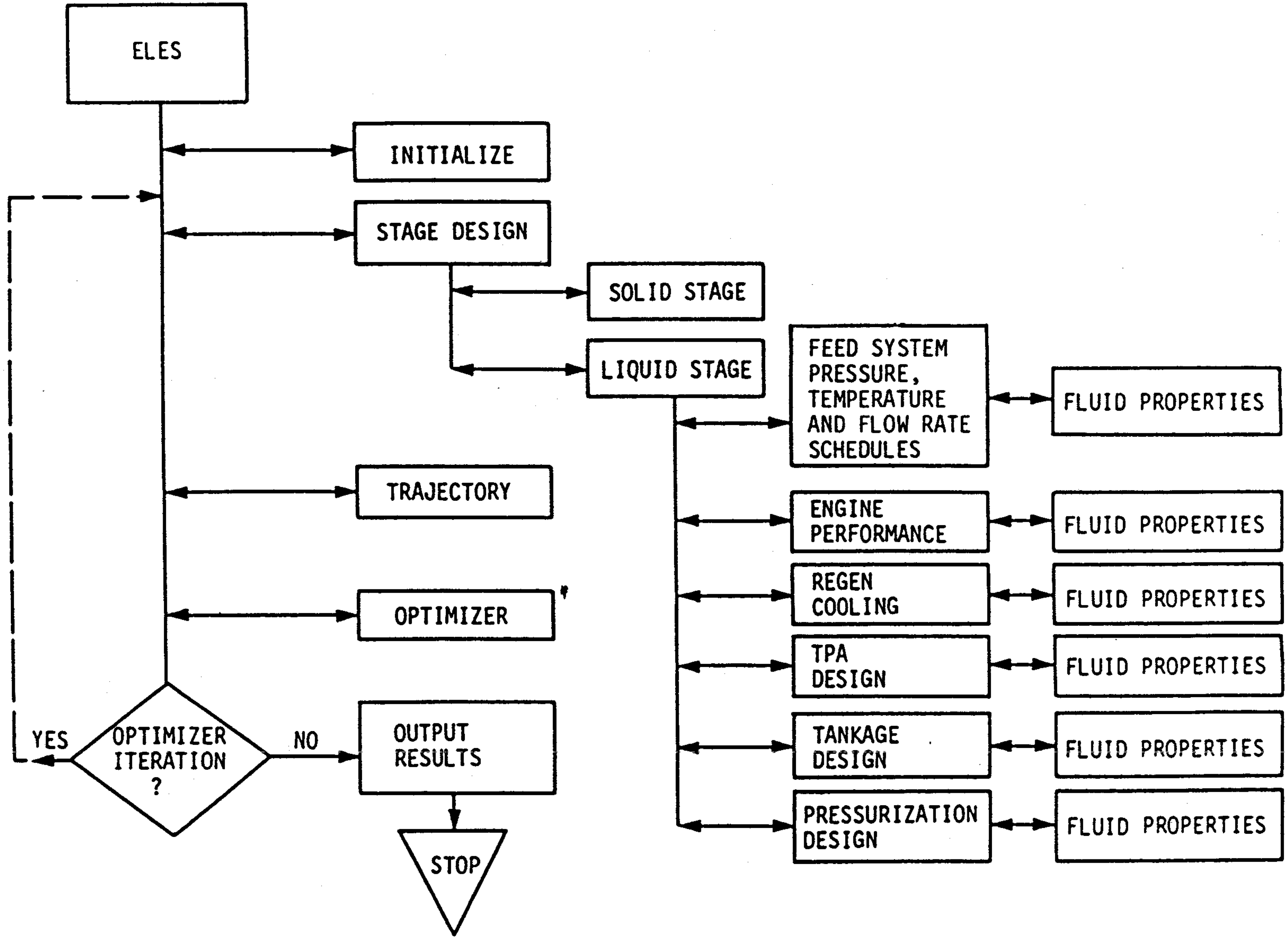


Figure 1a. ELES Flow Diagram

Figure 1b. Major Output Parameters of Liquid Stage Design Section

Propellant Tank Size/Weight

Pressurization Tank Size/Weight

Line Size/Weight

Positive Expulsion Size/Weight/Delta P

Engine Size/Weight/Performance (Nozzle, Valve, Injector, Chamber)

Thrust Mount Size/Weight

Gimbal System Size/Weight

Tank Residuals Weight

Tank Pressurization Requirements

Interstage Size/Weight

Delivered Specific Impulse (ideal one dimensional equilibrium performance degraded by kinetic, vaporization, boundary layer, mixing, two phase, divergence, and MR distribution losses)

Feed System Temperature/Pressure/Flowrate Schedules

Regenerative/Trans-Regen Cooling Requirements

Turbopump Assembly Size/Weight/Performance

Turbopump Design Parameter Breakdown

Regenerative Coolinig Jacket Summary

Required Engine Barrier Mixture Ratio

Stage Tank Mixture Ratio

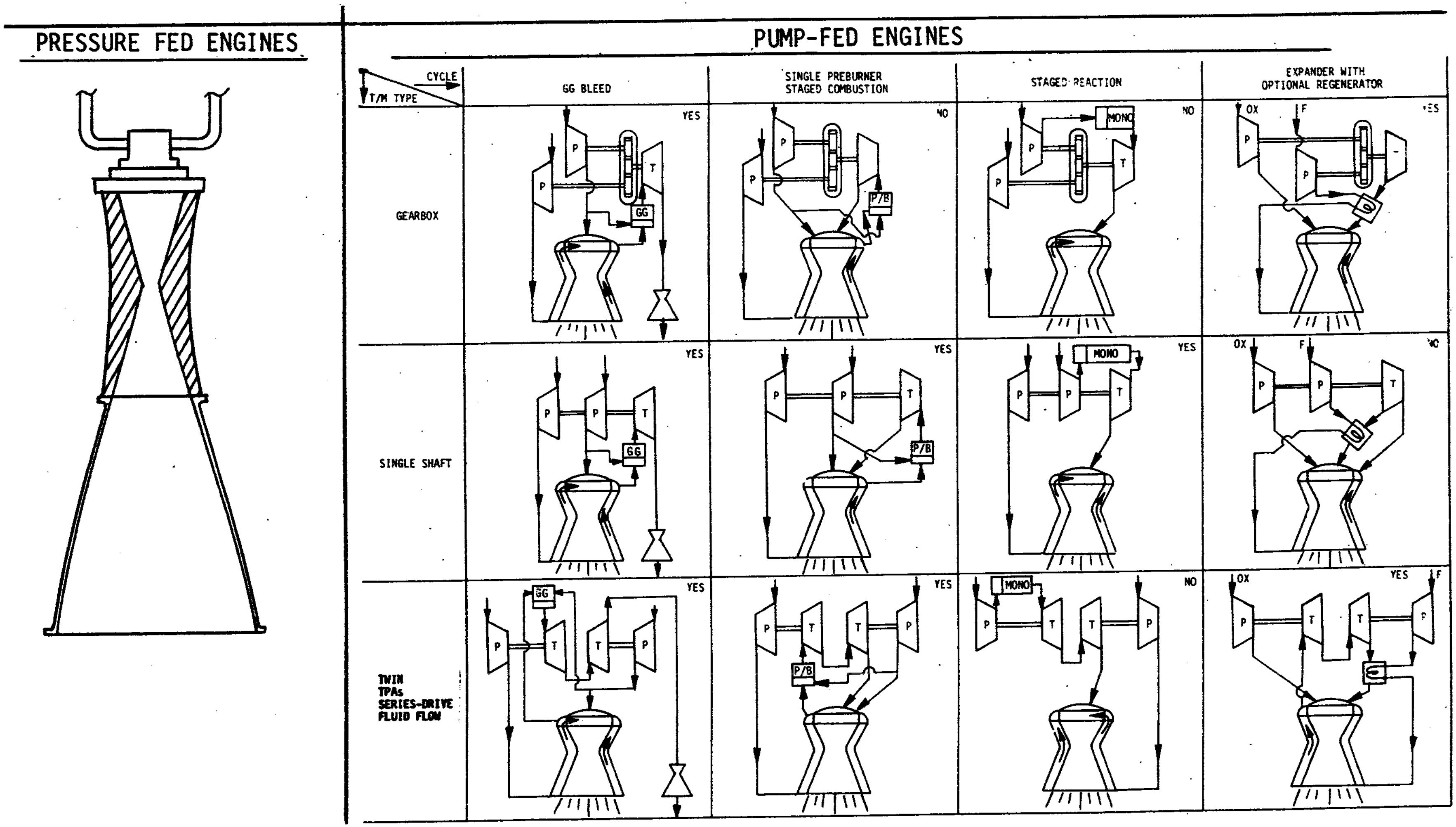


Figure 1c. Representative ELES Engine Cycles

The temperature and pressure drops across regenerative or trans-regenerative cooling jackets are calculated by creating a simplified thrust chamber geometry with slotted channels for coolant flow. Combustion gas and coolant heat transfer coefficients are calculated at discrete points along the chamber and are used to integrate the pressure drop necessary to maintain the chamber wall at nominal operating temperature. Transpiration cooled portions of the chamber are analyzed using techniques developed by Aerojet TechSystems for use with transpiration cooled re-entry vehicle nosetips.

A wide variety of tankage designs are available (see Figure 1d). Tandem tanks are designed by choosing tank head orientation, common or separate tank heads, suspended or monocoque construction, and pressurant tank location. The tanks may or may not contain a positive expulsion bladder or surface tension acquisition device. Non-conventional tankage is designed by choosing the number and type of propellant and pressurization tanks as well as propellant acquisition design. Each tank is individually specified to be toroidal, spherical, or cylindrical with elliptical heads. Tanks are located based on general location input and physical interference between the tanks and envelope.

Propellant tank pressurization options in ELES include cold gas, solid gas generator, and autogenous. With cryogenic propellants, the pressurant collapse is calculated with the Epstein correlation. Pressurization requirements are affected by the vehicle operating temperature regime, and external heating loads.

Throughout the liquid stage design portion of the code there is a need for propellant properties data over an extremely wide range of temperature and pressure. This data is stored in tables for hydrogen and helium. The properties for all other propellants are calculated by the method of corresponding states. This allows analysis to occur in regimes where propellant data may not exist and for propellants which have very little experimental data.

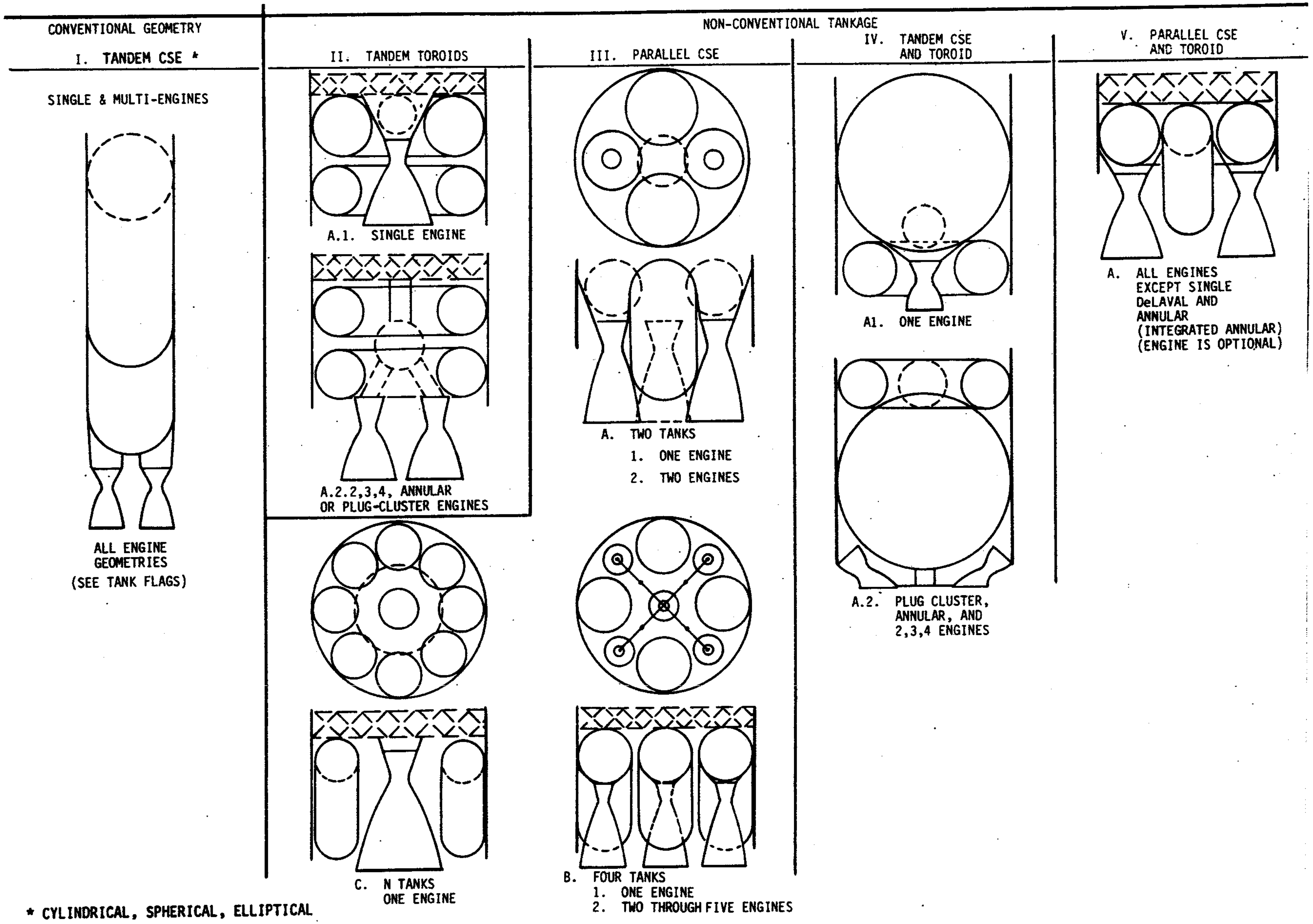


Figure 1d. Representative ELES Tankage Options

2. RECOMMENDED READING

The effective use of ELES-1984 can only be accomplished if the user has a clear understanding of: 1) the major components of a rocket vehicle, 2) the user interface, and 3) the assumptions implicit in the code. This required understanding can be obtained from a thorough reading of the following sources:

(1) Sutton, G.: "Rocket Propulsion Elements" 4th Ed., John Wiley & Son, 1976

(2) Taylor, C.E.: "Expanded Liquid Engine Simulation Computer Program - Technical Information Manual," Aerojet TechSystems Company, 1984

(3) Huzel, D. K.: "Design of Liquid Propellant Rocket Engines" 2nd Ed., NASA, 1971

(4) Your computer center's Fortran 77 manual with special attention to the use of sequential and direct access files, name list input, how to execute a large program, how to print a 132 column output file

(5) This manual

3. INSTALLATION OF ELES CODE

If ELES is not already operational on your computer system the following 2 steps are required.

1) Compile ELES using the FORTRAN 77 compiler available on your system and create an executable file (the procedure will vary from system to system, see your system analyst).

2) Put files PROPLIB and ELESINP onto the system's mass storage. Make sure that PROPLIB is in a direct access format [which corresponds to that shown in the OPEN statement of subroutine MAKCAS (Access = 'Direct', RECL = 132, Form = 'FORMATTED'].

The file ELESINP will need to be a valid input set such as the example input set which is provided with ELES or a copy of an example shown in this document (ELESINP is a sequential file).

If you are operating on a "core" based computer in which ELES is too large, an overlay procedure can be used to create an executable version. The subroutine flow diagram in the ELES-1984 Programmers Manual will be very helpful in creating the overlayed code. Most minicomputers will not have this problem because of their virtual memory design. (ELES was largely developed on a PRIME 750 minicomputer with little concern for core size.)

ELES-1984 has been made operational on a CDC 6600 using an overlay-like procedure. The CDC 6600 available memory was 377700 OCTAL 60 Bit words.

4. HOW ELES CODE OPERATES

ELES-1984 operates in a "batch" type mode. This means that during program execution there is no interaction between the user and the code. After normal program termination ELES will have created output files which can be examined by the user.

The main form of interaction between the user and ELES takes place prior to program execution when the user creates an input file. This input file is submitted to ELES at run time. The input file (named "ELESINP") contains up to 34 NAMELIST blocks which contain the input variables. Although all 34 blocks are not always read by ELES, it is recommended that all namelist blocks be included in ELESINP in their proper order. This precaution can prevent a whole class of termination errors.

When ELES begins execution it uses FORTRAN OPEN statements to open all files it requires for input, output, and scratch purposes. These files are as follows:

Unit No.	Name	Description
4	PLOTFIL	Special Purpose Graphics File
5	-	Scratch File
6	ELESOUT	ELES Output File
7*	ELESINP	ELES Namelist Input File
8	PROPLIB	Propellant Performance Library
9	-	Scratch File
7*	PUNCH	Stores optimizer intermediate values

The files ELESINP and PROPLIB must be in the local environmental in which the executable version of ELES has started execution. (See your computer system analyst for instructions as to how those two files can be accessed from within a FORTRAN program.) ELESINP is opened in subroutine FILOPN. PROPLIB is opened in subroutine MAKCAS.

*Unit Number Shared.

The main output file is ELESOUT. It is formatted to 132 characters per line and makes use of FORTRAN carriage control in column 1. Again see your computer system analyst for the method of printing the output file with carriage control in effect.

For a more detailed discussion of code operation see the "Expanded Liquid Engine Simulation Computer Program - Programmers Manual."

5. BASELINE CASE (N-II DELTA)

When ELES-1984 was first written, the baseline liquid stage was set to the N-II Delta upper stage manufactured by Aerojet. This means that most ELES default inputs are those required to model an N-II Delta. Because so few inputs are required, the easiest case for a new user to run is an N-II Delta.

Figure 5a shows an input data set which models the N-II stage. Notice that following the title on line 1, user comments can be included by placing a 'C' in column 1. Notice also that there are many namelists which have no inputs. This tells ELES to leave the inputs at their default (N-II Delta) values. The dummy optimizer inputs identified in namelist $INPOPT are required even though optimization is turned off (due to an error checking routine in the optimizer).

The input data set in Figure 5a is a complete copy of the file called ELESINP required in the execution environment of ELES. When ELES executes the FORTRAN command:

```
OPEN (UNIT = 7, FILE = 'ELESINP')
```

it expects to find an input file by the name ELESINP in the same format as shown in Figure 5a.

It is possible that system restrictions will dictate minor changes to the format (the starting column of namelist delimiters for example), however, more ELES-specific features such as the sequence of namelists and the variables in each namelist will remain unchanged.

There are a few instances in ELES where two dimensional arrays are input via namelist. Check with your system analyst to make sure that

```
CSTAR (1,2) = 5050., 5100., 5150., 5200.,
```

results in:

CSTAR (1,2) = 5050., CSTAR (2,2) = 5100.,
CSTAR (3,2) = 5150., CSTAR (4,2) = 5200.,

The output from the baseline N-II case is displayed in Figures 5b through 5i. Figure 5b is the warning page for N-II. Its purpose is to alert the user to potential design flaws or program problems.

The first warning is concerned with propellant temperatures at the injector inlet. In this pressure fed storable case, there are no corrections to the temperature schedule and therefore no disagreement in the updated injector temperatures.

The second warning concerns the injector layout. For normal injector design the angle between two injector elements when measured from the throat plane falls between 2.0 and 2.5 degrees. Because it is an existing piece of hardware, we can assume that the designers of the N-II injector responded to another overriding constraint (for example the need to increase performance). This is an example of a warning message which can be overlooked if engineering judgement is used.

The third warning message is strictly informative. It says that the structural wall is minimum gauge and is capable, therefore, of handling more stress than the stage design dictates. This message often appears in relation to tanks in which the tank pressure could be increased without affecting the tank weight.

Figure 5c is the tankage summary for N-II. The information at the top of the page identifies the power cycle, propellant location, pressurization method, and materials of construction. The more important tank and stage dimensions are listed on the left side of Figure 5c. Component lengths, diameters, and thicknesses are specified in inches. The various component weights are listed along the right side of Figure 5c in pounds. Notice that the safety factors used for the tanks are 1.0 because the actual design material properties were input instead of ideal material properties.

ie. Safety factor will be included
in your input ?

```
C
C BECAUSE THE N-II DELTA IS THE DEFAULT LIQUID DESIGN, VERY FEW
C INPUTS ARE REQUIRED TO REPRESENT IT
C
C (NOTICE THAT COMMENTS CAN BE INCLUDED IN THE INPUT DECK BY
C  PLACING A 'C' IN COLUMN ONE)
C
C (DO NOT USE LINE 1 AS A COMMENT LINE - IT IS THE TITLE LINE)
C
C MOST OF THE FOLLOWING NAMELISTS ARE EMPTY, HOWEVER, THEY MUST
C APPEAR IN THE ORDER SHOWN FOR SUCCESSFUL PROGRAM EXECUTION
C
$INPOPT
C
C    SET INDES=1 TO DESIGN STAGE ONLY (IE. DO NOT FLY TRAJECTORY)
    INDES=1,
C
C    DUMMY OPTIMIZER INPUTS REQUIRED
    IOPF=0,
    DELMIN=.07,
    DEL=5.,
   ITLIM=500, TLIMIT=900.,
  IPLOT=0,
    IPRINT=0,2,2,2,1,
   IOPT=92,42,
    IERRMD=0,
    IOBJF=13,
    OBJSCL=1.,
$END
$NLF
$END
$INPGEN
C    GENERAL STAGE DESCRIPTIONS
   EPS=65., PC=125., EPSATT=7.5,
   DMOTOR=68.6,
   KSTAGE=2,
   NSTGES=1,
   WMISC=71.0,
$END
$INTSTG
$END
$NOZZLE
$END
$MATER
$END
$FILMNT
$END
$PROPEL
$END
$INTRAJ
$END
$GUIDA
$END
$AEROD
$END
```

Figure 5a. Baseline Input Data Set (Sheet 1 of 3)

```
$END
$ORB
$END
$LIQUID
C
C   FORWARD SKIRT LENGTH
  FFSKTL=.3,
C
C   PRESSURE SCHEDULE INPUTS
  CPLINF=.115,
  CPLINO=.145,
  CPVLVF=.275,
  CPVLVO=.198,
  FCHGFL=.28,
  FCHGOX=.36,
C
C   ENGINE VACUUM THRUST
 FVAC=9850.,
$END
$LFLAG
C
C  USE PHYSICAL ENGINE WEIGHT MODEL
  KWTMOD=1,
$END
$LTANK
C   SET TANK ULLAGE FRACTIONS
  ULLFOX=.045,
  ULLFFL=.045,
$END
$TNKGEO
C
C   NUMBER OF HELIUM BOTTLES IN ENGINE BAY
    NPRB=3,
$END
$BLADER
$END
$COLDG
$END
$SOLDGG
$END
$PUMP
$END
$INJECT
$END
$LIQENG
$END
$INREGN
C
C   SET WALL TEMPERATURE FOR SILICA PHENOLIC ABLATIVE
  TGWNOM=3000.,
$END
$ABLATE
$END
$LIQMAT
C
C SAFETY FACTORS ARE INCLUDED IN DEFAULT USER DEFINED
C MATERIAL PROPERTIES
```

Figure 5a. Baseline Input Data Set (Sheet 2 of 3)

```
  SFOXTK=1.0,
  SFFLTK=1.0,
  SFPRTK=1.0,
  SFSTRC=1.0,
$END
$CXWMLT
C
C  USE NON-IDEAL TANK WEIGHT MULTIPLIER OF 1.25
  CXWTNK=1.25,
$END
$LPROP
$END
$LGPERF
$END
$THRCT
$END
$LFUEL
$END
$LOXID
$END
$NCTINP
$END
$TANKHX
$END
```

Figure 5a. Baseline Input Data Set (Sheet 3 of 3)

```
                                       @     @    @@@    @@@@   @     @   @@@   @     @  @@@@
                                       @     @   @   @   @   @  @     @    @    @     @ @
                                       @     @   @   @   @   @  @@    @    @    @@    @ @
                                       @     @   @@@@@   @@@@   @ @   @    @    @ @   @ @  @@
                                       @  @  @   @   @   @ @    @  @@ @    @    @  @@ @ @   @
                                       @@   @@   @   @   @  @   @     @    @    @     @ @   @
                                       @     @   @   @   @   @  @     @   @@@   @     @  @@@@


                                       THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TEMPERATURES USED FOR VAPORIZATION WERE         530.0      530.0
MOST RECENT CORRECTED VALUES    530.0      530.0

 INJECTOR ELEMENT TO THROAT ANGLE =   1.66          RECOMMENDED RANGE = 2.0 TO 2.5


 MINIMUM GAUGE DESIGNS STRUCTURAL WALL THICKNESS
```

Figure 5b. Baseline Warning Page

```
          TANKAGE SUMMARY FOR STAGE #1
                PRESSURE FED
                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 - USER DEF )  (PRESSURANT - USER DEF )


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

         STAGE DIAMETER                       68.6                      AFT TANK                               118.9
         TOTAL STAGE LENGTH                  221.0                      FORWARD TANK                           281.2
         TOTAL TANK LENGTH                   110.7                      PRESSURE TANK                          138.3
         NOZZLE LENGTH                        76.7                      TANK CONSTRUCTION WEIGHT               134.6
         CHAMBER LENGTH                       18.7
         INJECTOR FACE FORWARD LENGTH         12.9                      STRUCTURAL WALL                          0.0
         MOUNT LENGTH                          2.0                      AFT SKIRT                               30.7
                                                                        FORWARD SKIRT                           38.1
         TANK HEAD ELLIPSE RATIO               1.00                     TANK MOUNT                               0.0
         PRESSURE TANK ELLIPSE RATIO           1.00
         AFT TANK HEAD HEIGHT                 34.3                      PRESSURE TANK INSULATION                 0.0
         FORWARD TANK HEAD HEIGHT             34.3                      FUEL TANK INSULATION                     0.0
         PRESSURE TANK HEAD HEIGHT            11.2                      OXIDIZER TANK INSULATION                 0.0
         PRESSURE TANK DIAMETER               22.4
         AFT TANK CYLINDRICAL LENGTH           1.5                      REVERSE HEAD STIFFENER                   0.0
         FORWARD TANK CYLINDRICAL LENGTH      40.6                      FUEL ACQUISITION SYSTEM                  0.0
         PRESSURE TANK CYLINDRICAL LNGTH       0.0                      OXIDIZER ACQUISITION SYSTEM              0.0
                                                                        PRESSURANT CONTROL HARDWARE              6.7
         AFT LINE DIAMETER                     0.77                     TANK LINES                              14.4
         FORWARD LINE DIAMETER                 0.79
         AFT SKIRT LENGTH                      9.69                     BURNED FUEL                           4685.1
         FORWARD SKIRT LENGTH                 10.29                     BURNED OXIDIZER                       8565.8
                                                                        FUEL RESIDUAL                           12.2
         STRUCTURAL WALL THICKNESS             0.035                    OXIDIZER RESIDUAL                       20.8
         AFT TANK WALL THICKNESS               0.068                    STORED PRESSURANT                       25.0
         FORWARD TANK WALL THICKNESS           0.067                    HOLD TIME FUEL BOILOFF                   0.0
         PRESSURE TANK WALL THICKNESS          0.185                    HOLD TIME OX BOILOFF                     0.0
         AFT TANK DOME THICKNESS               0.035                    FLIGHT FUEL BOILOFF                      0.0
         FORWARD TANK DOME THICKNESS           0.035                    FLIGHT OXIDIZER BOILOFF                  0.0
         PRESSURE TANK DOME THICKNESS          0.185
                                                                        MISC EXPENDED FUEL                       0.0
         FUEL TANK MLI THICKNESS               0.00                     MISC EXPENDED OXIDIZER                   0.0
         FUEL TANK SOFI THICKNESS              0.00
         OXIDIZER TANK MLI THICKNESS           0.00                     MISCELLANEOUS WEIGHT                    71.0
         OXIDIZER TANK SOFI THICKNESS          0.00                     INTERSTAGE WEIGHT                        0.0
         PRESSURE TANK INSULATION THICK        0.00
                                                               ... INPUT MINIMUM SAFETY FACTORS ...

         FUEL TNK HEAT FLUX(BTU/HR IN**2)      0.00                     STRUCTURAL WALL                          1.00
         OX TANK HEAT FLUX(BTU/HR IN**2)       0.00                     LINES                                    2.00
         FUEL BOILOFF RATE (LB/SEC)            0.000                    OXIDIZER TANK                            1.00
         OX BOILOFF RATE (LB/SEC)              0.000                    FUEL TANK                                1.00
                                                                        PRESSURE TANK                            1.00
```

Figure 5c. Baseline Tankage Summary

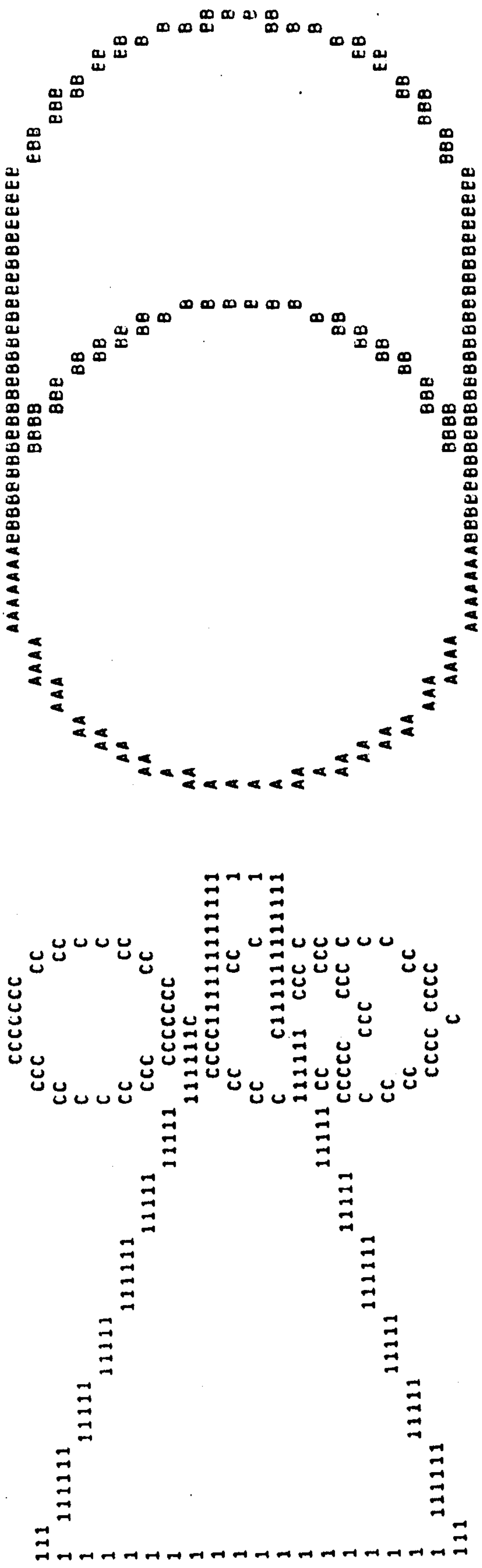


Figure 5d. Baseline Graphical Output

```
              PROPELLANT SUMMARY FOR STAGE #1
                   PROPELLANT COMBINATION IS USER DEFINED


                                         NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0461

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

      NOMINAL TANK PRESSURE(PSIA)          222.8               NOMINAL TANK PRESSURE(PSIA)          218.5

      NOMINAL PROPELLANT TEMP(DEGR)        530.0               NOMINAL PROPELLANT TEMP(DEGR)        530.0
      NOMINAL DENSITY(LB/IN**3)              0.0531            NOMINAL DENSITY(LB/IN**3)              0.0333
      NOMINAL VAPOR PRESSURE(PSIA)          14.8               NOMINAL VAPOR PRESSURE(PSIA)           2.1

      MAX PROPELLANT TEMP(DEGR)            550.0               MAX PROPELLANT TEMP(DEGR)            550.0
      MAX TEMP DENSITY(LB/IN**3)             0.0517            MAX TEMP DENSITY(LB/IN**3)             0.0329
      MAX TEMP VAPOR PRESSURE(PSIA)         25.8               MAX TEMP VAPOR PRESSURE(PSIA)          3.5

      MIN PROPELLANT TEMP(DEGR)            510.0               MIN PROPELLANT TEMP(DEGR)            510.0
      MIN TEMP DENSITY(LB/IN**3)             0.0545            MIN TEMP DENSITY(LB/IN**3)             0.0337
      MIN TEMP VAPOR PRESSURE(PSIA)          8.0               MIN TEMP VAPOR PRESSURE(PSIA)          1.3
```

Figure 5e. Baseline Propellant Summary

Figure 5d is the stage graphical output. The schematic is drawn to scale with actual tank head ellipse ratios. The size of the schematic is automatically adjusted to fill the page. Because some line printers do not use the standard number of characters per inch in the horizontal and vertical dimensions, that information may be input by the user. All graphics are performed by pseudo-Tektronix routines in ELES which mimic standard Tektronix commands. It is therefore relatively easy to convert ELES to create high resolution Tektronix schematics.

Tanks are drawn with alphabetic characters; engines are drawn with numeric characters. The sequence in which components are drawn can result in hidden lines. The sequence used by ELES is to begin with tank A and proceed alphabetically to tank C and then to begin with engine 1 and proceed up to the highest numbered engine. (Notice how the engine overwrites the three pressure tanks in the engine bay.)

Only a schematic of the engine is represented. For schematic purposes the combustion chamber diameter is considered constant from the injector to the throat plane. The nozzle is drawn as a cone regardless of actual contour. The exit diameter and length are drawn to scale.

Figure 5e is a propellant summary over the operating temperature range of the on-board propellants. For storable propellants this corresponds to the operating temperature range of the vehicle. The first line of the propellant summary declares that the propellant combination is a user defined propellant combination. The N-II Delta uses N_2O_4/A-50 which is not a library propellant combination (A-50 is 50% hydrazine and 50% UDMH). ELES allows for easy simulation of non-library propellants using propellant property inputs. Using the method of corresponding states, ELES predicts propellant properties over a very wide range of temperature and pressure. These calculations are used to design tanks, pumps, regenerative cooling jackets, etc.

The properties displayed in Figure 5e are primarily tank design parameters. The density of each propellant at its maximum temperature is used to calculate the tank volume requirements. The vapor pressure is used in determining tank pressure requirements.

An engine summary is displayed in Figure 5f. It begins with basic engine design information (power cycle, cooling method, propellant combination) and then proceeds to more detailed engine descriptions. The left side of the engine summary is devoted to size and weight information. The right side is devoted to performance-related engine parameters including a breakdown of individual loss mechanisms to engine performance. References to "core" and "barrier" are due to the core and barrier stream tube model used in the performance calculations.

The pressure and temperature schedules (Figure 5g) show the pressure and temperature at various key points in the propellant feed system as well as pressure and temperature changes across key sections of the feed system. A flowrate schedule is also included which shows flowrates through the major components of the feed system.

The overall stage weight summary (Figure 5h) is a list of all items in the stage which contribute to its weight. Inert weights are presented separately from propellant or pressurant weights.

The final page of output is the vehicle summary (Figure 5i) which gives an overview of all vehicle stages. The stage masses, mass fractions, dimensions, and performances are overviewed.

```
ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
      PRESSURE FED
      CHAMBER IS ABLATIVELY COOLED
      NOZZLE IS RADIATION COOLED
      PROPELLANT COMBINATION IS USER DEFINED

... ENGINE DIMENSIONS (INCHES) ...                          ... PERFORMANCE ...
      THROAT DIAMETER                     7.42
      CHAMBER DIAMETER                   11.82                    DELIVERED ISP(VAC),SEC              315.2
      NOZZLE EXIT DIAMETER               59.80                    IDEAL ISP(ODE),SEC                  345.0
      NOZZLE EXTENSION ATTACH DIAM       20.31
      CONVERGENT CHAMBER LENGTH          18.70                    DELIVERED CSTAR,FT/SEC             5562.
      CYLINDRICAL CHAMBER LENGTH          0.00                    IDEAL CSTAR,FT/SEC                 5633.
      ABLATIVE THICKNESS (THROAT)         1.17
      ABLATIVE THICKNESS (CHAMBER)        0.92                    CHAMBER PRESSURE,PSIA               125.
      CHAMBER STRUCTURAL THICKNESS        0.100                   THRUST PER ENGINE(VAC),LBF         9850.
      NOZZLE EXTENSION THICKNESS          0.019                   TOTAL VAC THRUST,LBF               9850.
                                                                  BURN TIME,SEC                       424.1
      NOZZLE EXIT AREA RATIO             65.0
      CHAMBER CONTRACTION RATIO           2.5                     OVERALL EFFICIENCY                    0.914
      NOZ EXTENSION ATTCH AREA RATIO      7.5
      NOZZLE LENGTH/(MIN RAO LENGTH)      1.177                   ENERGY RELEASE EFFICIENCY             0.987
      NOZZLE LENGTH                      76.65                    NOZZLE EFFICIENCY                     0.926
      CHAMBER LENGTH                     18.70
      INJECTOR FACE FORWARD LENGTH       12.94                    KINETIC EFFICIENCY                    0.959
      MOUNT LENGTH                        2.00                    VAPORIZATION EFFICIENCY               1.000
                                                                  MIXING EFFICIENCY                     0.953
                                                                  MR DISTRIBUTION EFFICIENCY            0.994
... ENGINE WEIGHTS (POUNDS) ...                                   BOUNDARY LAYER EFFICIENCY             0.977
      NOZZLE EXTENSION                   68.0                     DIVERGENCE EFFICIENCY                 0.988
      CHAMBER                            62.8                     TWO PHASE EFFICIENCY                  1.000
      DIPROPELLANT VALVE                  4.0
      INJECTOR                           13.7                     FOR   1 ENGINES
      TCA SUPPORT HARDWARE               10.1                     OXIDIZER FLOWRATE,LB/SEC             20.20
      TCA CONSTRUCTION                    7.4                     FUEL FLOWRATE,LB/SEC                 11.05
      ---------------------------                                 TOTAL FLOWRATE,LB/SEC                31.25
      SINGLE THRUST CHAMBER ASSY        166.0
                                                                  CORE MIXTURE RATIO                    1.90
      THRUST MOUNT                       26.7                     CORE TEMPERATURE,DEG R             5577.
      GIMBAL SYSTEM                      31.7                     BARRIER MIXTURE RATIO                 0.58
      ENGINE BAY LINES                    5.2                     BARRIER TEMPERATURE,DEG R          2988.
                                                                  ENGINE MIXTURE RATIO                  1.83
                                                                  FUEL FILM COOLING FRACTION            0.04

                                                                  INJ ELEMENT DENSITY,ELEM/IN**2        3.02
                                                                  OX ORIFICE DIAMETER (IN)              0.041
                                                                  FUEL ORIFICE DIAMETER (IN)            0.030
```

Figure 5f. Baseline Engine Summary

```
                        PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
                        PRESSURE FED


                                   PRESSURE(PSIA)                          TEMPERATURE(DEG R)
                                 FUEL          OXIDIZER                  FUEL          OXIDIZER

                                                     ... PRESSURANT ...
        MAX STORAGE            4365.0         4365.0                    550.0          550.0
        VENT                    240.3          245.1                    828.9          655.6 (SATURATION TEMP OF PROPELLANT)
        ULLAGE                  218.5          222.8                     ----           ----

                                                     ... PROPELLANT ...
        TANK PROPELLANT         218.5          222.8                    530.0          530.0
        MAIN VALVE INLET        203.5          203.8                    530.0          530.0
        MAIN VALVE OUTLET       167.5          177.9                    530.0          530.0
        INJECTOR INLET          167.5          177.9                    530.0          530.0
        INJECTOR FACE                  130.8
        COMBUSTION CHAMBER             125.0                                  5577.5

--------------------------------------------------------------------------------------------------------------

                                           ... COMPONENT PRESSURE/TEMPERATURE CHANGES ...
        FEED LINE                15.0           19.0                      0.0            0.0
        MAIN VALVE               36.0           25.9                      0.0            0.0
        INJECTOR                 36.6           47.1                      0.0            0.0

--------------------------------------------------------------------------------------------------------------

                             FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
                             PRESSURE FED


                                      FUEL          OXIDIZER
        TANK OUTFLOW                11.048         20.198
        MAIN VALVE                  11.048         20.198
        STORED PRESSURANT (AVE)             0.06
        INJECTOR                    11.048         20.198
```

Figure 5g. Baseline Temperature/Pressure/Flowrate Summary

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

          AFT TANK                                  118.9
          FORWARD TANK                              281.2
          PRESSURE TANK                             138.3
          TANK CONSTRUCTION WEIGHT                  134.6
          TANK LINES                                 14.4


          AFT SKIRT                                  30.7
          FORWARD SKIRT                              38.1
          TANK MOUNT                                  0.0
          STRUCTURAL WALL                             0.0

          PRESSURE TANK INSULATION                    0.0
          FUEL TANK INSULATION                        0.0
          OXIDIZER TANK INSULATION                    0.0

          FUEL ACQUISITION SYSTEM                     0.0
          OXIDIZER ACQUISITION SYSTEM                 0.0
          PRESSURANT CONTROL HARDWARE                 6.7

           1 THRUST CHAMBER ASSY(S)                 166.0
           1 THRUST MOUNT(S)                         26.7
           1 GIMBAL SYSTEM(S)                        31.7
           1 ENGINE BAY LINE(S)                       5.2

           1 IGNITION SYSTEM(S)                       0.0
           1 HOT GAS MANIFOLD(S)                      0.0
           1 TPA ASSY(S)                              0.0
           1 TPA START SYSTEM(S)                      0.0
           1 GAS GENERATOR/PREBURNER(S)               0.0

          FLIGHT FUEL BOILOFF                         0.0
          FLIGHT OXIDIZER BOILOFF                     0.0
          EXPENDABLE WEIGHT                           0.0
          MISCELLANEOUS WEIGHT                       71.0
          ---------------------------------------------------

          TOTAL INERT WEIGHT                       1063.3


          INTERSTAGE WEIGHT                           0.0
          BURNED FUEL                              4685.1
          BURNED OXIDIZER                          8565.8
          FUEL RESIDUAL                              12.2
          OXIDIZER RESIDUAL                          20.8
          STORED PRESSURANT                          25.0
          MISC ON-BOARD FUEL                          0.0
          MISC ON-BOARD OXIDIZER                      0.0

          ---------------------------------------------------

          GROSS IGNITION WEIGHT                   14372.2
          GROSS BURNOUT WEIGHT                     1121.3

          HOLD TIME FUEL BOILOFF                      0.0
          HOLD TIME OX BOILOFF                        0.0
```

Figure 5h. Baseline Weight Summary

```
  N-II DELTA UPPER STAGE

     ****  VEHICLE SUMMARY  ****

                                            STAGE #1

     ..WEIGHT,LB..

PAYLOAD                                          0.0
STAGE WEIGHT                               14372.2
   USABLE PROPELLANT                       13250.9
   FIXED INERT
     PROPULSION SYSTEM                      1063.3
     INTERSTAGE                                0.0
   EXPENDED INERT
     EXPELLED                                  0.0
     JETTISONED                                0.0
GROSS IGNITION WEIGHT                      14372.2
GROSS BURNOUT WEIGHT                        1121.3
PROPELLANT MASS FRACTION                       0.922


     ..DIMENSIONS,IN..

STAGE DIAMETER                               68.60
NOZZLE EXIT DIAMETER                         59.80
NUMBER OF NOZZLES                            1
STAGE LENGTH                                220.98


     ..PERFORMANCE..

PROPELLANT                                LIQUID
THRUST,VACUUM DELIVERED,LBF               9850.0
PC,PSIA                                    125.0
USABLE PROPELLANT MR                         1.83
NOZZLE AREA RATIO                           65.00
BURN TIME,SEC                              424.08
ISP,VACUUM DELIVERED,SEC                   315.2
ISP EFFICIENCY                               0.914
PROPELLANT FLOW RATE,LB/SEC                 31.25
```

Figure 5i. Baseline Vehicle Summary

6. FORMULATING AN INPUT DATA SET

There are four main areas of attention in ELES; liquid stage design, solid stage design, trajectory, and optimization. Although this document only attempts to address liquid stage design, each area is equally important to a simulation which employs them. Appropriate documentation for solid stage design, trajectory, and optimization are available through AFRPL.

Prior to running ELES considerable thought is required for each component in each stage of the vehicle being modeled. A clear understanding of what is to be modeled is absolutely essential if the results of ELES are to be meaningful. That understanding will more easily lead to an unambigous vehicle definition for which ELES can perform the desired analysis.

Because the translation from vehicle concept to computer input is so critical to the code's operation, a worksheet has been created to aid the process. The worksheet presented in Figure 6a is an aid to formulating a stage description prior to creating an input data set. It is highly recommended that the user photocopy the worksheet and use it whenever beginning a new modeling task. After the worksheet has been completed, it can be used to generate the namelist input data set directly.

Figure 6a. S 1984 - Input Worksheet

TITLE -

STAGE #

Total Number of Stages

Vehicle Payload Wt. (lbm)

Miscellaneous Stage Wt. (lbm)

Expendable Stage Wt. (lbm)

Upper Interstage Material Properties

density (lb/in^3)

design stress (psia)

modulus of elasticity (psia)

safety factor (-)

Kind of Stage
(Circle one)

1) solid

2) liquid

VARIABLE	NAMELIST	UNITS	DEFAULT
NSTGES	INPGEN	-	3
WPAYLD	INPGEN	lbm	0.0
WMISC	INPGEN	lbm	0.0
WEXPND	INPGEN	lbm	0.0
RHOINT	INTSTG	lb/in^3	0.101
SINST	INTSTG	psia	220000.
EINSTG	INTSTG	psia	1.8E6
SFINST	INTSTG	-	1.5
KSTAGE	INPGEN	-	1

Tank Geometry

Tandem Tanks

(Draw Sketch Here)

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

pressure tank forward (1-3)
pressure tank integral with forward tank (4)
pressure tank in engine bay (0)

propellant tank head ellipse ratio

pressurant tank head ellipse ratio

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

propellant location
(1 = fuel aft, 2 = not)

VARIABLE	NAMELIST	UNITS	DEFAULT
NCTNK	LFLAG	-	0
MNCQA	TNKGEO	-	1
MNCQF	TNKGEO	-	1
KDOME	TNKGEO	-	1
KPRESS	TNKGEO	-	0
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	ELTNK1-4	NCTINP	-	1.0
Tank types (1 = CSE, 2 = torus)	KTANK1-4	NCTINP	-	1
Tank contents (1 = ox, 2 = fuel, 3 = press)	INTNK1-4	NCTINP	-	1
Tank angular location (deg)	TANGL1-4	NCTINP	deg	0.0
Tank radial location	RADLO1-4	NCTINP	-	0.0
Kind of dimensional input				
dimensionless (0)	KALMOD	NCTINP	-	0
L_{cyl}/D ; R_{hub}/R_{tube}	RDIM1-4	NCTINP	-	2.0
major dimension (in) (1) R_{tank} ; R_{hub}	RMAJ1-4	NCTINP	in	25.0
Engine angular location (deg)	ENGAN1-4	NCTINP	deg	0.0
Engine radial location	ENGRD1-4	NCTINP	-	0.0
Stage Diamater (in) ☐	DMOTOR	INPGEN	in	66.0
Forward Skirt Length (in) ☐	FFSKTL	LIQUID	-	0.3
Aft Skirt Length (in) ☐	FASKTL	LIQUID	-	0.067

Figure 6a. nt.)

Propellant Combination (Circle One)	Nominal Mixture Ratio
0) user defined	-
1) N_2O_4/MMH	2.3
2) MON-25/MHF-3	2.2
3) CIF_5/MHF-3	2.8
4) MON-25/60% MHF-3 + 40% Al	0.85
5) LO_2/LH_2	5.0
6) LO_2/RP-1	2.7
7) LO_2/CH_4	3.4
8) LF_2/LH_2	9.0
9) LF_2/N_2H_4	2.3

Propellant Mixture Ratio ☐

Number of Engines ☐

Vacuum Thrust Per Engine (lb_f) ☐

Chamber Pressure (psia) ☐

VARIABLE	NAMELIST	UNITS	DEFAULT
IPROP	LFLAG	-	0
OFCORE	LQPERF	-	1.9
NTC	LIQENG	-	1
FVAC	LIQUID	lb_f	0.0
PC	INPGEN	psia	600.0

ure 6a. nt.)

Engine Powe cle
(Circle One)

0) Pressure Fed
1) Gas Generator Bleed
2) Staged Combustion (fuel rich preburner)
3) Expander Cycle (fuel cooled)
4) Staged Reaction (monopropellant fuel)

Gas Generator/Pre-Burner

Mixture Ratio

Ratio of Specific Heats

Specific Heat (BTU/lb °R)

Molecular Weight

Tank Outlet Net Positive Suction Pressures

Oxidizer (psia)

Fuel (psia)

Pump Configuration

1) Gearbox
2) Single Shaft TPA
3) Twin TPA in series
4) Twin TPA in parallel

Boost Pumps

oxidizer (o = no)

fuel (1 = yes)

VARIABLE	NAMELIST	UNITS	DEFAULT
KCYCLE	LFLAG	-	0
OFGGPB	PUMP	-	0.1
GAMGPB	PUMP	-	1.25
CPGGPB	PUMP	BTU/lb °R	0.721
WMGGPB	PUMP	-	14.0
OXNPSP	PUMP	psia	10.0
FLNPSP	PUMP	psia	10.0
JCNFIG	PUMP	-	2
JBPOX	PUMP	-	0
JBPFL	PUMP	-	0

Figure 6a. (cont.)

Burned Propellant Wt.

Ullage Fractions

Oxidizer

Fuel

Propellant Acquisition Device
(Circle One)

0) none
1) transverse collapsing aluminum bladder
2) full bonded rolling diaphram - aluminum
3) half bonded rolling diaphram - aluminum
4) full bonded rolling diaphram - stainless steel
5) half bonded rolling diaphram - stainless steel
6) surface tension device

Propellant Tank Pressurization
(Circle One)

0) non-autogenous
    1) solid gas generator
    2) cold helium

1) autogenous

Cold Helium Storage Pressure

Helium Tank Final Pressure Fraction
(less than 1.0 indicates blowdown)

VARIABLE	NAMELIST	UNITS	DEFAULT
WTLPRP	LIQUID	lb.	13250.0
ULLFFL	LTANK	-	0.02
ULLFOX	LTANK	-	0.02
KACQOX	LFLAG	-	0
KACQFL	LFLAG	-	0
KGASOX	LFLAG	-	0
KGASFL	LFLAG	-	0
KGAS	LFLAG	-	2
PICG	COLDG	psia	4365.0
FPULCG	COLDG	-	0.8

rigure 6 (cont.)

Materials of Construction
(fill in material ID#)

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 ☐
Oxidizer Tank ☐
Pressurant Tank ☐
Structure and Skirts ☐

Design Safety Factors

Fuel Tank ☐
Oxidizer Tank ☐
Pressure Tank ☐
Structure and Skirts ☐
lines ☐

VARIABLE	NAMELIST	UNITS	DEFAULT
MTNKFL	LIQMAT	-	1
MTNKOX	LIQMAT	-	1
MATPT	LIQMAT	-	2
MATSTR	LIQMAT	-	1
MATNK1-4	NCTINP	-	1
RHO	LIQMAT	lb/in^3	-
YMOD	LIQMAT	psi	-
SIGMAX	LIQMAT	psi	-
SPHEAT	LIQMAT	BTU/lb °R	-
CONDCT	LIQMAT	BTU/in sec °R	-
TMING	LIQMAT	in	0.035
TMINGS	LIQMAT	in	0.035
SFFLTK	LIQMAT	-	1.25
SFOXTK	LIQMAT	-	1.25
SFPRTK	LIQMAT	-	1.5
SFSTRC	LIQMAT	-	1.25
SFLINE	LIQMAT	-	2.0
SFTNK1-4	NCTINP	-	1.5

Figure 6a ont.)
Propellan k Insulation (in)

Fuel Tank	
SOFI Thickness	
MLI Thickness	
Oxidizer Tank	
SOFI Thickness	
MLI Thickness	
Engine Expansion Area Ratio	
Nozzle Extension Attach Area Ratio	
Engine Contraction Ratio	
Combustion Chamber Length (in)	

Nozzle Type (Circle One)	IPLUG	KNOZ
Conical	0	1
Rao/Bell	0	2
Plug Cluster	1	-
Annular	2	-

VARIABLE	NAMELIST	UNITS	DEFAULT
KHXOPT	LFLAG	-	0
TSOFIF	TANKHX	in	0.0
TMLIF	TANKHX	in	0.0
TSOFIO	TANKHX	in	0.0
TMLIO	TANKHX	in	0.0
EPS	INPGEN	-	10.0
EPSATT	INPGEN	-	1.0
CR	LIQENG	-	2.54
XLC	LIQENG	in	0.0
XLN	LIQENG	in	18.7
IPLUG	LIQUID	-	0
KNOZ	LIQENG	-	2
ALFNOZ	NOZZLE	deg	15.0
RATMLR	LIQENG	-	1.177
KEXNOZ	LIQENG	-	1

Combustion Chamber Cooling Method
(Circle One)

1) Ablative
2) Regenerative
3) Trans-Regen
4) Radiation

Nozzle Cooling Method
(Circle One)

1) Ablative
2) Regenerative
3) Trans-Regen
4) Radiation
5) Film

VARIABLE	NAMELIST	UNITS	DEFAULT
KOOLTC	LFLAG	-	1
TGWNOM	INREGN	°R	2000.0
DIFTBF	INREGN	-	1.0
IRPRNT	INREGN	-	0
GWMING	INREGN	in	0.025
WALLK	INREGN	BTU/in sec °R	0.00039
EPSTRU	INREGN	-	2.0
EPSTRD	INREGN	-	1.2
TDESTR	INREGN	°R	2000.0
KOOLNZ	LFLAG	-	4
TNENOM	LIQENG	°R	2000.0

Pressure Drop Across Injector

(15% of Pc is optimistic)
(25% of Pc is nominal)
(40% of Pc is conservative)

Fuel ☐

Oxidizer ☐

Pressure Drop Across Valve

(3-30% of Pc)

Fuel ☐

Oxidizer ☐

Pressure Drop Across Lines

(3-30% of Pc)

Fuel ☐

Oxidizer ☐

Injector Element Density (elem/in^2)

(1.0 = coarse pattern, 4.0 = nominal pattern)
(15.0 = platelets, 40.0 = hyperthin platelet)

☐
(IELDEN = 1)

Injector Element Type
(used to correct drop size)

(Circle One)

(Groups are in increasing order of atomizing efficiency)

3.0) Showerhead, shear co-ax

1.0) like-doublets, splash plate,
X doublet, V doublet,
Pre-atomized triplet

0.5) Vortex, swirl coax

0.33) unlike Triplet, unlike doublet

VARIABLE	NAMELIST	UNITS	DEFAULT
FCHGFL	LIQUID	-	0.15
FCHGOX	LIQUID	-	0.15
CPVLVF	LIQUID	-	0.409
CPVLVO	LIQUID	-	0.28
CPLINF	LIQUID	-	0.172
CPLINO	LIQUID	-	0.207
ELDENS	INJECT	elem/in^2	3.1
IELDEN	INJECT	-	1
RMFFL	LQPERF	-	0.33
RMFOX	LQPERF	-	0.33
FLOPEL	INJECT	-	2.0
OXOPEL	INJECT	-	1.5

Translating Nozzle
(Circle One)

0) None
1) Spring Actuated
2) Gas Deployed Skirt

Translating Nozzle Material Density (lb/in^3) ☐

Gimbal Angle (deg) ☐

Number of Gimbaling Engines ☐

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

Aluminum	0.098 lb/in^3, 25000 psia	
Stainless Steel	0.28 lb/in^3, 25000 psia	
Columbium	0.32 lb/in^3, 25000 psia	
Silica Phenolic	0.0632 lb/in^3, 25000 psia	

(used with KWTMOD = 1)

	density (lb/in^3)	strength (psi)
CHAMBER		
NOZZLE		
INJECTOR		
VALVE		☒

Stage Operating Temperature Range (°F)

Minimum temperature ☐

Nominal temperature ☐

Maximum temperature ☐

VARIABLE	NAMELIST	UNITS	DEFAULT
KTRNOZ	LIQENG	-	0
EPTRAT	LIQENG	-	50.0
ROTRNZ	LIQMAT	lb/in^3	0.28
GMBANG	LIQUID	deg	6.0
NGIMB	LIQUID	-	1
KGPOWR	LIQUID	-	0
KWTMOD	LFLAG	-	0
RHCABL	LIQMAT	lb/in^3	0.0632
RHCSTR	LIQMAT	lb/in^3	0.0632
RHOGW	LIQMAT	lb/in^3	0.28
RHOCLS	LIQMAT	lb/in^3	0.322
SIGCHM	LIQMAT	psi	25000.0
SIGCLS	LIQMAT	psi	25000.0
RHONZE	LIQMAT	lb/in^3	0.32
SIGNZE	LIQMAT	psi	25000.0
TNZMIN	LIQENG	in	0.010
RHOINJ	LIQMAT	lb/in^3	0.098
SIGINJ	LIQMAT	psi	25000.0
RHOVLV	LIQMAT	lb/in^3	0.098
TMIN	LIQUID	°F	60.0
TOP	LIQUID	°F	75.0
TMAX	LIQUID	°F	90.0

Figure 6a. nt.)

Weight Multipliers

All Tanks	
Fuel Tanks	
Oxidizer Tanks	
Pressure Tanks	
Structure	
Propellant Lines	
Total Engine	
Injector	
Valve	
Chamber	
Nozzle Extension	
Hot Gas Ducts	
Gimbal System	
Thrust Mount	
Gas Generator Injector	
Turbo Pump Assembly	
Engine Bay Lines	

VARIABLE	NAMELIST	UNITS	DEFAULT
CXWTNK	CXWMLT	-	1.7
CXNCT1-4	NCTINP	-	1.0
CXWFLT	CXWMLT	-	1.0
CXWOXT	CXWMLT	-	1.0
CXWPTN	CXWMLT	-	1.0
CXWSTR	CXWMLT	-	1.0
CXWATL	CXWMLT	-	1.0
CXWFTL	CXWMLT	-	1.0
CXWPTL	CXWMLT	-	1.0
CXWENG	CXWMLT	-	1.05
CXINJ	CXWMLT	-	1.0
CXVALV	CXWMLT	-	1.0
CXWCHM	CXWMLT	-	1.0
CXWNZE	CXWMLT	-	1.1
CXWDUC	PUMP	-	2.5
CXWGIM	CXWMLT	-	1.0
CXWTHM	CXWMLT	-	1.0
CXWIGG	PUMP	-	1.0
CXWTPA	CXWMLT	-	1.0
CXWLIN	PUMP	-	2.5

	VARIABLE	NAMELIST	UNITS	DEFAULT
Engine Mounting Length Adjustment (in) ☐	XMOUNT	LIQENG	in	2.0
Propellant Expulsion Efficiency				
0) calculate	INPEXF	LFLAG	-	0
1) input	INPEXO	LFLAG	-	0
Fuel expulsion efficiency ☐	EXPLFL	LTANK	-	0.995
Oxidizer expulsion efficiency ☐	EXPLOX	LTANK	-	0.995

NEW USER TRANSLATION OF WORKSHEET TO ELES INPUT

The first line of the ELES-1984 input data set is the job title. A blank line may be substituted for the title, however the namelist input must not begin until after line 1.

Any number of comments may be placed after line 1 by placing a "C" in column 1.

The number of stages (NSTGES) and the payload weight (WPAYLD) are in namelist INPGEN. A three stage vehicle with a 1000 pound payload would have input of the format:

```
NSTGES = 3,
WPAYLD = 1000.,
```

Notice that NSTGES is an integer and WPAYLD is a floating point number. ELES follows the FORTRAN convention of naming integers with a first letter of I, J, K, L, M, or N. Floating point variables begin with any other letter.

Up until now only the input format required for a single stage vehicle has been addressed. The design parameters which apply to all stages are four dimensional arrays. This allows for up to four stages in the vehicle. As an example, if a three stage vehicle has first, second, and third stage diameters of 100., 75., and 50. inches respectively, then the input for diameter (DMOTOR) would be:

```
DMOTOR (1) = 100.,
DMOTOR (2) =  75.,
DMOTOR (3) =  50.,
```

Most namelist implementations would allow the above to be shortened to:

```
DMOTOR = 100., 75., 50.,
```

While going through the worksheet for each stage of the vehicle to be modeled, pay special attention to the stage number since it will be used as an index to the design input variables.

It is important to remember that ELES models both solid and liquid stages. The flag which indicates which type is being modeled is KSTAGE (1 = solid, 2 = liquid). If the previous three stage vehicle example were a solid booster with two liquid upper stages, then KSTAGE would be input as:

KSTAGE = 1, 2, 2,

The miscellaneous weight for each stage includes those items not specifically modeled by ELES. It includes such weight items as guidance and control packages, attitude control systems, electrical systems, range safety systems, separation systems, and propellant utilization systems. It is anticipated that a future version of ELES will model these systems. At present the variable WMISC in namelist INPGEN should be set to the users estimate of those weights.

The expendable weight (WEXPND) for each stage includes those weights which are expended gradually throughout the stage burn. Examples could include ablation losses, gas generator overboard dump, attitude control propellant, or open loop hydraulic actuator overboard dump. If ELES is instructed to simulate a trajectory, the expendable weight is used to linearly reduce the stage weight over the total burn time by the amount of WEXPND. WEXPND is in namelist INPGEN.

Namelist INTSTG contains the variables RHOINT, SINST, EINSTG, and SFINST which corresponds to the material density, design stress, modulus of elasticity, and safety factor of the upper interstage. If these properties were input for stage one, they would apply to the interstage between stages one and two.

The specification of tank geometry involves the setting of a number of different flags and values. The first major flag (NCTNK) selects either the tandem tank model or the non-conventional tank model (see Section 1 for an overview of the two tank models). NCTNK is in namelist LFLAG. NCTNK = 1 indicates non-conventional tankage; NCTNK = 0 indicates tandem tanks. Two completely different sets of tankage inputs are required for each model as indicated by NCTNK.

For tandem tankage (NCTNK = 0) the choice between monocoque or suspended tankage must be made separately for the aft, forward, and pressure tanks. The aft and forward tanks are specified by the flags MNCQA and MNCQF respectively in namelist TNKGEO. A value of 1 indicates a monocoque tank; a value of 0 indicates a suspended tank.

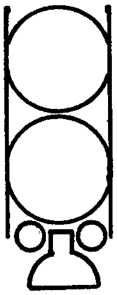
The pressure tank is specified with the flag KPRESS in namelist TNKGEO. KPRESS specifies the pressure tank in the following manner:

0 = spherical in engine bay
1 = suspended forward of forward tank
2 = monocoque with separate dome
3 = monocoque with common dome
4 = cylindrical in forward tank

If the aft and forward propellant tanks share a common dome, the flag KDOME in namelist TNKGEO should be set to 1. A value of 0 indicates separate domes.

The ellipse ratio of a tank is defined as the tank head height divided by the tank radius. The ellipse ratios of tandem tanks are set with the variables ELDOME and ELRP in namelists INPGEN and LTANK respectively. ELDOME refers to both the aft and forward tanks while ELRP refers to the pressure tank(s). Ordinarily ELDOME will range from 1.0 to 2.0 while ELRP is seldom other than 1.0.

The directions of all four tank heads in the tandem tank geometry can be specified by the flags KXATAH, KXATFH, KXFTAH, and KXFTFH which correspond to the aft tank aft head, aft tank forward head, forward tank aft head, and forward tank forward head respectively. These flags, in namelist TNKGEO, use a value of -1 to indicate convex forward and 1 to indicate convex aft. An example is shown below:



MNCQF = 1,
KDOME = 0,
MNCQA = 1,
KPRESS = 0,

KXFTFH = -1,
KXFTAH = 1,

KXATFH = -1,
KXATAH = 1,

Finally, the location of each propellant is specified with KPRPA in namelist TNKGEO. A value of 1 indicates fuel in the aft tank. A value of 2 indicates oxidizer in the aft tank.

If non-conventional tanks are specified (NCTNK = 1), then the previously mentioned tandem tank inputs are ignored, and the following set of non-conventional inputs are used. The basic idea behind the non-conventional tank model is that an odd assortment of tanks and engines are desired to be placed into a cylindrical envelope. The user must tell the program how many tanks and engines are to be placed into the stage, the sequence in which they are to be placed, and their radial and angular locations. ELES begins with an empty cylinder of diameter DMOTOR, and sequentially places tanks as far forward as they will go without interfering with other tanks.

All inputs in this non-conventional tank discussion are located in namelist NCTINP. The total number of tanks (fuel, oxidizer, and pressurant) are indicated by NTANKS. NTANKS is an array which is dimensioned to four in order to indicate Stages 1-4. Many of the remaining non-conventional tank inputs are dimensioned to fifteen in order to indicate tank 1-15 for a given stage. TANGL3(6), for example, is the tank angular location of tank number six in stage number three. Simiarly some of the inputs are dimensioned to five in order to indicate engine 1-5 for a given stage. ENGAN2(5) is the engine angular location of engine number five in stage number two.

All of the non-conventional tank inputs which end in a number indicate the stage number to which they apply. The array indices for those variables refer to the appropriate tank or engine within that stage.

The contents of each tank are specified with the variables INTNK1-INTNK4. A value of 1 indicates oxidizer, 2 indicates fuel, and 3 indicates pressurant. The tank shapes are specified with KTANK1 - KTANK4 (1 = CSE, 2 = torus). A CSE tank is one with a possible cylindrical section and spherical or elliptical ends.

There are two different ways to input tank dimensions; the flag KALMOD indicates which way it is to be used. If KALMOD equals 0 then use dimensionless input (RDIM1 - RDIM4). If KALMOD equals 1 then use major tank dimension (RMAJ1 - RMAJ4).

For CSE tanks, the dimensionless inputs (RD1M1 - RD1M4) correspond to the length of the tank cylindrical section divided by the tank diameter. A sphere would have a value of 0.0 whereas a tank with 2:1 elliptical ends and a total L/D of 3.0 would have a value of 2.5.

For toroidal tanks, the dimensionless inputs (RD1M1 - RD1M4) correspond to the torus hub radius divided by the torus tube radius. The hub radius is defined as the distance from the overall tank centerpoint to the circular centerline of the enclosed volume. The tube radius is the inside radius of the volume-enclosing tube. For a value of 1.0, there is no hole in the middle of the torus. Values less than 1.0 are not allowed.

When major tank dimensions (RMAJ1 - RMAJ4) are used instead of dimensionless inputs, they allow the user to more easily place adjacent tanks. For CSE tanks the major dimension is the tank radius; for torii it is the hub radius.

Unlike dimensionless inputs, there are cases for which the major dimensional inputs cannot meet the tank volume requirements. The major radius of a CSE can dictate a larger volume tank than required. The major radius of a torus can limit the tank volume to a value lower than required. For these reasons dimensional input must be used with caution.

The tanks are located in the stage by placing their centerpoints at given angles and radial locations about the stage centerline. The tank angle (TANGL1 - TANGL4) is in degrees (0-360). The radial location (RADL01 - RADL04) is a fraction in the range of 0.0 - 1.0. The fraction applies to the maximum possible outboard location. A value of 1.0 indicates the tank is to be placed outboard as far as possible. A value of 0.0 indicates the tank is on the stage centerline.

The engines are placed in the stage exactly analogous to the tanks. The angle and radial location are represented by ENGAN1 - ENGAN4 and ENGRD1 - ENGRD4.

For both tankage models, the outside stage diameters are indicated by the input DMOTOR.

The forward and aft skirt lengths for both tankage models are indicated with the inputs FFSKTL and FASKTL. These inputs indicate the fractional length of each skirt with respect to a baseline length. For tandem tanks the baseline lengths are the forward dome height and the engine bay length respectively. For non-conventional tanks the baseline lengths are the stage diameter and the stage length respectively.

In order to fully shroud a tandem tank stage, FFSKTL and FASKTL should each be set to 1.0. To fully shroud a non-conventional stage, they should be set to 0.0 and 1.0 respectively.

The propellant combination is chosen by setting the flag IPROP equal to one of the ID numbers indicated on the worksheet. The mixture ratios on the worksheet are intended as guidelines for each propellant combination and may not be optimum for all cases.

Although defining a non-library propellant is beyond the scope of this new-users manual, chosing IPROP = 0 is still valid. Because of the values implicit in ELES, the baseline user-defined propellant is N_2O_4/A50. The use of non-library propellant combinations other than N_2O_4/A50 is a straightforward procedure. The input required to do so is described in the "Expanded Liquid Engine Simulation Computer Program - Advanced Users Manual."

The engine performance model in ELES examines two stream tubes in the combustion chamber, the core stream tube and the barrier stream tube. The performance of the engine is mainly dependent on the mixture ratio at the central or core stream tube. This mixture ratio is input as OFCORE. The indicated nominal mixture ratios are good first estimates of OFCORE. OFCORE is in namelist LQPERF.

The number of engines, vacuum thrust per engine, and engine chamber pressure are indicated by the inputs NTC, FVAC, and PC in namelists LIQENG, LIQUID, and INPGEN. The units of FVAC and PC are in pounds and psia, respectively.

When using a plug cluster nozzle, NTC and FVAC indicate the number of plug modules and module vacuum thrust. Except for plug clusters, the value of NTC is 5 or less.

The input KCYCLE in namelist LFLAG chooses the power cycle by the ID numbers shown on the worksheet. As with many of the other stage design choices, there are a considerable number of trade-offs involved with the selection of a power cycle.

The choice of a propellant feed power cycle can significantly affect the size, weight, performance, cost, and complexity of a stage. The simplest power cycle is the pressure fed cycle, which requires either cold gas pressurization or a solid gas generator to force propellants from the propellant tanks into the combustion chamber. The tanks must be designed to contain pressures above the chamber pressure of the engine, and therefore they tend to be heavy.

Pump fed cycles can operate with much lower tank pressures and lower associated tank weights, however, they have the additional weight, cost, and complexity of a turbopump assembly. In the case of the gas generator bleed cycle, there is also an engine performance loss (the turbine exhaust is dumped overboard).

Current ELES-1984 requirements are: 1) pressure fed engines require cold gas or solid gas pressurization, 2) use of the expander cycle requires a regeneratively cooled engine (preferably hydrogen cooled), 3) use of the staged reaction cycle requires a monopropellant (e.g., hydrazine or MMH).

If a pump fed cycle is chosen, the turbine gas properties must be defined. The inputs required are the mixture ratio, specific heat, ratio of specific heats,and molecular weight. These are provided with the inputs OFGGPB, CPGGPB, GAMGPB, and WMGGPB in namelist PUMP.

For fuel cooled expander cycles and staged reaction cycles the mixture ratio is zero. For all cycles the gas properties are those at the mixture ratio, temperature, and pressure at the turbine inlet.

The kind of turbopump assembly (TPA) is specified with the flag JCNFIG in namelist PUMP. The options for JCNFIG are 1) a turbine which drives pumps through a gearbox, 2) a single shaft TPA (turbine and both pumps have same RPM), 3) twin TPAs in series (two direct-drive turbine-pump pairs), 4) twin TPAs in parallel.

Flags JBPOX and JBPFL are used to indicate boost pumps on either oxidizer or fuel circuits in namelist PUMP (0 = no boost pump, 1 = boost pump).

The tank outlet pressure for pump fed engines is determined by the net positive suction pressure (NPSP) for each pump. The NPSP is input through the variables OXNPSP and FLNPSP in namelist PUMP with units of psia.

Two of the main contributors to tank volume calculations are the amount of burned propellant and the ullage volumes. Burned propellant is input via WTLPRP in namelist LIQUID in units of pounds. Based on the overall engine mixture ratio, this weight is apportioned between the oxidizer and fuel.

The ullage fractions for the oxidizer and fuel tanks are input via ULLFOX and , ULLFFL in namelist LTANK. An ullage fraction of 0.02 corresponds to an ullage gas volume which is 2% of the free tank volume. If non-conventional tanks are used and there are mutliple oxidizer or fuel tanks, then each of the multiple tanks has the same ullage fraction as dictated by ULLFOX or ULLFFL.

The propellant acquisition options available are displayed on the worksheet. In order to choose a device for both the oxidizer and fuel tanks, the flags KACQOX and KACQFL must be set equal to the appropriate ID number in namelist LFLAG. The choice for propellant acquisition system is normally based on mission requirements such as startup environment, restart capability, acceleration loads, propellant compatibility with materials, or propellant heat transfer and vapor pressure.

There are three main flags to be set in order to indicate the pressurization method. The first pair of inputs, KGASOX and KGASFL, respectively indicate whether or not the oxidizer or fuel are pressurized autogenously. Both are placed in namelist LFLAG. A value of 1 indicates autogenous pressurization, 0 indicates not autogenous. If autogenous pressurization is chosen, then the temperature of the autogenous pressurant at the tank inlet must be input through the variables TULLOX and TULLFL in namelist PUMP. TULLOX and TULLFL are in degrees Rankine and correspond to the oxidizer and fuel pressurant respectively.

If either propellant is not pressurized autogenously, (for example all pressure fed stages), then the flag KGAS indicates whether the pressurant source is 1) solid gas generator or 2) cold gas (He). Either or both propellants can be pressurized from the source indicated by KGAS in namelist LFLAG. Although the characteristics of the solid grain can be input, the default solid propellant is TAL-8. Modification of the solid propellant is described in the "Expanded Liquid Engine Simulation Computer Program - Advanced Users Manual."

When cold gas pressurization is indicated by KGAS, there are several other design choices required. The storage pressure of the cold gas PICG in namelist COLDG can be a major factor in determining the pressurization requirements. PICG is input in psia and must be at least as high as the maximum required tank pressure. PICG is often in the range of 3000 to 5000 psia and in extreme cases can be up to 10,000.

Another large influence on the cold gas pressurant requirements is the final pressure in the pressurant tank. A blowdown cycle, for example, requires less pressurant than a cycle which maintains the tank pressures at nominal levels throughout the burn. The parameter FPULCG in namelist COLDG is used to calculate the final pressurant tank pressure. The value of that final pressure is equal to FPULCG times the maximum nominal ullage pressure of the oxidizer and fuel tanks.

The pressurant requirements of an 80% blowdown cycle would be reflected in FPULCG = 0.8. The final pressurant tank pressure would be equal to the final propellant tank pressures which would be 80% of their nominal values. Setting FPULCG to a value greater than 1.0 would indicate a fully regulated tank pressure through burnout.

The tank materials of construction are indicated via material flags corresponding to each tank. There is a list of library materials (see worksheet) and space available for the user to define his/her own materials. The material stress properties in the library are yield properties. If ultimate properties are desired, the user defined option should be invoked.

For tandem tanks, the oxidizer, fuel, and pressure tank material flags are the inputs MTNKOX, MTNKFL, and MATPT in namelist LIQMAT. For non-conventional tanks, the material flags are the inputs MATNK1-MTNK4 in namelist NCTINP.

When a material flag is set equal to the ID number of a library or user-defined material, it then specifies the density of the material, modulus of elasticity, design stress, specific heat, thermal conductivity, and minimum gauge. For library materials

(ID numbers greater than 10) those values are invisible to the user. For user-defined materials (ID numbers 1-10) they must be input through the variables RHO, YMOD, SIGMAX, SPHEAT, CONDCT, and TMING in the namelist LIQMAT. All variables except TMING are arrays dimensioned to 10 and may be used by any of the four possible liquid stages. TMING has the typical dimension of 4; one value per stage. As with most other inputs in ELES, the above variables have units of inch, pound, second, BTU, and degree Rankine.

The structural wall of both tandem and non-conventional tanks uses the material flag MATSTR in namelist LIQMAT. The associated minimum gauge input for user-defined materials is the variable TMINGS in the same namelist.

Safety factors may be applied to the design stresses of both library and user-defined materials. Tandem tanks use SFOXTK, SFFLTK, and SFPRTK in namelist LIQMAT to indicate safety factors for the oxidizer, fuel, and pressurant tanks. Non-conventional tanks use SFTNK1-SFTNK4 in namelist NCTINP. Both tankage models use SFSTRC in namelist LIQMAT for the structural wall.

Propellant tank insulation may be applied simply by specifying the thickness desired. Two types of insulation are available; spray on foam insulation (SOFI) and multilayer insulation (MLI). Both types may be used separately or in concert. The oxidizer tank(s) use TSOFIO and TMLIO in namelist TANKHX to specify SOFI and MLI thickness (inches). The fuel tank(s) use TSOFIF and TMLIF. These inputs are used for both tandem and non-conventional tanks. The use of tank heat transfer and boiloff models are described in the "Expanded Liquid Engine Simulation Computer Program - Advanced Users Manual."

The thrust chamber expansion ratio is the nozzle exit area divided by the throat area. The input variable name is EPS in namelist INPGEN. If there is a nozzle extension, a translating nozzle extension, or a gas deployed skirt, then EPS refers to the exit area with the nozzle fully deployed.

A common thrust chamber assembly (TCA) construction process involves attaching a nozzle extension to the chamber downstream of the throat (typically at area ratios in the range of 5 to 10). One of the reasons for doing this is to allow the nozzle extension to be cooled in a manner different than the combustion chamber. A common scenario is to switch from ablative or regenerative cooling in the combustion chamber to radiation cooling in the nozzle extension.

If a nozzle extension is desired, it may be indicated with the flag NEXNOZ in namelist LIQENG. KEXNOZ = 0 indicates no nozzle extension; KEXNOZ = 1 indicates a nozzle extension.

The area ratio at which the nozzle extension attaches should be input with the variable EPSATT in namelist INPGEN. The choice of EPSATT can have a large influence on the cooling models in ELES. If a radiation cooled nozzle extension is attached at a low area ratio, then it will be exposed to hot combustion gases which have not undergone as much cooling expansion as would the gases at higher area ratios. ELES will adjust the barrier mixture ratio in the combustion chamber in order to accommodate the nozzle cooling requirements. This will result in a performance loss which can be avoided by attaching the nozzle extension at a larger area ratio.

Similarly if an ablative cooled chamber were attached to a radiation cooled nozzle, it is likely that the ablative material requires significantly more barrier mixture ratio control than the nozzle. In that case, a low nozzle extension attach area ratio could reduce the overall engine weight while not adversely affecting the engine performance.

The contraction ratio of a combustion chamber is equal to the injector face area divided by the throat area. A typical range for contraction ratio is 1.5 to 4.0 (2.5 being a typical value). Low contraction ratios are often attributed to very high thrust engines. For these engines a higher contraction ratio would mean a much higher engine weight. High contraction ratios are often attributed to small engines for performance reasons.

The shorter chamber lengths normally used by smaller engines require finer drop sizes in order to attain more complete combustion, and, hence more injection elements, larger injectors, and high contraction ratios. The contraction ratio is input to ELES through the variable CR in namelist LIQENG.

The normal distance from the injector face to the throat plane is the combustion length or L'. The longer L' gets, the better the propellant mixing and vaporization effi ciencies can get. As L' gets longer it is also true that the engine gets longer, heavier, and more difficult to cool. The optimization of L' is specific to the engine under consideration.

There are two portions of combustion chamber length to input in ELES the cylindrical chamber length and the convergent chamber length. These are input via the variables XLC and XLN respectively in namelist LIQENG.

There are four nozzle geometries available in ELES Rao, conical, plug cluster, and annular contours. Rao nozzles are, by far, the most common liquid nozzle geometry (often called "bell" nozzles). Conical nozzles are fairly rare in liquid propellant stages. Although conical nozzles have lower performance than Rao nozzles, they are easier to manufacture and have better durability when particulates are entrained in the exhaust gas (more common to solid propellant motors). Plug clusters and annular nozzles both result in relatively short engine geometries. In some situations it is possible to attain an effectively zero length engine. The resulting short stage length is compensated by additional weight and cooling difficulties in most cases.

The first input which selects nozzle geometry is the variable IPLUG in namelist LIQUID. If IPLUG is set to a value of 0 it indicates conventional nozzle geometry (conical or Rao), a value of 1 indicates plug cluster, and 2 indicates an annular nozzle. If IPLUG = 0, then the variable KNOZ in namelist LIQENG chooses between conical and Rao. KNOZ = 1 means conical; KNOZ = 2 means Rao.

If a conical nozzle is chosen, its expansion half angle is input via ALFNOZ in namelist NOZZLE. ALFNOZ is in degrees with 15° being the nominal value.

The length of a Rao nozzle is indicated by comparison to a minimum length Rao. RATMLR (in namelist LIQENG) is the input variable which indicates the length of the nozzle divided by the length of a minimum length Rao nozzle. Because flow separation occurs for nozzles which are shorter than a minimum length Rao, the value of RATMLR should not be set below 1.0. A typical range for RATMLR is from 1.05 to 1.2. The tradeoff to consider when specifying RATMLR is that longer nozzles perform better but are heavier.

When calculating the value of RATMLR for an existing nozzle, the following equation will be of use. It is based on empirical data for Rao nozzles.

$$\mathrm{RATMLR} = \frac{L_{noz}}{\left(\frac{\varepsilon + 1009}{1612.1}\right) \frac{R_t\ (\sqrt{\varepsilon}-1)}{0.26795}}$$

where: L_{noz} = nozzle length (in.)
ε = total area ratio
R_t = throat radius (in.)

The use of plug clusters and annular nozzles is described in the "Expanded Liquid Engine Simulation Computer Program - Advanced Users Manual."

The combustion chamber can be cooled by any of four different methods: 1) ablative, 2) regenerative, 3) trans-regen, and 4) radiation. These are selected by setting the flag KOOLTC in namelist LFLAG to a value 1-4. The user must make the chamber material specifications consistent with the cooling method.

If ablative cooling is chosen (KOOLTC = 1) then the chamber barrier temperature must be held at or below the maximum temperature which the ablative material is capable of withstanding. This maximum temperature (TGWNOM) is input through namelist INREGN in units of degrees Rankine. For silica phenolic ablative material, the nominal temperature at which ablation cooling can support the chamber structural properties is about 3000°R (3900°R is an absolute maximum).

When regenerative cooling is selected (KOOLTC = 2), the chamber wall temperature is again selected with the variable TGWNOM. In this case, however, the barrier temperature is selected by the user through the input DIFTBF in namelist INREGN. The choices for the barrier temperature are 1) to run the barrier at the same temperature as the core, 2) to run the barrier at the maximum wall temperature, 3) to run somewhere in between those values.

The equation for DIFTBF which reflects the above three choices is:

$$\mathrm{DIFTBF} = \frac{T - \mathrm{TGWNOM}}{T_{\mathrm{core}} - \mathrm{TGWNOM}}$$

Where T is the desired barrier temperature, T_{core} is the core temperature, and TGWNOM is the user input for maximum wall temperature. The allowed range for DIFTBF is 0.0 to 1.0 inclusive. A value of 1.0 indicates a barrier temperature equal to the core temperature and a value of 0.0 indicates a barrier temperature equal to the maximum wall temperature. In order to obtain a specific barrier temperature, the user must first run a test case to determine the core temperature and calculate DIFTBF by employing the above equation.

The material structural properties of the chamber wall (discussed later) are used to calculate a gas wall thickness, however, the user may input a minimum gauge wall thickness through the parameter GWMING in namelist INREGN. The thermal conductivity is input via WALLK in INREGN. The units of GWMING and WALLK are inches and BTU/in sec deg R respectively.

In order to get a summary of the regenerative cooling analysis, the flag IRPRNT in namelist INREGN should be set to 1.

The trans-regen model (KOOLTC = 3) employs all of the same inputs as the regenerative model. In addition to these inputs it is necessary to specify what portion of the chamber is to be transpiration cooled and what portion is to be regeneratively cooled. The inputs which perform this are EPSTRU and EPSTRD in the namelist INREGN.

EPSTRU is the upstream area ratio at which transpiration cooling begins. The value of EPSTRU is typically in the range of 1.1 to 2.0. The downstream area ratio at which transpiration cooling ends (EPSTRD) is typically in the range of 1.1 to 1.5.

When the analysis is carried out, ELES calculates the transpiration coolant flowrate required to hold the gas side wall temperature to the input material temperature (TDESTR in INREGN) of the transpiration cooled section. The portion of the chamber which is regeneratively cooled is still governed by TGWNOM. Both temperatures are in degrees Rankine.

A summary of the trans-regen cooling analysis is generated if IRPRNT is set to 1. Check the stage flowrate schedule to see the transpiration flowrate.

The radiation cooling model (KOOLTC = 4) calculates the barrier gas temperature based on the heat flux which can be radiated to the ambient environment. It assumes that the chamber material will be at the nominal operating temperature (TGWNOM) input by the user. ELES calculates view factors to the major components and to the ambient environment in order to solve the coupled radiation equations. After the radiation equations are solved, the heat flux through the chamber wall is known. That flux is used to determine the temperature difference which can be supported between the barrier combustion gas and the chamber wall. Knowing the barrier temperature, ELES calculates the barrier mixture ratio and uses it in the engine performance calculations.

If a nozzle extension is used on the chamber (KEXNOZ = 1) then its cooling method must be selected with the flag KOOLNZ in namelist LFLAG. The selections are

1) ablative, 2) regenerative, 3) trans-regen, 4) radiation, 5) film. The nominal operating temperature of the nozzle material is TNENOM in namelist LIQENG; it is used like TGWNOM is used in the chamber.

The following restrictions apply to the nozzle cooling model. 1) The nozzle can be regenerative or trans-regen cooled only if the chamber is cooled by the same method. 2) Gas film cooling applies only to engines which use the gas generator bleed power cycle.

For ablatively cooled nozzles (KOOLNZ = 1) the nominal wall temperature (TNENOM) is chosen as TGWNOM is for the chamber. Although some engines do exist which use an ablatively cooled nozzle on a non-ablatively cooled chamber, they are rare. Ordinarily the weight associated with this type of nozzle is a deterrent to its use.

As previously stated, regenerative and trans-regen cooled nozzles (KOOLNZ = 2 and 3) should only be used on chambers which are cooled by the same method. All of the inputs described for the chamber are used throughout the regenerative or trans-regen nozzle.

Radiation cooled nozzle extensions (KOOLNZ = 4) use the same general solution method as described for radiation cooled chambers except that TNENOM is the material temperature used.

Film cooled nozzle extensions (KOOLNZ = 5) use the turbine exhaust gas from a gas generator bleed cycle as a barrier coolant. The exhaust gas is introduced into the nozzle at the attach area ratio (EPSATT) from a tapered ring manifold. It contributes to the engine performance based on its temperature, flowrate, and net expansion ratio. Although a rigorous heat transfer analysis is not performed, the turbine exhaust temperature is checked for compatibility with TNENOM.

The pressure drop across the injector is the main parameter which controls engine chugging (chugging is a coupling of combustion instability with the propellant feed system, which results in large oscillations of chamber pressure). For most engines, if the injector pressure drop is 25% of the chamber pressure, then the engine will not chug. This is only a rule-of-thumb, however, since many engine design parameters will determine the actual chugging requirement.

The input variables FCHGOX and FCHGFL in namelist LIQUID determine the chugging requirement for the oxidizer and fuel injector pressure drops respectively. Both are input as fractions of chamber pressure such that values of 0.25 would correspond to the nominal chugging requirement. The range of chug requirements would be from about 0.15 to 0.40.

The pressure drops across the bipropellant valve and the feed lines are similarly input as fractions of the chamber pressure. CPVLVO and CPVLVF in namelist LIQUID correspond to the oxidizer and fuel valves. CPLINO and CPLINF in LIQUID are the oxidizer and fuel feed line pressure drop fractions. The lower these fractions are, the lower the pressurization requirements become (this will also result in larger and heavier valves and lines). Often a minimum pressure drop is required for feed control purposes. Typical values for the valve and line pressure drop fractions are 0.03 to 0.30.

The number of elements per square inch of injector face area can be a measure of its technology and performance levels. As orifices become smaller and more densely packed, the manufacturing difficulty increases and, in general, the performance increases. (For engines which already have 100% propellant mixing and vaporization efficiency, there is no performance increase with element density.)

The input which reflects the injector technology is ELDENS in namelist INJECT. ELDENS is the element density in elements per square inch. A nominal injector drilled orifice pattern would be about 4 elem/in.^{2}. An order of magnitude improvement is possible with platelet technology which can attain 40 elem/in.^{2}.

The input flag IELDEN should also be set in namelist INJECT to indicate that ELDENS is being used. If IELDEN is set to 1, then ELES will use the value input in ELDENS. If IELDEN equals 0, ELDENS will be ignored.

Although element density plays a major part in the vaporization of propellants, it is also true that element design affects vaporization. Different element types are capable of atomizing propellant streams into finer droplets which, in turn, leads to better vaporization. The list of element types on the worksheet are in increasing order of atomizing efficiency. Unlike-triplets and unlike doublets are the most efficient in the list at atomizing the propellants.

The ELES inputs which hold element type information are the drop size multipliers RMFOX and RMFFL in namelist LQPERF. These variables adjust the calculated drop sizes of the oxidizer and fuel respectively. They are used as multipliers on drop radius. Groups a through d have values of 3.0, 1.0, 0.5, and 0.33 respectively.

Another factor in the drop size calculations is the number of oxidizer and fuel orifices per element. This information is in the variables OXOPEL and FLOPEL in namelist INJECT. An F-O-F triplet, for example, would be indicated by:

```
RMFOX  = 0.33,
RMFFL  = 0.33,
FLOPEL = 2.0,
OXOPEL = 1.0,
```

If there is a translating nozzle on the engine, it should be indicated with the flag KTRNOZ in namelist LIQENG. If there is no translating nozzle, KTRNOZ = 0. A spring actuated translating nozzle is indicated by KTRNOZ = 1. A gas deployed skirt corresponds to KTRNOZ = 2.

The area ratio at which a translating nozzle attaches is input as EPTRAT in namelist LIQENG. The overall engine area ratio is input as EPS in namelist INPGEN. EPTRAT should always be less than EPS in order to assure proper translating nozzle geometry.

Gas deployed skirts are folded into the fixed nozzle and deploy at engine ignition. For proper deployment, it is necessary to keep the skirt short enough to prevent self-interference as it passes through the fixed nozzles exit plane. Although ELES will not design the gas deployed skirt to fit that criteria, it will issue a warning message if the criteria is violated.

The material density required for calculating the translating nozzles weight is input as ROTRNZ in namelist LIQMAT.

The stage gimbal system is sized for the engine thrust and gimbal angle requirements. The gimbal angle is input via GMBANG in namelist LIQUID. The units of GMBANG are degrees. A nominal value is about 5 degrees.

In a multiple engine stage, it is possible to designate how many of the engines gimbal with the flag NGIMB in namelist LIQUID.

Pressure fed stages commonly use a battery powered hydraulic system to drive the gimbal actuators. For these stages the battery power may be provided by an upper stage or payload. If the battery power is provided by another source then the flag KGPOWR in namelist LIQUID should be set to zero. If the power supply is on-board then KGPOWR = 1. KGPOWR does not apply to pump fed stages since gimbal power is supplied by the turbopump assembly (TPA).

The weight of the engine is calculated by either a physical model or a simplified correlation which applies to ablative engines. For most cases it is best to use the physical weight model. That option is used when the flag KWTMOD in namelist LFLAG is set to 1. If KWTMOD is set to 0 the simplified ablative model is used. The engine weight may be input by the user if KWTMOD = -1.

It is recommended that the physical model be used almost exclusively (KWTMOD = 1). Under that circumstance, the engine materials of construction should be defined with values for their density and design stress. All of the material properties to follow are input through namelist LIQMAT. The units of density and stress are lb/in.^{3} and psia respectively.

The chamber input varies with the cooling method chosen. Ablative engines require a density for the ablative material (RHCABL) and the structural overwrap (RHCSTR). The overwrap design stress is input as SIGCHM.

For regenerative and trans-regen chambers the density and strength at the gas wall are input as RHOGW and SIGCHM. The chamber closeout material, which is normally the main structural material, is input with RHOCLS and SIGCLS.

Radiation chambers use RHCSTR and SIGCHM.

Nozzle extensions material property inputs are also based on the cooling model chosen. Ablative nozzles use RHCABL for the ablative density and RHONZE for the nozzle extension structural overwrap. The overwrap design stress is input as SIGNZE.

For regenerative and trans-regen nozzles the nozzle is considered a part of the chamber unless KEXNOZ = 1. If KEXNOZ = 1 then the nozzle is considered to be a regeneratively cooled tube bundle for weight purposes. In that case the tubes are of density RHONZE with strength SIGNZE and wall thickness TNZMIN.

The radiation and film cooled nozzles use RHONZE and SIGNZE for density and strength.

All of the nozzle models use TNZMIN as the nozzle structural material minimum guage.

The injector material is defined through RHOINJ and SIGINJ. The bipropellant valve material density is input as RHOVLV.

The operating temperature range of the stage is the range of ambient temperatures with which the stage can come to equilibrium. This will affect the propellant density and vapor pressure for storable propellants as well as a cold gas pressurization system. The propellant tanks must be large enough to hold the propellant at its minimum density and strong enough to withstand the maximum propellant vapor pressure. Also the pressurant tank storage pressure cannot exceed its design point when the stage gets hot while still maintaining enough cold gas to expel the propellant at the low temperature.

One of the few temperature inputs which is in degrees Fahrenheit instead of Rankine is the set of stage operating temperatures. TMIN, TOP, and TMAX are the minimum, nominal and maximum operating temperatures. They are input via namelist LIQUID.

The component weight multipliers are normally used after an initial run has been made and the predictions made by ELES are not in agreement with engineering judgement. The most common uses are: 1) to match the weight of an existing piece of hardware, 2) to reflect an added component complexity not included in the basic ELES model, 3) to include empirical adjustments based on experience.

The tank weight multipliers are used to adjust the ideal tank weight calculated by hoop stress. A tankage survey has been conducted to determine a good nominal value for that non-optimum factor. The result was 1.7 however the distribution about 1.7 was fairly wide. Values of 1.25 are common for spherical pressure tanks and values greater than 2.0 are common for unusual geometries or low technology.

The variable CXWTNK is multiplied times all tanks in the stage. Its default value is 1.7 so that no input is required if all tanks use that non-optimum factor. If tanks are to be individually adjusted, then CWNTNK should normally be set to 1.0 so that its effect will be cancelled. The tandem tanks can be individually adjusted through the variables CXWFLT, CXWOXT, and CXWPTN for the fuel, oxidizer, and pressure tanks. The non-conventional tanks use the variables CXNCT1, CXNCT2, CXNCT3, and CXNCT4 for the tanks in stages I through IV respectively.

The weight of the structural walls of the stage are multiplied by CXWSTR. The propellant line weights from the tanks to the engine bay for the tandem tank model are multiplied by CXWATL, CXWFTL, and CXWPTL (individually they multiply the aft tank lines, the forward tank lines, and the pressure tank lines). The engine bay lines are multiplied by CXWLIN. In non-conventional tank geometries, all lines are multiplied by CXWLIN.

The engine is multiplied by CXWENG after the subcomponents are multiplied by their respective constants CXINJ, CXVALV, CXWCHM, and CXWNZE for the injector, bipropellant valve, chamber, and nozzle extension.

The remainder of the weight multipliers are straightforward. CXWDUC, CXWGIM, CXWTHM, CXWIGG, and CXWTPA are used with hot gas ducts, gimbal system, thrust mount, gas generator injector, and turbopump assembly respectively.

The engine mounting length is calculated in ELES as the distance from the injector face to the gimbal point (assumes head end gimbaling). This calculation is based on empirical data of many other liquid engines. The distance from the gimbal point to the tank is normally very small (i.e., the length of the gimbal ball mounting bracket). It can be input with the variable XMOUNT in namelist LIQENG with units of inches.

When using non-conventional tanks, XMOUNT is used in a different way. In the normal mode of nesting engines, the nozzle exit plane is placed at the end of the largest tank plus XMOUNT.

In both cases the value of XMOUNT can be positive or negative depending on engineering judgement.

The expulsion efficiency of the propellant tanks is normally calculated by ELES using empirical correlations of actual tank data. If it is desired to input expulsion efficiency, it can be done by first setting the flags INPEXF, INPEXO to 1 and then setting EXPLFL, EXPLOX to the correct values for the fuel and oxidizer tanks respectively.

7. TRANSTAGE SAMPLE CASE

Transtage (Figure 7a) is the third stage of the Titan 34D launch vehicle. It is 10 feet in diameter by 15 feet long, and consists of a control module (forward) and a propulsion module (aft) connected by a manufacturing splice. The control module contains inertial guidance, portions of flight control, tracking and flight safety, instrumentation, electrical, hydraulic, and attitude systems. The propulsion module consists of two rocket engines, propellant tanks and tank pressurization and feed systems. The two rocket engines provide a combined total of approximately 16,000 pounds vacuum thrust and have a multiple start capability. This enables Transtage to transfer orbits, to modify an established orbit, or to rondezvous with other space vehicles.

The Transtage propulsion system is pressure-fed using helium to maintain tank pressure at approximately 160 psia to force propellants into the combustion chambers. Series and parallel redundant solenoid valves, operated by pressure switches, control tank pressure. Flow of propellant into the engine is controlled by a bipropellant valve which is hydraulically operated using fuel pressure. A solenoid-operated pilot valve controls bipropellant valve operation. Pivots located in the engine mounts make it possible to individually gimbal the two Transtage engine subassemblies, providing pitch, yaw and roll control.

An ELES-1984 input worksheet was prepared for the Transtage module (see Figure 7b). The resulting ELES inputs which generate the Transtage model are shown in Figure 7c. Associated with many of the inputs are explanations of their origin. The comments in the input listing refer to those explanations which are found in Figure 7d.

The output from the Transtage input set is displayed in Figures 7e through 7o. Notice in the non-conventional tank output (Figures 7f through 7j) that each tank has an identifying letter and each engine has an identifying number.

TRANSTAGE

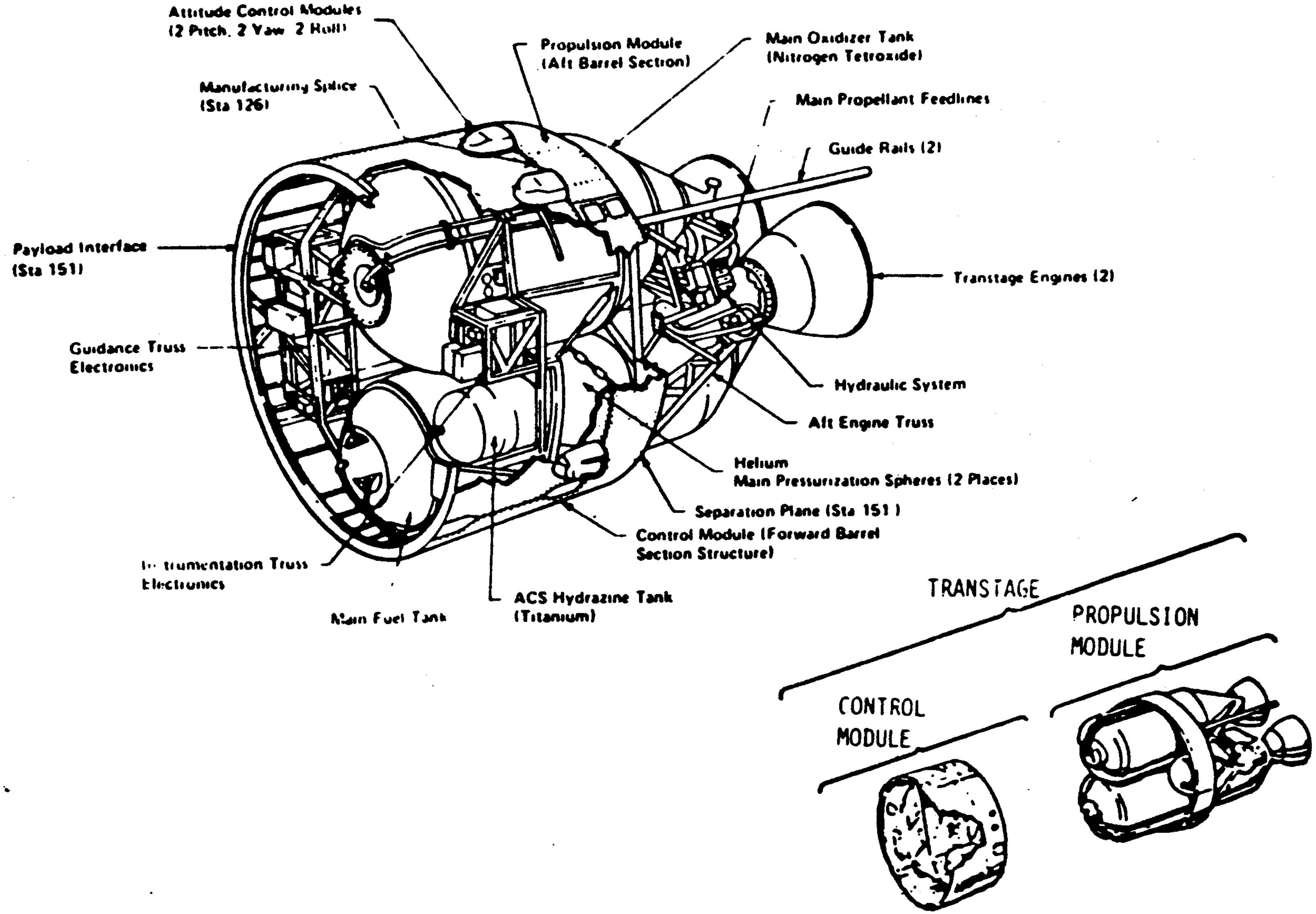


Figure 7a. Transtage

TITLE - TRANSTAGE VERIFICATION

STAGE # 1

Total Number of Stages 1

Vehicle Payload Wt. (lbm)

Miscellaneous Stage Wt. (lbm) 1299

Expendable Stage Wt. (lbm)

Upper Interstage Material Properties

density (lb/in^3)

design stress (psia)

modulus of elasticity (psia)

safety factor (-)

Kind of Stage
(Circle one)

1) solid

[✓ 2) liquid]

	VARIABLE	NAMELIST	UNITS	DEFAULT
	NSTGES	INPGEN	-	3
	~~WPAYLD~~	INPGEN	lbm	0.0
	WMISC	INPGEN	lbm	0.0
	~~WEXPND~~	INPGEN	lbm	0.0
	~~RHOINT~~	INTSTG	lb/in^3	0.101
	~~SINST~~	INTSTG	psia	220000.
	~~EINSTG~~	INTSTG	psia	1.8E6
	~~SFINST~~	INTSTG	-	1.5
2	KSTAGE	INPGEN	-	1

Tank Geometry

Tandem Tanks

raw Sketch Here)

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

pressure tank forward (1-3)
pressure tank integral with forward tank (4)
pressure tank in engine bay (0)

propellant tank head ellipse ratio

pressurant tank head ellipse ratio

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

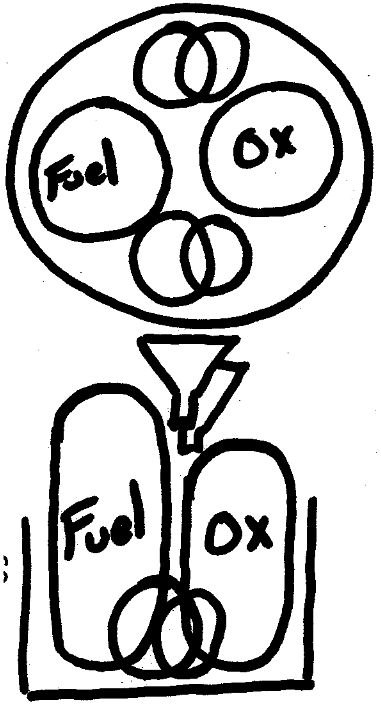
propellant location
(1 = fuel aft, 2 = not)

1

VARIABLE	NAMELIST	UNITS	DEFAULT
NCTNK	LFLAG	-	0
MNCQA	TNKGEO	-	1
MNCQF	TNKGEO	-	1
KDOME	TNKGEO	-	1
KPRESS	TNKGEO	-	0
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)



Total number of tanks 4

Tank ellipse ratios 1.414, 1.414, 1., 1.,

Tank types ([✓ 1 = CSE], 2 = torus)

Tank contents (1 = ox, 2 = fuel, 3 = press) 1,2,3,3,

Tank angular location (deg) 10., 190., 100., 280.,

Tank radial location 1., 1., 1., 1.,

Kind of dimensional input

[✓ dimensionless (0) L_{cyl}/D ; R_{hub}/R_{tube}] 1.2, 2.6, 0., 0.,

major dimension (in) (1) R_{tank} ; R_{hub}

Engine angular location (deg) 100., 280.,

Engine radial location 1., 1.,

Stage Diamater (in)	120.	
Forward Skirt Length (in)	~1.0	→ 0.01
Aft Skirt Length (in)	~75.	→ 0.42

VARIABLE	NAMELIST	UNITS	DEFAULT
NTANKS	NCTINP	-	3
ELTNK1-4	NCTINP	-	1.0
KTANK1-4	NCTINP	-	1
INTNK1-4	NCTINP	-	1
TANGL1-4	NCTINP	deg	0.0
RADLO1-4	NCTINP	-	0.0
0 KALMOD	NCTINP	-	0
RDIM1-4	NCTINP	-	2.0
~~RMAJ1-4~~	NCTINP	in	25.0
ENGAN1-4	NCTINP	deg	0.0
ENGRD1-4	NCTINP	-	0.0
DMOTOR	INPGEN	in	66.0
FFSKTL	LIQUID	-	0.3
FASKTL	LIQUID	-	0.067

Propellant Combination (Circle One)		Nominal Mixture Ratio
[✓ 0) user defined]	N_2O_4/A50	-
1) N_2O_4/MMH		2.3
2) MON-25/MHF-3		2.2
3) CIF_5/MHF-3		2.8
4) MON-25/60% MHF-3 + 40% Al		0.85
5) LO_2/LH_2		5.0
6) LO_2/RP-1		2.7
7) LO_2/CH_4		3.4
8) LF_2/LH_2		9.0
9) LF_2/N_2H_4		2.3

Propellant Mixture Ratio 2.06

Number of Engines 2

Vacuum Thrust Per Engine (lb_f) 8240

Chamber Pressure (psia) 105

0

VARIABLE	NAMELIST	UNITS	DEFAULT
IPROP	LFLAG	-	0
OFCORE	LQPERF	-	1.9
NTC	LIQENG	-	1
FVAC	LIQUID	lb_f	0.0
PC	INPGEN	psia	600.0

Figure 6a. (ont.)

Engine Power le
(Circle One)

[✓ 0) Pressure Fed]
1) Gas Generator Bleed
2) Staged Combustion (fuel rich preburner)
3) Expander Cycle (fuel cooled)
4) Staged Reaction (monopropellant fuel)

~~Gas Generator/Pre-Burner~~

~~Mixture Ratio~~	
~~Ratio of Specific Heats~~	
~~Specific Heat (BTU/lb °R)~~	
~~Molecular Weight~~	

~~Tank Outlet Net Positive Suction Pressures~~

~~Oxidizer (psia)~~	
~~Fuel (psia)~~	

~~Pump Configuration~~

~~1) Gearbox~~
~~2) Single Shaft TPA~~
~~3) Twin TPA in series~~
~~4) Twin TPA in parallel~~

~~Boost Pumps~~

~~oxidizer (0 = no)~~
~~fuel (1 = yes)~~

0

VARIABLE	NAMELIST	UNITS	DEFAULT
KCYCLE	LFLAG	-	0
~~OFGGPB~~	PUMP	-	0.1
~~GAMGPB~~	PUMP	-	1.25
~~CPGGPB~~	PUMP	BTU/lb °R	0.721
~~WMGGPB~~	PUMP	-	14.0
~~OXNPSP~~	PUMP	psia	10.0
~~FLNPSP~~	PUMP	psia	10.0
~~JCNFIG~~	PUMP	-	2
~~JBPOX~~	PUMP	-	0
~~JBPF~~	PUMP	-	0

Burned Propellant Wt. 23302

Ullage Fractions

Oxidizer 2.5%

Fuel 2.5%

Propellant Acquisition Device
(Circle One)

0) none
1) transverse collapsing aluminum bladder
2) full bonded rolling diaphram - aluminum
3) half bonded rolling diaphram - aluminum
4) full bonded rolling diaphram - stainless steel
5) half bonded rolling diaphram - stainless steel
[✓ 6) surface tension device]

Propellant Tank Pressurization
(Circle One)

[✓ 0) non-autogenous]
  1) solid gas generator
  [✓ 2) cold helium]

1) autogenous

Cold Helium Storage Pressure 3250

Helium Tank Final Pressure Fraction
(less than 1.0 indicates blowdown) 1.0

	VARIABLE	NAMELIST	UNITS	DEFAULT
	WTLPRP	LIQUID	lb.	13250.0
	ULLFFL	LTANK	-	0.02
	ULLFOX	LTANK	-	0.02
6	KACQOX	LFLAG	-	0
6	KACQFL	LFLAG	-	0
0	KGASOX	LFLAG	-	0
0	KGASFL	LFLAG	-	0
2	KGAS	LFLAG	-	2
	PICG	COLDG	psia	4365.0
	FPULCG	COLDG	-	0.8

Materials of Construction
(fill in material ID#)

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	12
Oxidizer Tank	12
Pressurant Tank	12
Structure and Skirts	11

Design Safety Factors

Fuel Tank	1.25
Oxidizer Tank	1.25
Pressure Tank	1.5
Structure and Skirts	1.25
lines	2.0

VARIABLE	NAMELIST	UNITS	DEFAULT
~~MTNKFL~~	LIQMAT	-	1
~~MTNKOX~~	LIQMAT	-	1
~~MATPT~~	LIQMAT	-	2
MATSTR	LIQMAT	-	1
MATNK1-4	NCTINP	-	1
~~RHO~~	LIQMAT	lb/in^3	-
~~YMOD~~	LIQMAT	psi	-
~~SIGMAX~~	LIQMAT	psi	-
~~SPHEAT~~	LIQMAT	BTU/lb °R	-
~~CONDCT~~	LIQMAT	BTU/in sec°R	-
~~TMING~~	LIQMAT	in	0.035
~~TMINGS~~	LIQMAT	in	0.035
~~SFFLTK~~	LIQMAT	-	1.25
~~SFOXTK~~	LIQMAT	-	1.25
~~SFPRTK~~	LIQMAT	-	1.5
SFSTRC	LIQMAT	-	1.25
SFLINE	LIQMAT	-	2.0
SFTNK1-4	NCTINP	-	1.5

Figure 6a. (t.)

Propellant Insulation (in)

Fuel Tank

SOFI Thickness	0
MLI Thickness	0.2

Oxidizer Tank

SOFI Thickness	0
MLI Thickness	0.2

Engine Expansion Area Ratio	40
Nozzle Extension Attach Area Ratio	6
Engine Contraction Ratio	2.54
Combustion Chamber Length (in)	18.7

Nozzle Type (Circle One)

	IPLUG	KNOZ
Conical	0	1
[✓ Rao/Bell]	[✓ 0]	[✓ 2]
Plug Cluster	1	-
Annular	2	-

	VARIABLE	NAMELIST	UNITS	DEFAULT
	KHXOPT	LFLAG	-	0
	TSOFIF	TANKHX	in	0.0
	TMLIF	TANKHX	in	0.0
	TSOFIO	TANKHX	in	0.0
	TMLIO	TANKHX	in	0.0
	EPS	INPGEN	-	10.0
	EPSATT	INPGEN	-	1.0
	CR	LIQENG	-	2.54
	XLC	LIQENG	in	0.0
	XLN	LIQENG	in	18.7
0	IPLUG	LIQUID	-	0
2	KNOZ	LIQENG	-	2
	~~ALFNOZ~~	NOZZLE	deg	15.0
1.026	RATMLR	LIQENG	-	1.177
1	KEXNOZ	LIQENG	-	1

Combustion Chamber Cooling Method
(Circle One)

[✓ 1) Ablative]

2) Regenerative

3) Trans-Regen

4) Radiation

Nozzle Cooling Method
(Circle One)

1) Ablative

2) Regenerative

3) Trans-Regen

[✓ 4) Radiation]

5) Film

	VARIABLE	NAMELIST	UNITS	DEFAULT
1	KOOLTC	LFLAG	-	1
	TGWNOM	INREGN	°R	2000.0
	~~DIFTBF~~	INREGN	-	1.0
	~~IRPRNT~~	INREGN	-	0
	~~GW[illegible]ING~~	INREGN	in	0.025
	~~WALLK~~	INREGN	BTU/in sec °R	0.00039
	~~EPSTRU~~	INREGN	-	2.0
	~~EPSTRD~~	INREGN	-	1.2
	~~TDEST[illegible]~~	INREGN	°R	2000.0
4	KOOLNZ	LFLAG	-	4
	TNENOM	LIQENG	°R	2000.0

			VARIABLE	NAMELIST	UNITS	DEFAULT
Pressure Drop Across Injector (15% of Pc is optimistic) (25% of Pc is nominal) (40% of Pc is conservative)	Fuel	25%	FCHGFL	LIQUID	-	0.15
	Oxidizer	25%	FCHGOX	LIQUID	-	0.15
Pressure Drop Acorss Valve (3-30% of Pc)	Fuel	10%	CPVLVF	LIQUID	-	0.409
	Oxidizer	10%	CPVLVO	LIQUID	-	0.28
Pressure Drop Across Lines (3-30% of Pc)	Fuel	10%	CPLINF	LIQUID	-	0.172
	Oxidizer	10%	CPLINO	LIQUID	-	0.207
Injector Element Density (elem/in^2) (1.0 = coarse pattern, 4.0 = nominal pattern) (15.0 = platelets, 40.0 = hyperthin platelet)		10	ELDENS	INJECT	elem/in^2	3.1
		(IELDEN = 1) 1	IELDEN	INJECT	-	1
Injector Element Type (used to correct drop size) (Circle One) (Groups are in increasing order of atomizing efficiency)	3.0) Showerhead, shear co-ax 1.0) like-doublets, splash plate, X doublet, V doublet, Pre-atomized triplet 0.5) Vortex, swirl coax [✓ 0.33) unlike Triplet, unlike doublet]		RMFFL	LQPERF	-	0.33
			RMFOX	LQPERF	-	0.33
			FLOPEL	INJECT	-	2.0
			OXOPEL	INJECT	-	1.5

Translating Nozzle
(Circle One)

[✓ 0) None]
1) Spring Actuated
2) Gas Deployed Skirt

Translating Nozzle Material Density (lb/in^3)

Gimbal Angle (deg) 6

Number of Gimbaling Engines 2

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

Aluminum	0.098 lb/in^3,	25000 psia
Stainless Steel	0.28 lb/in^3,	25000 psia
Columbium	0.32 lb/in^3,	25000 psia
Silica Phenolic	0.0632 lb/in^3,	25000 psia

(used with KWTMOD = 1)

	density (lb/in^3)	strength (psi)
CHAMBER	.0632	25K
NOZZLE	.32	25K
INJECTOR	.098	25K
VALVE	.098	☒

1

Stage Operating Temperature Range (°F)

Minimum temperature	45
Nominal temperature	65
Maximum temperature	95

VARIABLE	NAMELIST	UNITS	DEFAULT
KTRNOZ	LIQENG	-	0
~~EPTRAT~~	LIQENG	-	50.0
~~ROTRNZ~~	LIQMAT	lb/in^3	0.28
GMBANG	LIQUID	deg	6.0
NGIMB	LIQUID	-	1
KGPOWR	LIQUID	-	0
KWTMOD	LFLAG	-	0
RHCABL	LIQMAT	lb/in^3	0.0632
RHCSTR	LIQMAT	lb/in^3	0.0632
~~RHOGW~~	LIQMAT	lb/in^3	0.28
~~RHOCLS~~	LIQMAT	lb/in^3	0.322
SIGCHM	LIQMAT	psi	25000.0
~~SIGCLS~~	LIQMAT	psi	25000.0
RHONZE	LIQMAT	lb/in^3	0.32
SIGNZE	LIQMAT	psi	25000.0
TNZMIN	LIQENG	in	0.010
RHOINJ	LIQMAT	lb/in^3	0.098
SIGINJ	LIQMAT	psi	25000.0
RHOVLV	LIQMAT	lb/in^3	0.098
TMIN	LIQUID	°F	60.0
TOP	LIQUID	°F	75.0
TMAX	LIQUID	°F	90.0

Weight Multipliers

All Tanks	1.0
Fuel Tanks	2.25
Oxidizer Tanks	2.0
Pressure Tanks	1.25
Structure	4.2
Propellant Lines	/
Total Engine	/
Injector	1.6
Valve	/
Chamber	2.0
Nozzle Extension	/
Hot Gas Ducts	/
Gimbal System	/
Thrust Mount	/
Gas Generator Injector	/
Turbo Pump Assembly	/
Engine Bay Lines	/

VARIABLE	NAMELIST	UNITS	DEFAULT
CXWTNK	CXWMLT	-	1.7
CXNCT1-4	NCTINP	-	1.0
~~CXWFLT~~	CXWMLT	-	1.0
~~CXWOXT~~	CXWMLT	-	1.0
~~CXWPTN~~	CXWMLT	-	1.0
CXWSTR	CXWMLT	-	1.0
~~CXWATL~~	CXWMLT	-	1.0
~~CXWFTL~~	CXWMLT	-	1.0
~~CXWPTL~~	CXWMLT	-	1.0
~~CXWENG~~	CXWMLT	-	1.05
CXINJ	CXWMLT	-	1.0
~~CXVALV~~	CXWMLT	-	1.0
CXWCHM	CXWMLT	-	1.0
~~CXWNZE~~	CXWMLT	-	1.1
~~CXWDUC~~	PUMP	-	2.5
~~CXWGIM~~	CXWMLT	-	1.0
~~CXWTHM~~	CXWMLT	-	1.0
~~CXWIGG~~	PUMP	-	1.0
~~CXWTPA~~	CXWMLT	-	1.0
CXWLIN	PUMP	-	2.5

		VARIABLE	NAMELIST	UNITS	DEFAULT
Engine Mounting Length Adjustment (in)	20	XMOUNT	LIQENG	in	2.0
Propellant Expulsion Efficiency					
0) calculate	1	INPEXF	LFLAG	-	0
[✓ 1) input]	1	INPEXO	LFLAG	-	0
Fuel expulsion efficiency	.9935	EXPLFL	LTANK	-	0.995
Oxidizer expulsion efficiency	.9989	EXPLOX	LTANK	-	0.995

```
    TRANSTAGE VERIFICATION   5/4/84
$INPOPT
   INDES=1,
   IOPF=0,
 IPLOT=0,
   IPRINT=0,2,2,2,1,
  IOPT=92,42,
   IERRMD=0,
   IOBJF=13,
   OBJSCL=1.,
$END
$NLP
$END
$INPGEN
  EPS=40., PC=105., EPSATT=6.,
  DMOTOR=120.,
  KSTAGE=2,
    NSTGES=1,
C >>>>>>>>>  SEE NOTE 1
  WMISC=1299.,
$END
$INTSTG
$END
$NOZZLE
$END
$MATER
$END
$FILMNT
$END
$PROPEL
$END
$INTRAJ
$END
$GUIDA
$END
$AERОD
$END
$THVST
$END
$ORB
$END
$LIQUID
  NGIMB=2,
C >>>>>>>>>  SEE NOTE 2
   FFSKTL=.01,
    FASKTL=.42,
C >>>>>>>>>  SEE NOTE 3
   CPLINF=.1,
   CPLINO=.1,
   CPVLVF=.1,
   CPVLVO=.1,
   FCHGFL=.25,
   FCHGOX=.25,
   FVAC=8240.,
   TOP=65.,TMIN=45.,TMAX=95.,
   WTLPRP=23302.,
 $END
 $LFLAG
   INPEXO=1,
   INPEXF=1,
   KWTMOD=1,
   NCTNK=1,
   KACQFL=6, KACQOX=6,
 $END
 $LTANK
```

Figure 7c. Transtage Input Data Set (Sheet 1 of 3)

```
C >>>>>>>>>  SEE NOTE 4
  EXPLFL=.9935,
  EXPLOX=.9989,
  ULLFOX=.025,
  ULLFFL=.025,
$END
$TNKGEO
$END
$BLADER
$END
$COLDG
  FPULCG=1.0,
  PICG=3250.,
$END
$SOLDGG
$END
$PUMP
$END
$INJECT

C
C >>>>>>>>>  SEE NOTE 5
  ELDENS=10.,
  IELDEN=1,
$END
$LIQENG
C
C >>>>>>>>>  SEE NOTE 6
  RATMLR=1.026,
C
C >>>>>>>>>  SEE NOTE 7
  XLN=18.7,
  CR=2.54,
  NTC=2,
C
C >>>>>>>>>  SEE NOTE 8
  XMOUNT=20.,
$END
$INREGN
C
C >>>>>>>>>  SEE NOTE 9
  TGWNOM=3000.,
$END
$ABLATE
$END
$LIQMAT
  MATSTR=11,
$END
$CXWMLT
C
C >>>>>>>>>  SEE NOTE 11
  CXWTNK=1.0,
C
C >>>>>>>>>  SEE NOTE 12
  CXWSTR=4.2,
  CXINJ=1.6,
  CXWCHM=2.0,
$END
$LPROP
$END
$LQPERF
```

Figure 7c. Transtage Input Data Set (Sheet 2 of 3)

```
C
C >>>>>>>>>  SEE NOTE 10
  OFCORE=2.08,
$END
$THROT
$END
$LFUEL
$END
$LOXID
$END
$NCTINP
C
C >>>>>>>>>  SEE NOTE 13
  RADLO1=4*1.,
  NTANKS=4,
  INTNK1=1,2,3,3,
  TANGL1=10.,190.,100.,280.,
  ENGRD1=2*1.,
  ENGAN1=100.,280.,
C
C >>>>>>>>>  SEE NOTE 11
  CXNCT1=2.0,2.25,2*1.25,
  ELTNK1=1.414,1.414,1.,1.,
  MATNK1=4*12,
  SFTNK1=2*1.25,2*1.5,
  RDIM1=1.2,2.6,0.,0.,
$END
$TANKHX
  TMLIF=0.2,
  TMLIO=0.2,
$END
```

Figure 7c. Transtage Input Data Set (Sheet 3 of 3)

1. Miscellaneous Weight (WMISC)

engine truss (estimated)	100
hydrazine ACS system	237
electrical	341
guidance	219
instrumentation	170
environment	86
separation and destruct	115
Payload peculiar	31
WMISC	1299

2. Skirt Lengths

Input FFSKTL and FASKTL in order to make skirt lengths equal to the total length of Transtage skirts (skirt lengths = 74.6).

3. Pressure Schedule

From stage data is is known that P_c = 105 psia and that tank pressures are 160 psia. The parameters CPLINF, CPLINO, CPVLVF, and CPVLVO are estimated based on known injector Δ P = 27.5 psia. The helium storage bottle (PICG) is at 3250 psia.

4. Expulsion Efficiency

Setting INPEXO and INPEXF allows expulsion efficiency to be input (EXPLFG and EXPLOX). From propellant utilization data those values are input as 0.9935 and 0.9989 respectively.

Ullage fractions of 0.25% where chosen as representative in lieu of data.

Figure 7d. Transtage Input Notes Page 2 of 3

5. Injector Description

Because the improved Transtage injector is a higher technology injector, the element density and fuel film-cooling fraction reflect that technology. The element density is 10 elements per square inch.

6. Ratio of nozzle length to minimum length Rao nozzle (RATMLR)

$$\text{RATMLR} = L_{noz} / \frac{\varepsilon + 1009}{1612.1} \frac{R_t \ (n\varepsilon -1)}{0.26795}$$

$L_{nox} = 49.61$

$\varepsilon = 40$

$R_t = 3.74$

→ RATMLR = 1.026

7. Chamber Geometry

The chamber has an 18.7 inch convergent section with no cylindrical section. The contraction ratio is 2.54.

8. Engine Mount Length (XMOUNT)

From inspection of Transtage drawings the engine exit planes are seen to be 20 inches past the end of the fuel tank. Setting XMOUNT = 20 will accomplish that same design.

9. Nominal Gas Wall Temperature (TGWNOM)

For silica phenolic ablative engines, the nominal temperature to which the ablative should be exposed is about 3000°R (3900°R is an absolute upper limit).

10. Engine Performance

Both the engine thrust and core mixture ratio were input based on the results of ELES. The core mixture ratio was input as 2.08 such that the known overall mixture ratio of 2.00 was obtained. The thrust, although nominally 8000, was input as 8240 such that the engine throat area and nozzle length correspond to the known values.

11. Tank Weight Multipliers

Normally the tank weight multipliers (CXWTNK) is used to modify all tank weights from their ideal value to their actual value. The recommended value for CXWTNK is 1.7. Because Transtage tanks are so unusual, however, CXWTANK is set equal to 1.0 and the non-conventional tank multipliers (CXNCT1) are used instead. The values used for each tank are 2.0 for oxidizer tank, 2.25 for fuel tank, and 1.25 for each pressurant tank.

12. Miscellaneous Weight Multipliers

From component weight data it was found that the structural weight multiplier (CXWSTR) is 4.2, the injector weight multiplier (CXINJ) is 1.6, and the chamber weight multiplier (CXWCHM) is 2.0.

13. Tank Geometry

The inputs in namelist $NCTINP are taken directly from actual stage data. Component location angles are offset by 10° to enhance the graphic output.

```
                                         @   @   @@@   @@@@   @   @   @@@   @   @   @@@@
                                         @   @  @   @  @   @  @   @    @    @   @  @
                                         @   @  @   @  @   @  @@  @    @    @@  @  @
                                         @   @  @@@@@  @@@@   @ @ @    @    @ @ @  @  @@
                                         @ @ @  @   @  @ @    @  @@    @    @  @@  @   @
                                         @@ @@  @   @  @  @   @   @    @    @   @  @   @
                                         @   @  @   @  @   @  @   @   @@@   @   @   @@@@


                                        THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

TEMPERATURES USED FOR VAPORIZATION WERE          530.0      530.0
MOST RECENT CORRECTED VALUES     530.0      530.0

 INJECTOR ELEMENT TO THROAT ANGLE =   0.92          RECOMMENDED RANGE = 2.0 TO 2.5

 FUEL ORIFICE =  0.018          RECOMMENDED MIMIMUM = .020
```

Figure 7e. Transtage Warning Page

```
                    NON-CONVENTIONAL TANKAGE SUMMARY FOR STAGE #1

Stage Length                178.7
Stage Radius                 60.0
Stage Wall Thickness          0.042
Component Spacing             1.0
Total Tank Weights         1173.4


Tank #                        A            B            C            D
Tank Contents             oxidizer       fuel       pressure     pressure
Tank Pressure              159.4        159.4       3250.0       3250.0
Material                  titanium     titanium     titanium     titanium
Safety Factor                1.250        1.250        1.500        1.500
Wall Thickness            constant     constant     constant     constant
Volume (x10**-3)           311.18       244.68        17.71        17.71
Ideal Weight               199.7        145.0        179.1        179.1
Constructed Weight         399.4        326.2        223.9        223.9


Tank Type                   CSE          CSE          CSE          CSE
Inside Radius               30.9         23.3         16.2         16.2
CSE Ellipse Ratio            1.4          1.4          1.0          1.0
CSE Tank Length            118.0        154.2         32.3         32.3
Torus Hub Radius            ----         ----         ----         ----
Min Wall Thickness           0.037        0.030        0.327        0.327
Max Wall Thickness           0.052        0.039        0.327        0.327
Const Wall Thickness         0.052        0.039        0.327        0.327


Location of tank forward center points
X                           27.2        -34.7         -7.4          7.4
Z                            4.8          6.1         41.8        -41.8
Y                           23.5         18.1         17.5         17.5



Engine #                     1            2
Chamber Radius               6.0          6.0
Exit Radius                 23.6         23.6
Chamber Length              18.7         18.7
Nozzle Length               49.6         49.6


Engines nest to give common exit plane past longest tank


Location of injector dome center point
X                           -6.1          6.1
Z                           34.8        -34.8
Y                          109.2        109.2

  * * * ALL UNITS ARE  INCH - POUND - SECOND * * *
```

Figure 7f. Transtage Non-Conventional Tankage Summary

```
          TANKAGE PARAMETERS FOR STAGE #1
                PRESSURE FED
                FUEL TANK(S) ARE PRESSURIZED WITH COLD GAS
                OXIDIZER TANK(S) ARE PRESSURIZED WITH COLD GAS


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

     STAGE DIAMETER                       120.0               TANK CONSTRUCTION WEIGHT            0.0
     TOTAL STAGE LENGTH                   178.7
     NOZZLE LENGTH                         49.6               AFT SKIRT                         487.0
     CHAMBER LENGTH                        18.7               FORWARD SKIRT                      46.6
     INJECTOR FACE FORWARD LENGTH          12.2               TANK MOUNT                          0.0
     MOUNT LENGTH                          20.0
                                                              PRESSURE TANK INSULATION            0.0
     AFT SKIRT LENGTH                      74.55              FUEL TANK INSULATION                9.2
     FORWARD SKIRT LENGTH                   1.20              OXIDIZER TANK INSULATION            9.5

     STRUCTURAL WALL THICKNESS              0.042             FUEL ACQUISITION SYSTEM             7.4
     FUEL TANK MLI THICKNESS                0.20              OXIDIZER ACQUISITION SYSTEM         7.8
     FUEL TANK SOFI THICKNESS               0.00              PRESSURANT CONTROL HARDWARE        18.6
     OXIDIZER TANK MLI THICKNESS            0.20              TANK LINES                          7.1
     OXIDIZER TANK SOFI THICKNESS           0.00
     PRESSURE TANK INSULATION THICK         0.00              BURNED FUEL                      7777.9
                                                              BURNED OXIDIZER                 15524.1
                                                              FUEL RESIDUAL                      58.4
.. SAFETY FACTORS                                             OXIDIZER RESIDUAL                  42.9
                                                              STORED PRESSURANT                  40.0
     STRUCTURAL WALL                        1.25              HOLD TIME FUEL BOILOFF              0.0
     LINES                                  2.00              HOLD TIME OX BOILOFF                0.0
                                                              FLIGHT FUEL BOILOFF                 0.0
.. MISCELLANEOUS ..                                           FLIGHT OXIDIZER BOILOFF             0.0
     FUEL TNK HEAT FLUX(BTU/HR IN**2)       0.00              MISC ON-BOARD FUEL                  0.0
     OX TANK HEAT FLUX(BTU/HR IN**2)        0.00              MISC ON-BOARD OXIDIZER              0.0
     FUEL BOILOFF RATE (LB/SEC)             0.000
     OX BOILOFF RATE (LB/SEC)               0.000             MISCELLANEOUS WEIGHT             1299.0
                                                              INTERSTAGE WEIGHT                   0.0
```

Figure 7g. Transtage Tankage Parameters

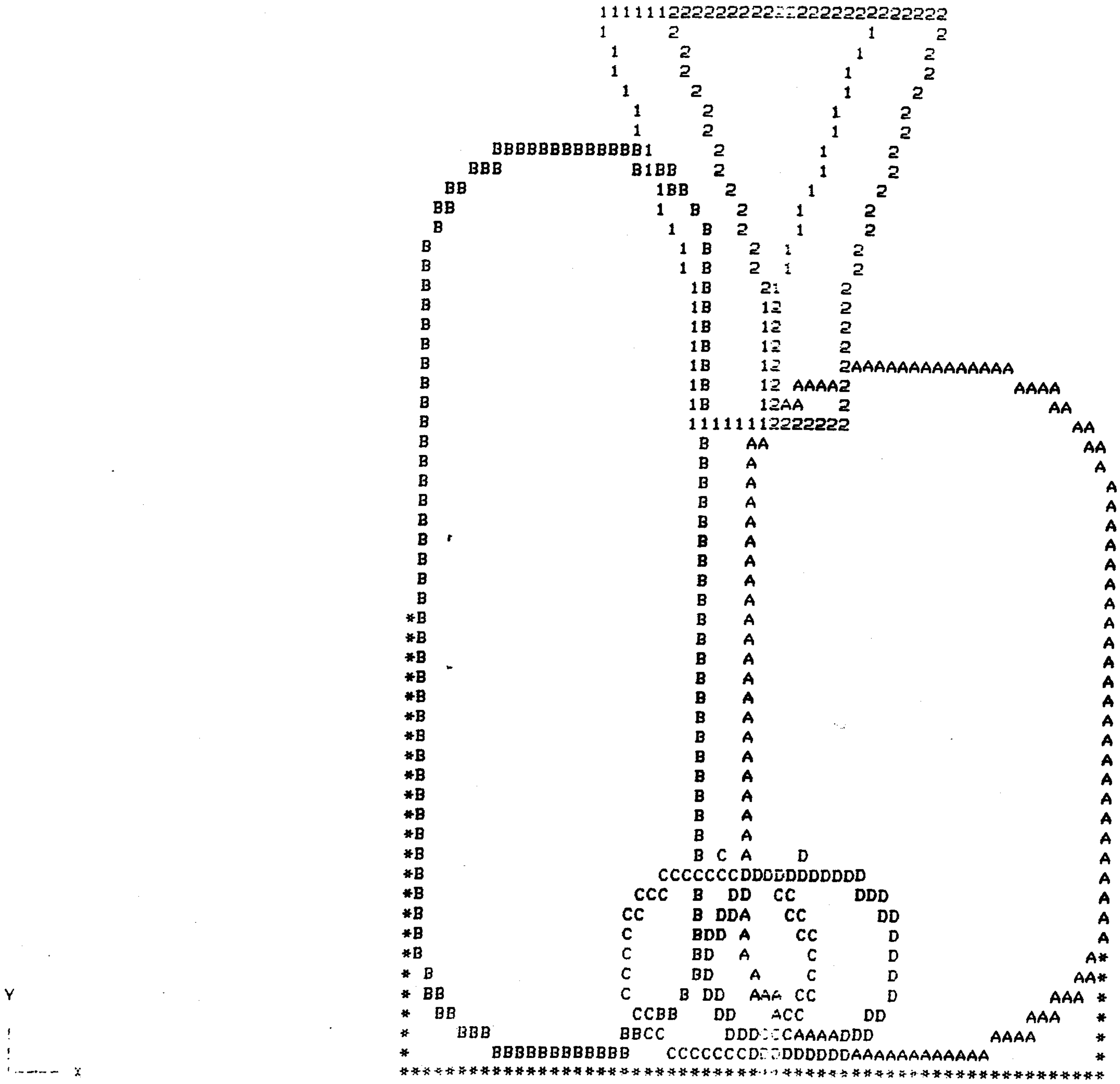


Figure 7h. Transtage Graphical Output, Page 1

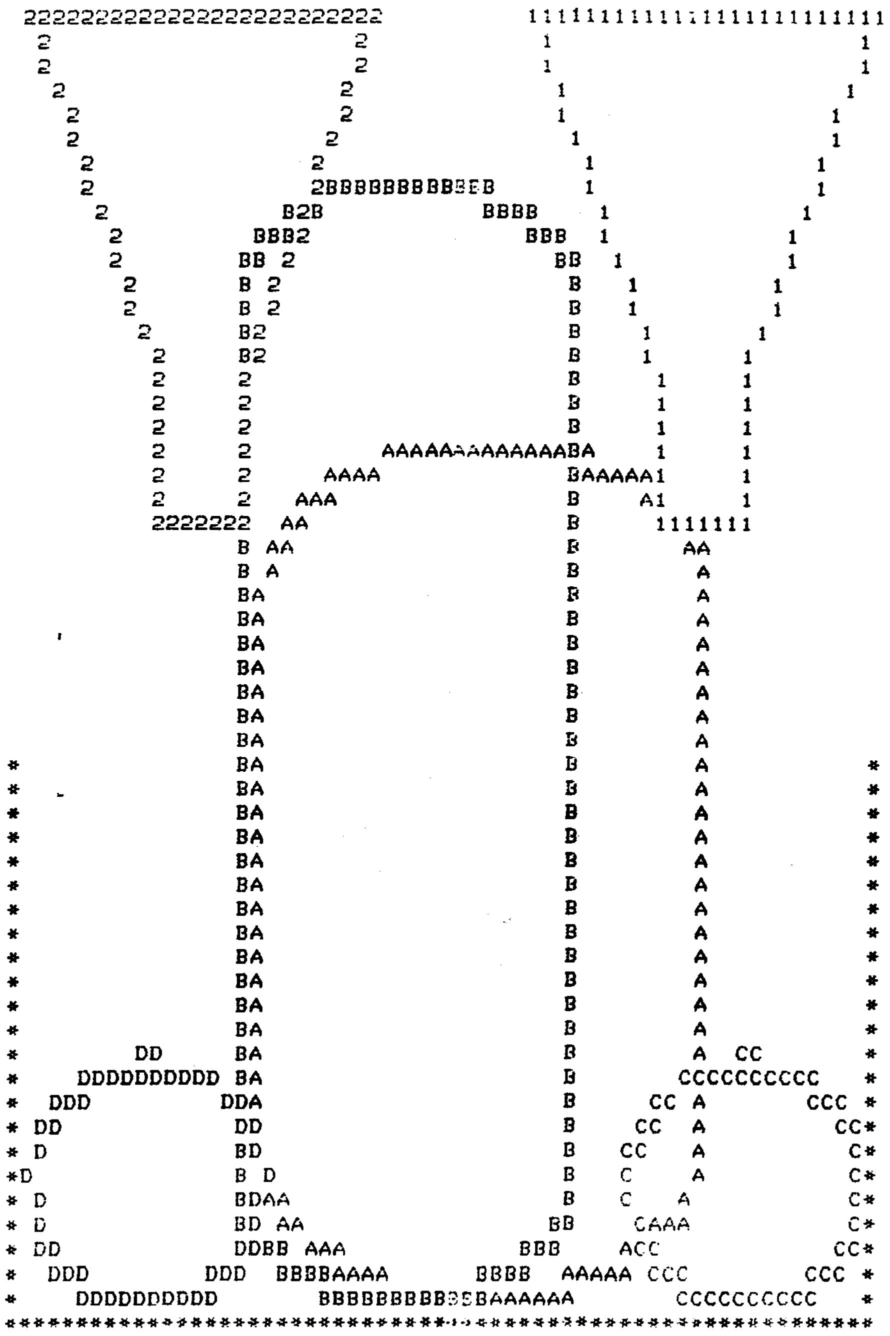


Figure 7i. Transtage Graphical Output, Page 2

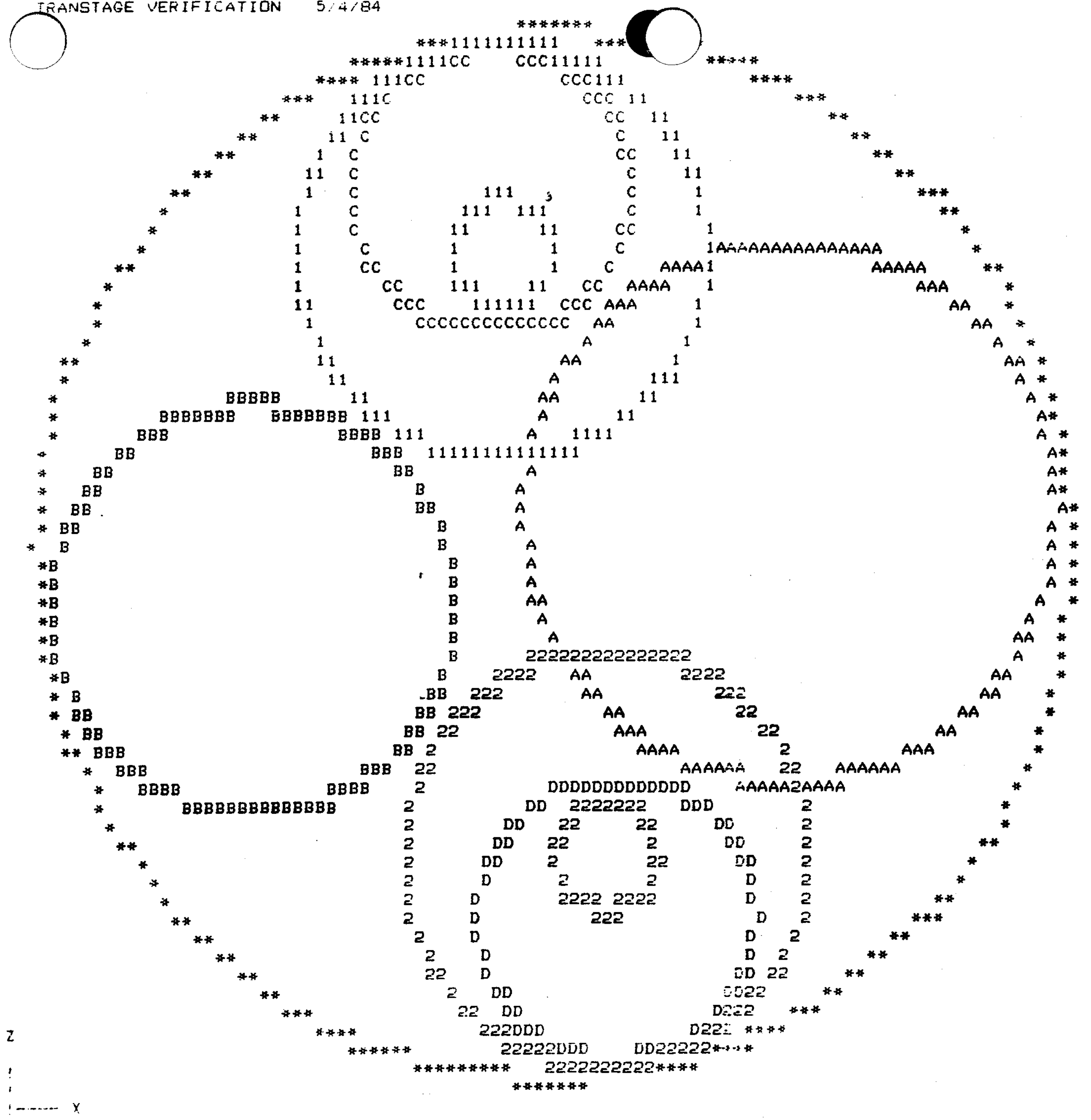


Figure 7j. Transtage Graphical Output, Page 3

```
          PROPELLANT SUMMARY FOR STAGE #1
               PROPELLANT COMBINATION IS USER DEFINED


                              NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0461

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

       NOMINAL TANK PRESSURE(PSIA)           159.4            NOMINAL TANK PRESSURE(PSIA)            159.4

       NOMINAL PROPELLANT TEMP(DEGR)         530.0            NOMINAL PROPELLANT TEMP(DEGR)          530.0
       NOMINAL DENSITY(LB/IN**3)               0.0526         NOMINAL DENSITY(LB/IN**3)                0.0332
       NOMINAL VAPOR PRESSURE(PSIA)           14.8            NOMINAL VAPOR PRESSURE(PSIA)             2.1

       MAX PROPELLANT TEMP(DEGR)             550.0            MAX PROPELLANT TEMP(DEGR)              550.0
       MAX TEMP DENSITY(LB/IN**3)              0.0512         MAX TEMP DENSITY(LB/IN**3)               0.0328
       MAX TEMP VAPOR PRESSURE(PSIA)          25.8            MAX TEMP VAPOR PRESSURE(PSIA)            3.5

       MIN PROPELLANT TEMP(DEGR)             510.0            MIN PROPELLANT TEMP(DEGR)              510.0
       MIN TEMP DENSITY(LB/IN**3)              0.0540         MIN TEMP DENSITY(LB/IN**3)               0.0336
       MIN TEMP VAPOR PRESSURE(PSIA)           8.0            MIN TEMP VAPOR PRESSURE(PSIA)            1.3
```

Figure 7k. Transtage Propellant Summary

```
ENGINE SIZE, WEIGHT, & PERFORMANCE SUMMARY FOR STAGE #1
      PRESSURE FED
      CHAMBER IS ABLATIVELY COOLED
      NOZZLE IS RADIATION COOLED
      PROPELLANT COMBINATION IS USER DEFINED


ENGINE DIMENSIONS (INCHES) ...                                   ... PERFORMANCE ...
     THROAT DIAMETER                    7.47
     CHAMBER DIAMETER                  11.91          DELIVERED ISP(VAC), SEC              306.9
     NOZZLE EXIT DIAMETER              47.27          IDEAL ISP(ODE), SEC                  338.1
     NOZZLE EXTENSION ATTACH DIAM      18.31
     CONVERGENT CHAMBER LENGTH         18.70          DELIVERED CSTAR, FT/SEC             5519.
     CYLINDRICAL CHAMBER LENGTH         0.00          IDEAL CSTAR, FT/SEC                 5559.
     ABLATIVE THICKNESS (THROAT)        1.15
     ABLATIVE THICKNESS (CHAMBER)       0.87          CHAMBER PRESSURE, PSIA               105.
     CHAMBER STRUCTURAL THICKNESS       0.100         THRUST PER ENGINE(VAC), LBF         8240.
     NOZZLE EXTENSION THICKNESS         0.018         TOTAL VAC THRUST, LBF              16480.
                                                      BURN TIME, SEC                       433.9
     NOZZLE EXIT AREA RATIO            40.0
     CHAMBER CONTRACTION RATIO          2.5           OVERALL EFFICIENCY                     0.908
     NOZ EXTENSION ATTCH AREA RATIO     6.0
     NOZZLE LENGTH/(MIN RAD LENGTH)     1.026         ENERGY RELEASE EFFICIENCY              0.992
     NOZZLE LENGTH                     49.57          NOZZLE EFFICIENCY                      0.915
     CHAMBER LENGTH                    18.70
     INJECTOR FACE FORWARD LENGTH      12.24          KINETIC EFFICIENCY                     0.954
     MOUNT LENGTH                      20.00          VAPORIZATION EFFICIENCY                1.000
                                                      MIXING EFFICIENCY                      0.998
                                                      MR DISTRIBUTION EFFICIENCY             0.994
.. ENGINE WEIGHTS (POUNDS) ...                        BOUNDARY LAYER EFFICIENCY              0.979
     NOZZLE EXTENSION                  34.4           DIVERGENCE EFFICIENCY                  0.980
     CHAMBER                          101.5           TWO PHASE EFFICIENCY                   1.000
     BIPROPELLANT VALVE                 5.6
     INJECTOR                          21.2           FOR   2 ENGINES
     TCA SUPPORT HARDWARE              11.1           OXIDIZER FLOWRATE, LB/SEC             35.78
     TCA CONSTRUCTION                   8.1           FUEL FLOWRATE, LB/SEC                 17.93
     ------------------------------                   TOTAL FLOWRATE, LB/SEC                53.71
     SINGLE THRUST CHAMBER ASSY       181.9
                                                      CORE MIXTURE RATIO                     2.08
     THRUST MOUNT                      23.9           CORE TEMPERATURE, DEG R             5562.
     GIMBAL SYSTEM                     28.5           BARRIER MIXTURE RATIO                  0.58
     ENGINE BAY LINES                   4.8           BARRIER TEMPERATURE, DEG R          3009.
                                                      ENGINE MIXTURE RATIO                   2.00
     TOTAL NUMBER OF ENGINES            2             FUEL FILM COOLING FRACTION             0.04
     TOTAL ENGINE                     363.8
     TOTAL THRUST MOUNT                47.8           INJ ELEMENT DENSITY, ELEM/IN**2        9.63
     TOTAL GIMBAL SYSTEM               57.0           OX ORIFICE DIAMETER (IN)               0.024
     TOTAL ENGINE BAY LINES             9.6           FUEL ORIFICE DIAMETER (IN)             0.016
```

Figure 71. Transtage Engine Summary

```
                    PRESSURE AND TEMPERATURE SCHEDULES FOR STAGE #1
                    PRESSURE FED


                           PRESSURE(PSIA)                           TEMPERATURE(DEG R)
                          FUEL        OXIDIZER                   FUEL        OXIDIZER

                                                ... PRESSURANT ...
MAX STORAGE             3250.0         3250.0                   555.0        555.0
VENT                     175.3          175.3                   797.2        636.6 (SATURATION TEMP OF PROPELLANT)
ULLAGE                   159.4          159.4                   ----         ----

                                                ... PROPELLANT ...
TANK PROPELLANT          159.4          159.4                   530.0        530.0
MAIN VALVE INLET         148.4          148.4                   530.0        530.0
MAIN VALVE OUTLET        137.4          137.4                   530.0        530.0
INJECTOR INLET           137.4          137.4                   530.0        530.0
INJECTOR FACE                   109.9
COMBUSTION CHAMBER              105.0                                  5561.9

---------------------------------------------------------------------------------------

                                  ... COMPONENT PRESSURE/TEMPERATURE CHANGES ...
ACQUISITION DEVICE         0.0            0.0
FEED LINE                 11.0           11.0                     0.0          0.0
MAIN VALVE                11.0           11.0                     0.0          0.0
INJECTOR                  27.5           27.5                     0.0          0.0

---------------------------------------------------------------------------------------

                       FLOWRATE SCHEDULE (LB/SEC) FOR STAGE #1
                       PRESSURE FED


                             FUEL        OXIDIZER
TANK OUTFLOW                17.926        35.780
MAIN VALVE                   8.963        17.890
STORED PRESSURANT (AVE)              0.09
INJECTOR                     8.963        17.890
```

Figure 7m. Transtage Temperature/Pressure/Flowrate Summary

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

     TANK WEIGHT                            1173.4
     TANK LINES                                7.1

     AFT SKIRT                               487.0
     FORWARD SKIRT                            46.6
     TANK MOUNT                                0.0
     STRUCTURAL WALL                           0.0

     PRESSURE TANK INSULATION                  0.0
     FUEL TANK INSULATION                      9.2
     OXIDIZER TANK INSULATION                  9.5

     FUEL ACQUISITION SYSTEM                   7.4
     OXIDIZER ACQUISITION SYSTEM               7.8
     PRESSURANT CONTROL HARDWARE              18.6

      2 THRUST CHAMBER ASSY(S)               363.8
      2 THRUST MOUNT(S)                       47.8
      2 GIMBAL SYSTEM(S)                      57.0
      2 ENGINE BAY LINE(S)                     9.6

      2 IGNITION SYSTEM(S)                     0.0
      2 HOT GAS MANIFOLD(S)                    0.0
      2 TPA ASSY(S)                            0.0
      2 TPA START SYSTEM(S)                    0.0
      2 GAS GENERATOR/PREBURNER(S)             0.0

     FLIGHT FUEL BOILOFF                       0.0
     FLIGHT OXIDIZER BOILOFF                   0.0
     EXPENDABLE WEIGHT                         0.0
     MISCELLANEOUS WEIGHT                   1299.0
    ----------------------------------------------------

     TOTAL INERT WEIGHT                     3543.9


     INTERSTAGE WEIGHT                         0.0
     BURNED FUEL                            7777.9
     BURNED OXIDIZER                       15524.1
     FUEL RESIDUAL                            58.4
     OXIDIZER RESIDUAL                        42.9
     STORED PRESSURANT                        40.0
     MISC ON-BOARD FUEL                        0.0
     MISC ON-BOARD OXIDIZER                    0.0

    ----------------------------------------------------

     GROSS IGNITION WEIGHT                 26987.2
     GROSS BURNOUT WEIGHT                   3685.2

     HOLD TIME FUEL BOILOFF                    0.0
     HOLD TIME OX BOILOFF                      0.0
```

Figure 7n. Transtage Weight Summary

```
   TRANSTAGE VERIFICATION   5/4/84

    ****  VEHICLE SUMMARY  ****

                                    STAGE #1

    ..WEIGHT,LB..

PAYLOAD                                 0.0
STAGE WEIGHT                        26987.2
   USABLE PROPELLANT                23302.0
   FIXED INERT
     PROPULSION SYSTEM               3543.9
     INTERSTAGE                         0.0
   EXPENDED INERT
     EXPELLED                           0.0
     JETTISONED                         0.0
GROSS IGNITION WEIGHT               26987.2
GROSS BURNOUT WEIGHT                 3685.2
PROPELLANT MASS FRACTION                0.863


    ..DIMENSIONS,IN..

STAGE DIAMETER                        120.00
NOZZLE EXIT DIAMETER                   47.27
NUMBER OF NOZZLES                      2
STAGE LENGTH                          178.69


    ..PERFORMANCE..

PROPELLANT                           LIQUID
THRUST,VACUUM DELIVERED,LBF         16480.0
PC,PSIA                               105.0
USABLE PROPELLANT MR                    2.00
NOZZLE AREA RATIO                      40.00
BURN TIME,SEC                         433.88
ISP,VACUUM DELIVERED,SEC              306.9
ISP EFFICIENCY                          0.908
PROPELLANT FLOW RATE,LB/SEC            53.71
```

Figure 7o. Transtage Vehicle Summary

ID # 11183

840318

ELES-1984 June 1984

EXPANDED LIQUID ENGINE SIMULATION COMPUTER PROGRAM

NEW USERS GUIDE

Prepared By:

Charles E.Taylor

Aerojet TechSystems Company
P.O. Box 13222
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AA0090

ACKNOWLEDGEMENTS

The mathematical models used in ELES-1984 are the result of many analysts committing their knowledge and experience to the task of producing simplified, preliminary-design algorithms. The following is a list of contributors:

Roger Anderson
Ed Barth (AFRPL)
Randy Bickford
Kirk Christensen
Don Culver
Jack Dever
Al Epes
Fred Fischietto
Keith Hamlyn (MMDA)
Ross Hewitt
John Hidahl
Bob Holman (SEA)
Jack Ito
Joe Jellison
Craig Judd
Tom Lee
Don Lemke
Bruce Lindley
Barbara Loch/Bicknell (MMDA)
Rich Matlock (AFRPL)
Gregg Meagher
Joe Mellish
Gary Nickerson (SEA)
Charles O'Brien
Dave Perkins (AFRPL)
Bob Schwantes
Adam Siebenhaar
Jim Smith
Charles Taylor
Vic Viteri
Dick Walker

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INTRODUCTION

The ELES-1984 computer code is a landmark development in the preliminary systems analysis of liquid rocket vehicles. It is capable of revealing subsystem interactions and design choice impacts on total vehicle performance. Its use enables very rapid determinations of optimum vehicle designs.

The liquid propulsion system models in ELES have been developed by Aerojet TechSystems Company under the auspices of AFRPL during the past few years (1980-1984). The main purpose of ELES is to find optimum vehicle designs for specified mission requirements. Toward that end it is capable of evaluating the size, weight, and performance of system components over a range of design configurations, materials of construction, and operating points. These capabilities allow the code to act as an excellent propulsion system preliminary design training tool.

The objective of this manual is to explain the basic use of the ELES-1984 computer code. The main topics to be covered by this manual include defining a problem statement and formulating an input set for liquid stages in a rocket vehicle.

Use of the non-liquid portions of ELES (solid stage design, trajectory simulation, method of multipliers optimization, etc.) are documented by other sources available through AFRPL.

There are four manuals which describe the operation of the ELES-1984 Computer Program.

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
New Users Guide, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Technical Information Manual, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Programmers Manual, Aerojet TechSystems Company, 1984

Taylor, C. E.
Expanded Liquid Engine Simulation Computer Program
Advanced Users Manual, Aerojet TechSystems Company, 1984

Introduction (cont.)

Both users guides are concerned with proper formulation and input of a problem statement. The new users guide does so in a more basic manor than the advanced users guide. The technical information manual describes the mathematical algorithms used in ELES to model the various propulsion subsystems. The programmers manual deals with the internal structure of the FORTRAN code, its file structure, and internal communication.

For more information regarding the ELES-1984 computer program contact

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8. GENERAL GUIDELINES

Review the input worksheet carefully in order to properly define the stages to be modeled. Very often assumptions about the stage design will be required; keep them in mind when reviewing the output in order to assess their impact on the stage performance.

Inspect the messages on the warning page for each stage. Deviations from standard engineering practices should be justified or corrected.

When using bonded rolling diaphrams (BRD) for positive expulsion, the domes of the tank must be oriented in the same direction. BRD expulsion cannot be used in spherical or conventional cylindrical tanks.

When pressurizing tanks with a solid gas generator, it is usually best to have a bladder in the tank to protect the propellant from the pressurant. Without a barrier, it is possible to thermally detonate monopropellant fuels with hot gas. The hot fuel-rich pressurant is also very reactive with oxidizers.

When bladders are used, the propellant lines are always full at engine burnout.

The miscellaneous weight input should include those items not specifically modeled by ELES. This includes guidance and control packages, attitude control systems, electrical systems, range safety systems, separation systems, and propellant utilization systems. It is anticipated that future versions of ELES will model those systems, however, at present the user must make his best estimate and include it in WMISC.

The same situation as exists for WMISC exists for WEXPND. WEXPND should include those weights which are expended gradually throughout the burn. Examples include ablation losses, gas generator overboard dump, attitude control propellant, and open loop hydraulic actuator overboard dump. The user's best estimate should be used.

Combustion gas properties in gas generators or preburners can be obtained by executing a version of the One Dimensional Equilibrium (ODE) program which calculates them.

The net positive suction head (NPSH) of a pump can be adjusted to change the pump diameter. The pump diameter is approximately inversely proportional to the NPSH (the inverse relationship is not linear) so that an increased NPSH will result in a decreased pump diameter.

The choice of a propellant acquisition device, if any, should be made on the basis of mission requirements. A stage which must start or restart under conditions which do not assure orientation of the propellant at the tank outlet (e.g., low g or adverse acceleration environment) will require a propellant acquisition system. Positive expulsion bladders are often used in high adverse acceleration environments and for double wall containment of hypergolic propellants. Surface tension devices are often used in low g environments.

Autogenous pressurization is used exclusively with pump fed power cycles in order to provide the NPSH for the pump inlets. For most propellants, the weight of the autogenous pressurant is more than helium would be for the same pressurization task. Autogenous pressurization is made competitive by the fact that the pressurant is stored at low pressure and high density.

The structural properties of user defined materials of construction are contained in the arrays RHO, SIGMAX, and YMOD, each of which is dimensioned to 10. Any given tank in the vehicle can be constructed from any of the materials in the material arrays. For example, to make the third stage aft tank from material number 4 in the material arrays, set MATAT(3) = 4. (MATAT is the aft tank material selection flag.)

In the previous example the material arrays might contain the following values.

RHO = .29, .16, .296, .001, 6 * 0
SIGMAX = 112300, 130000, 185000, 999000, 6 * 0
YMOD = 2.9E7, 1.7E7, 3.1E7, 1.0E7, 6 * 0

which would correspond to heat treated 410 stainless with a 1.5 safety factor (SF), titanium with a 1.3 SF, Inconel 718 with a 1.0 SF, and a fictitious material.

Tankage heat transfer calculations obtain their material properties when user defined materials are used from the arrays SPHEAT and CONDCT (also dimensioned to 10). The minimum gauge information, however, is contained in the arrays TMING and TMINGS which are dimensioned to 4 (one for each stage).

There are two basic insulation types available within ELES; multilayer insulation (MLI) and spray on foam insulation (SOFI). MLI is used primarily outside the atmosphere where its insulation properties are extremely good. Used alone, it is a very poor insulator at sea level. SOFI is more appropriate to boost stages which operate largely in the atmosphere.

The formula for calculating the ratio of nozzle length to that of a minimum length Rao (RATMLR) is:

$$\text{RATMLR} = \frac{L_{noz}}{\left(\frac{\varepsilon + 1009}{1612.1}\right) \frac{R_t\ (\sqrt{\varepsilon}-1)}{0.26795}}$$

The choice of engine power cycle is dependent on the specific case under consideration.

Pressure fed - pressure fed stages are most competitive in applications where a low P_c engine is feasible. Low total impulse and small diameter stages suffer less from high tank pressures than do larger stages. When tank material minimum gauge dictates the tank weight, the chamber pressure is "free" in terms of its impact on tank weight.

8, General Guidelines (cont.)

Gas Generator Bleed - gas generator bleed cycles are normally competitive at chamber pressures up to 1000 psia.

Staged Combustion - Most competitive above 1000 psia chamber pressure.

Expander Cycle - Used exclusively with hydrogen cooled engines. Feasible at chamber pressures up to 1500 psia currently.

Staged Reaction - Has some real advantages in aiding the turbine design, and control system, since the preburner is a monopropellant fuel reactor. Also, no oxidizer tank zero "g" acquisition device is needed, because the monopropellant fuel start transient delivers settling thrust. Staged reaction cycles can power balance above 1000 psia combustor pressure, in general.

9. ELES-1984 INPUTS

The following is a list of all available inputs to ELES-1984. They are listed in alphabetical order and include information concerning their units, default value, namelist, and common block.

Many of the inputs that are not discussed in this users manual are discussed in the "Expanded Liquid Engine Simulation Computer Program - Advanced Users Manual." Not covered are the inputs which pertain to solid stage design and the optimizer. Those topics are discussed in other documents available through AFRPL.

```
C
CIIIIIIIIIIIIIIIIIII  INPUT      INPUT      INPUT  IIIIIIIIIIIIIIIIIIIII
CI                                                                    I
CI                  ( UNITS DEFAULT $NAMELIST /COMMON/ )              I
CI                                                                    I
CI       ACAMAX    MAXIMUM ALLOWABLE AXIAL ACCELERATION DURING FLIGHT I
CI                 ( G'S 50 $INTRAJ /MOTOR/  )                        I
CI       AE        FIBER AREA                                         I
CI                 ( IN**2/END 0.000135 $FILMNT /MOTOR/  )            I
CI       AESSR     CROSS SECTIONAL AREA OF ENGINE SHROUD STIFFENING   I
CI                 RING                                               I
CI                 ( IN**2 0.152 $LTANK /TANKS/  )                    I
CI       AEXIT     EXIT AREA OF NOZZLE                                I
CI                 ( IN**2 1.0 $THVST /PERF/  )                       I
CI       AFSSR     CROSS SECTIONAL AREA OF FORWARD SHROUD STIFFENING  I
CI                 RING                                               I
CI                 ( IN**2 0.25 $LTANK /TANKS/  )                     I
CI       ALFMIX    BARRIER MIXING ANGLE IN CHAMBER                    I
CI                 ( DEG 0.15 $INJECT /LIQUID/  )                     I
CI       ALFNOZ    NOZZLE DIVERGENCE ANGLE OF CONICAL NOZZLES OR EXIT I
CI                 ANGLE OF CONTOURED NOZZLES                         I
CI                 ( DEG 15.  $NOZZLE ///EQ///  )                     I
CI       ALFTRN    INITIAL FLOW TURNING ANGLE FOR CONTOURED NOZZLES   I
CI                 (FOR BELL(1) = 1 ONLY)                             I
CI                 ( DEG 27 $MATER /MOTOR/  )                         I
CI       ALPH      ANGLE OF ATTACKS FOR WHICH AERODYNAMIC             I
CI                 COEFFICIENTS ARE INPUT                             I
CI                 ( DEG 0.  $AEROD /AERO/  )                         I
CI       ALFHA     INITIAL ANGLE OF ATTACK                            I
CI                 ( DEG 0  $INTRAJ ///EQ///  )                       I
CI       ALPHAC    COMMANDED CONSTANT ANGLE OF ATTACK; INPUT FOR      I
CI                 TRAJECTORY GUIDANCE SECTIONS UTILIZING GUIDANCE    I
CI                 OPTION 1                                           I
CI                 ( DEG 0 $GUIDA ///EQ///  )                         I
CI       ALPMLD    ANGLE OF ATTACKS PRODUCING MAXIMUM LIFT-TO-DRAG    I
CI                 INPUT AS A FUNCTION OF MACH NUMBER FOR TRAJEC-     I
CI                 TORIES UTILIZING GUIDANCE OPTION 9                 I
CI                 ( DEG 0  $GUIDA /AERO/  )                          I
CI       ALPTOL    CONVERGENCE TOLERANCE FOR LC-RHA ITERATION FOR     I
CI                 ANGLE OF ATTACK, ALPHA                             I
CI                 ( --- .000001 $AEROD /TRAJ/  )                     I
CI       ALTI      INITIAL MISSILE ALTITUDE                           I
CI                 ( FT 0.0 $INTRAJ ///EQ///  )                       I
CI       ALTRE     ALTITUDE TO BEGIN RE-ENTRY CALCULATIONS            I
CI                 ( FT 3.E5 $INTRAJ /TRAJ/  )                        I
CI       ALTSF     ALTITUDES FOR WHICH SKIN FRICTION COEFFICIENTS     I
CI                 ARE INPUT                                          I
CI                 ( FT 0.  $AEROD /AERO/  )                          I
CI       ALTTGT    ALTITUDE OF TARGET                                 I
CI                 ( FT 0.0 $INTRAJ /TRAJ/  )                         I
CI       AMACH     MACH NUMBERS FOR WHICH AERODYNAMIC COEFFICIENTS    I
CI                 ARE INPUT                                          I
CI                 ( --- 0.  $AEROD /AERO/  )                         I
CI       APARK     SEMIMAJOR AXIS OF PARKING ORBIT                    I
CI                 ( FT 0.0 $ORB ///EQ///  )                          I
CI       APATGG    MINIMUM PORT TO THROAT AREA RATIO                  I
CI                 ( --- 3.0 $SOLDGG /GASGEN/  )                      I
CI       AREF      MISSILE AERODYNAMIC REFERENCE AREA INPUT FOR EACH  I
CI                 STAGE                                              I
CI                 ( FT**2 0.0 $THVST /AERO/  )                       I
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```
CI        AT        NOMINAL THROAT AREA FOR EACH STAGE                   I
CI                  ( IN**2 100. $INPGEN ///EQ///  )                     I
CI        BETA      TOLERANCE TO TEST FOR PENALTY CONSTANT INCREASE      I
CI                  ( --- 0.25 $NLP /WARN/  )                            I
CI        BIG       A LARGE POSITIVE NUMBER                              I
CI                  ( --- 1.E99 $NLP /---/  )                            I
CI        BLSPFL    FUEL TANK TRANSVERSE COLLAPSING BLADDER SPACE        I
CI                  ( IN .01 $BLADER /TANKS2/  )                         I
CI        BLSPOX    OXIDIZER TANK TRANSVERSE COLLAPSING BLADDER SPACE    I
CI                  ( IN .01 $BLADER /TANKS2/  )                         I
CI        BPFRFL    FUEL BOOST PUMP FRACTION OF TOTAL HEAD RISE          I
CI                  ( --- 0.0464 $PUMP /PRESCH/  )                       I
CI        BPFROX    OXIDIZER BOOST PUMP FRACTION OF TOTAL HEAD RISE      I
CI                  ( --- 0.0464 $PUMP /PRESCH/  )                       I
CI        BTEGGG    RATIO OF EQUILIBRIUM TEMPERATURE IN PROPELLANT       I
CI                  TANK TO MINIMUM OPERATING TEMPERATURE (TMIN)         I
CI                  ( --- 1.5 $SOLDGG /GASGEN/  )                        I
CI        BULK      COMPOSITE MOTOR CASE MATERIAL BULK FACTOR FOR        I
CI                  EACH STAGE                                           I
CI                  ( --- 1. $MATER /MOTOR/  )                           I
CI        BURNRA    GRAIN BURN RATE FOR START CARTRIDGE (ISTART=3)       I
CI                  ( IN/SEC 0.14 $PUMP /TPAIN/  )                       I
CI        BYPREG    REGEN JACKET BYPASS FLOW FRACTION                    I
CI                  ( --- 0.0 $INREGN /SCHEDW/  )                        I
CI        BYPTUR    TURBINE BYPASS FLOW FRACTION                         I
CI                  ( --- 0.0 $INREGN /SCHEDW/  )                        I
CI        CA        AERODYNAMIC AXIAL FORCE COEFFICIENTS INPUT AS        I
CI                  FUNCTIONS OF MACH NUMBER AND ANGLE OF ATTACK         I
CI                  CA(I,J) CORRESPONDS TO AMACH(I)                      I
CI                  ( --- --- $AEROD /AERO/  )                           I
CI        CAB       BASE DRAG CORRECTION FACTOR; DECREASE IN CA FOR      I
CI                  POWER-ON                                             I
CI                  ( --- 0. $AEROD /AERO/  )                            I
CI        CBM       CRITICAL BENDING MOMENT                              I
CI                  ( IN/LBF 0.0 $LTANK /TANKS/  )                       I
CI        CBMLT     BASE PRESSURE THRUST MULTIPLIER ON PLUG CLUSTER      I
CI                  AND ANNULAR ENGINES                                  I
CI                  ( --- 0.7 $NOZZLE /PLUGCL/  )                        I
CI        CBRGG     BURN RATE COEFFICIENT OF SOLID GRAIN                 I
CI                  ( IN/SEC 0.095 $SOLDGG /GASGEN/  )                   I
CI        CDESGG    DESIGN COMPLEXITY MULTIPLIER ON GAS GENERATOR        I
CI                  ( --- 1.25 $SOLDGG /GASGEN/  )                       I
CI        CDIFL     FUEL INJECTOR DISCHARGE COEFFICIENT                  I
CI                  ( --- 0.77 $INJECT /LIQUID/  )                       I
CI        CDIOX     OXIDIZER INJECTOR DISCHARGE COEFFICIENT              I
CI                  ( --- 0.72 $INJECT /LIQUID/  )                       I
CI        CFTCAB    ABLATIVE THICKNESS COEFFICIENT FOR CHAMBER           I
CI                  ( --- 0. $ABLATE /TCA/  )                            I
CI        CFTNAB    ABLATIVE THICKNESS COEFFICIENT FOR NOZZLE            I
CI                  ( --- 0. $ABLATE /TCA/  )                            I
CI        CFTTAB    ABLATIVE THICKNESS COEFFICIENT FOR THROAT            I
CI                  ( --- 0. $ABLATE /TCA/  )                            I
CI        CHIDOT    COMMAND CONSTANT INERTIAL PITCH RATE; INPUT FOR      I
CI                  TRAJECTORY GUIDANCE SECTIONS UTILIZING GUIDANCE      I
CI                  OPTION 5                                             I
CI                  ( DEG/SEC --- $GUIDA ///EQ///  )                     I
CI        CHIPO     INITIAL VALUE OF INERTIAL ATTITUDE                   I
CI                  ( DEG --- $INTRAJ /TRAJ/  )                          I
CI        CHIPC     COMMANDED CONSTANT INERTIAL ATTITUDE; INPUT FOR      I
CI                  TRAJECTORY GUIDANCE SECTIONS UTILIZING GUIDANCE      I
```

```
CI                  OPTION 2                                                I
CI                  ( DEG ---- $GUIDA ///EQ///  )                           I
 I       CHMULT     COOLING CHANNEL MULTIPLIER IN REGEN COOLING LOGIC       I
 I                  ( --- 1.0 $INREGN /WTREGN/   )                          I
CI       CHRPIX     CHARACTERS PER INCH OUTPUT BY THE LINE PRINTER          I
CI                  IN THE HORIZONTAL DIRECTION                             I
CI                  (USED BY PSEUDO-TEKTRONIX ROUTINES)                     I
CI                  ( CHAR/IN 10 $NCTINP /PSUTEK/   )                       I
CI       CHRPIY     CHARACTERS PER INCH IN THE Y DIRECTION OUTPUT           I
CI                  BY THE LINE PRINTER (FOR PSEUDO-TEKTRONIX ROUTINE)      I
CI                  ( CHAR/IN 6 $NCTINP /PSUTEK/   )                        I
CI       CLRAF      SPACE BETWEEN AFT AND FORWARD TANK HEADS                I
CI                  ( IN 0.0 $LTANK /TANKS/   )                             I
CI       CLRFP      SPACE BETWEEN FORWARD TANK HEAD AND PRESSURE TANK       I
CI                  HEAD                                                    I
CI                  ( IN 0.0 $LTANK /TANKS/   )                             I
CI       CLRNOZ     (NOT USED)                                              I
CI                  ( IN 0.0 $NOZZLE ///EQ///   )                           I
CI       CLRTNK     CLEARANCE BETWEEN NON-CONVENTIONAL TANKS WHEN           I
CI                  LOADING THEM INTO STAGE ENVELOPE                        I
CI                  ( IN 2.0 $NCTINP /NCTIN/   )                            I
CI       CM         MOTOR EFFICIENCY FOR EACH STAGE; AFFECTS THRUST         I
CI                  ONLY                                                    I
CI                  ( --- 0.9 $PROPEL /MOTOR/   )                           I
CI       CMMAX      MAXIMUM CARRY MOMENT                                    I
CI                  ( IN/LBF 0.0 $LTANK /TANKS/  )                          I
CI       CN         AERODYNAMIC NORMAL FORCE COEFFICIENTS INPUT AS          I
CI                  FUNCTIONS OF MACH NUMBER AND ANGLE OF ATTACK;           I
 I                  CN(I,J) CORRESPONDS TO AMACH(I) AND ALPH(J)             I
CI                  ( --- --- $AEROD /AERO/   )                             I
CI       CNMLI      EFFECTIVE THERMAL CONDUCTIVITY OF MULTILAYER            I
CI                  INSULATION (MLI)                                        I
CI                  ( BTU/IN-SEC-DEGR 4.E-9 $TANKHX /INSLHX/   )            I
CI       CNSOFI     EFFECTIVE THERMAL CONDUCTIVITY OF SPRAY ON FOAM         I
CI                  INSULATION (SOFI)                                       I
CI                  ( BTU/IN-SEC-DEGR 3.5E-7 $TANKHX /INSLHX/   )           I
CI       CNSTRN     VALUE OF CONSTRAINT                                     I
CI                  ( --- --- $INPOPT /OPTIM/   )                           I
CI       CONDCT     MATERIAL THERMAL CONDUCTIVITY TABLE                     I
CI                  ( BTU/IN-SEC-DEGR .00023,.0001,8*0 $LIQMAT /MTPROP      I
CI       CONDNZ     NOZZLE EXTENSION THERMAL CONDUCTIVITY AT TNENOM         I
CI                  ( BTU/IN/SEC/DEGR .000555 $LIQENG /COOLNT/   )          I
CI       CONREF     PRODUCT OF EQUIVALENCE RATIO AND MIXTURE RATIO          I
CI                  FOR USER DEFINED PROPELLANT (IPROP=0)                   I
CI                  ( --- 2.249 $LPROP /EQUIVR/   )                         I
CI       CONTOL     TOLERANCE FOR CONSTRAINT                                I
CI                  ( --- --- $INPOPT /OPTIM/   )                           I
CI       CPCNAF     CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY         I
CI                  FOR FUEL                                                I
CI                  ( --- --- $LFUEL /PROPRO/   )                           I
CI       CPCNAO     CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY         I
CI                  FOR OX                                                  I
CI                  ( --- --- $LOXID /PROPRO/   )                           I
 I       CPCNBF     CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY         I
 I                  FOR FUEL                                                I
CI                  ( --- --- $LFUEL /PROPRO/   )                           I
CI       CPCNBO     CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY         I
CI                  FOR OX                                                  I
CI                  ( --- --- $LOXID /PROPRO/   )                           I
CI       CPCNCF     CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY         I
```

```
CI                FOR FUEL                                                   I
CI                ( ------- $LFUEL /PROPRO/  )                               I
         CPCNCO   CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY            I
 I                FOR OX                                                     I
CI                ( --- --- $LOXID /PROPRO/  )                               I
CI       CPCNDF   CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY            I
CI                FOR FUEL                                                   I
CI                ( --- ---- $LFUEL /PROPRO/  )                              I
CI       CPCNDO   CONSTANT IN EQUATION OF IDEAL GAS HEAT CAPACITY            I
CI                FOR OX                                                     I
CI                ( --- --- $LOXID /PROPRO/  )                               I
CI       CPCONA   IDEAL HEAT CAPACITY CONSTANT                               I
CI                ( --- 3.89 $LPROP /COOLNT/  )                              I
CI       CPCONB   IDEAL HEAT CAPACITY CONSTANT                               I
CI                ( --- 23.2 $LPROP /COOLNT/  )                              I
CI       CPCONC   IDEAL HEAT CAPACITY CONSTANT                               I
CI                ( --- -9.818 $LPROP /COOLNT/  )                            I
CI       CPCOND   IDEAL HEAT CAPACITY CONSTANT                               I
CI                ( --- 1.666 $LPROP /COOLNT/  )                             I
CI       CPGGPB   HEAT CAPACITY OF GAS GENERATOR/PREBURNER                   I
CI                COMBUSTION GAS                                             I
CI                ( BTU/LB/DEGR .721 $PUMP /TPAIN/  )                        I
CI       CPLINF   FRACTION OF FACE P ACROSS FUEL LINE                        I
CI                ( --- 0.172 $LIQUID /LIQUID/  )                            I
CI       CPLINO   FRACTION OF FACE P ACROSS OXIDIZER LINE                    I
CI                ( --- 0.207 $LIQUID /LIQUID/  )                            I
CI       CPREF    REFERENC HEAT CAPACITY FOR COOLANT                         I
                  ( BTU/LBM/DEGR 0.725 $LPROP /COOLNT/  )                    I
         CPREFF   FUEL REFERENCE HEAT CAPACITY                               I
CI                ( BTU/LB/DEGR --- $LFUEL /PROPRO/  )                       I
CI       CPREFO   OX REFERENCE HEAT CAPACITY                                 I
CI                ( BTU/LB/DEGR --- $LOXID /PROPRO/  )                       I
CI       CPVLVF   FRACTION OF FACE P ACROSS FUEL VALVE                       I
CI                ( --- 0.409 $LIQUID /LIQUID/  )                            I
CI       CPVLVO   FRACTION OF FACE P ACROSS OXIDIZER VALVE                   I
CI                ( --- 0.28 $LIQUID /LIQUID/  )                             I
CI       CR       CONTRACTION RATIO OF LIQUID ENGINE                         I
CI                ( --- 2.54 $LIQENG ///EQ///  )                             I
CI       CREF     REFERENCE THERMAL CONDUCTIVITY FOR COOLANT                 I
CI                ( BTU/IN/SEC/DEGR 3.85E-6 $LPROP /COOLNT/  )               I
CI       CREFFL   FUEL REFERENCE THERMAL CONDUCTIVITY                        I
CI                ( BTU/IN/SEC/DEGR --- $LFUEL /PROPRO/  )                   I
CI       CREFOX   OX REFERENCE THERMAL CONDUCTIVITY                          I
CI                ( BTU/IN/SEC/DEGR --- $LOXID /PROPRO/  )                   I
CI       CSGG     SOLID GRAIN CHARACTERISTIC VELOCITY                        I
CI                ( FT/SEC 3932. $SOLDGG /GASGEN/  )                         I
CI       CSRMX    CSTAR FOR USER PROPELLANT AT PC=500 AND OFRMX              I
CI                ( FT/SEC 5689. $LPROP /EQUIVR/  )                          I
CI       CSTAR    PROPELLANT CHARACTERISTIC VELOCITY INPUT AS A              I
CI                FUNCTION OF CHAMBER PRESSURE; CSTAR(J,I) CORRES-           I
CI                PONDS TO PCR(J) FOR THE I-TH STAGE                         I
CI                ( FT/SEC 0. $PROPEL /MOTOR/  )                             I
 I       CSTARL   DELIVERED CSTAR FOR TCA  (KPERF=0)                         I
                  ( FT/SEC 5523. $LQPERF /LIQUID/  )                         I
 I       CTMLT    MULTIPLIER ON THRUST COEFFICIENT FOR PLUG CLUSTER          I
CI                AND ANNULAR ENGINES                                        I
CI                ( --- 0.99 $NOZZLE /PLUGCL/  )                             I
CI       CV       START VALVE COMPLEXITY MULTIPLIER                          I
CI                ( --- 1.0 $PUMP /TPAIN/  )                                 I
CI       CVACUM   ACCUMULATOR VALVE COMPLEXITY MULTIPLIER (ISTART=2)         I
```

```
CI                   ( --- 1.0 $PUMP /TPAIN/  )                              I
CI       CVMAX       MAXIMUM VALUES FOR CONTROL VECTOR (IOPT) ELEMENTS      I
CI                   ( --- --- $INPOPT /CVBOND/  )                           I
CI       CVMIN       MINIMUM VALUES FOR CONTROL VECTOR (IOPT) ELEMENTS      I
CI                   ( --- --- $INPOPT /CVBOND/  )                           I
CI       CVMLTF      CONTROL VALVE PRESSURE DROP MULTIPLIER USED TO          I
CI                   CALCULATE PRESSURE DROP FROM PUMP DISCHARGE TO          I
CI                   GAS GENERATOR/PRE-BURNER INJECTOR INLET                 I
CI                   ( --- 0.65 $PUMP /PRESCH/  )                            I
CI       CXINJ       INJECTOR COMPLEXITY MULTIPLIER                          I
CI                   ( --- 1.  $CXWMLT /TCA/  )                              I
CI       CXNCT1      NON-CONVENTIONAL TANK WEIGHT MULTIPLIER FOR STG 1      I
CI                   ( --- 1.0 $NCTINP /---/  )                              I
CI       CXNCT2      NON-CONVENTIONAL TANK WEIGHT MULTIPLIER FOR STG 2      I
CI                   ( --- 1.0 $NCTINP /---/  )                              I
CI       CXNCT3      NON-CONVENTIONAL TANK WEIGHT MULTIPLIER FOR STG 3      I
CI                   ( --- 1.0 $NCTINP /---/  )                              I
CI       CXNCT4      NON-CONVENTIONAL TANK WEIGHT MULTIPLIER FOR STG 4      I
CI                   ( --- 1.0 $NCTINP /---/  )                              I
CI       CXVALV      VALVE COMPLEXITY MULTIPLIER                             I
CI                   ( --- 1.  $CXWMLT /TCA/  )                              I
CI       CXWATL      AFT TANK LINE WEIGHT MULTIPLIER                         I
CI                   ( --- 1.  $CXWMLT /MULT/  )                             I
CI       CXWCHM      CHAMBER WEIGHT MULTIPLIER                               I
CI                   ( --- 1.  $CXWMLT /TCA/  )                              I
CI       CXWDUC      HOT GAS DUCT WEIGHT MULTIPLIER                          I
CI                   ( --- 2.5 $PUMP /TPAIN/  )                              I
CI       CXWENG      ENGINE WEIGHT MULTIPLIER                                I
CI                   ( --- 1.05 $CXWMLT /TCA/  )                             I
CI       CXWFLT      FUEL TANK WEIGHT MULTIPLIER                             I
CI                   ( --- 1.  $CXWMLT /TWTMLT/  )                           I
CI       CXWFTL      FORWARD TANK LINE WEIGHT MULTIPLIER                     I
CI                   ( --- 1.  $CXWMLT /MULT/  )                             I
CI       CXWGIM      WEIGHT MULTIPLIER ON ENGINE GIMBALING SYSTEM            I
CI                   ( --- 1.0 $CXWMLT /TWTMLT/  )                           I
CI       CXWIGG      GAS GENERATOR OR PRE-BURNER INJECTOR WEIGHT             I
CI                   MULTIPLIER                                              I
CI                   ( --- 1.0 $PUMP /TPAIN/  )                              I
CI       CXWLIN      ENGINE BAY PROPELLANT LINE WEIGHT MULTIPLIER            I
CI                   ( --- 2.5 $PUMP /TPAIN/  )                              I
CI       CXWNZE      NOZZLE EXTENSION WEIGHT MULTIPLIER                      I
CI                   ( --- 1.1 $CXWMLT /TCA/  )                              I
CI       CXWOXT      OXIDIZER TANK WEIGHT MULTIPLIER                         I
CI                   ( --- 1.  $CXWMLT /TWTMLT/  )                           I
CI       CXWPCH      PRESSURANT CONTROL HARDWARE WEIGHT MULTIPLIER           I
CI                   ( --- 1.  $CXWMLT /MULT/  )                             I
CI       CXWPTL      PRESSURE TANK LINE WEIGHT MULTIPLIER                    I
CI                   ( --- 1.  $CXWMLT /MULT/  )                             I
CI       CXWPTN      PRESSURE TANK WEIGHT MULTIPLIER                         I
CI                   ( --- 1.  $CXWMLT /TWTMLT/  )                           I
CI       CXWSTR      STRUCTURAL WALL WEIGHT MULTIPLIER                       I
CI                   ( --- 1.  $CXWMLT /MULT/  )                             I
CI       CXWTHM      WEIGHT MULTIPLIER ON ENGINE THRUST MOUNT                I
CI                   ( --- 1.0 $CXWMLT /TWTMLT/  )                           I
CI       CXWTNK      TANK WEIGHT MULTIPLIER                                  I
CI                    (FOR BOTH TANDEM AND NON-CONVENTIONAL)                 I
CI                   ( --- 1.7 $CXWMLT /MULT/  )                             I
CI       CXWTPA      TURBOPUMP ASSEMBLY WEIGHT MULTIPLIER                    I
CI                   ( --- 1.  $CXWMLT /TPAIN/  )                            I
CI       DACQFL      FUEL TANK ACQUISITION DEVICE DENSITY (KACQFL=6)         I
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CI                  ( LB/IN**3 0.1 $LTANK /TANKS2/   )                    I
CI       DACQOX     OXIDIZER TANK ACQUISITION DEVICE DENSITY(KACQOX=6)    I
CI                  ( LB/IN**3 0.1 $LTANK /TANKS2/   )                    I
CI       DANEX      DIAMETER OF ANNULAR THROAT OF ANNULAR ENGINE          I
CI                  ( IN 48 $NOZZLE /PLUGCL/   )                          I
CI       DBEXPA     EXPONENT ON REYNOLDS NUMBER IN LIQUID HEAT TRANS-     I
CI                  FER COEFFICIENT CALCULATION                           I
CI                  ( --- 0.95 $LPROP /COOLNT/   )                        I
CI       DBEXPB     EXPONENT ON PRANDTL NUMBER IN LIQUID HEAT TRANS-      I
CI                  FER COEFFICIENT CALCULATION                           I
CI                  ( --- 0.4 $LPROP /COOLNT/   )                         I
CI       DBMLTK     MULTIPLYING FACTOR IN LIQUID HEAT TRANSFER            I
CI                  COEFFICIENT CALCULATION                               I
CI                  ( --- 0.005 $LPROP /COOLNT/   )                       I
CI       DBNDFL     FUEL TANK BOND DENSITY                                I
CI                  ( LB/IN**3 .04 $BLADER /TANKS2/   )                   I
CI       DBNDOX     OXIDIZER TANK BOND DENSITY                            I
CI                  ( LB/IN**3 .04 $BLADER /TANKS2/   )                   I
CI       DCHARC     REFERENCE CHAR DEPTH IN CHAMBER                       I
CI                  ( IN 1.02 $ABLATE /TCA/   )                           I
CI       DCHARN     NOZZLE REFERENCE CHAR DEPTH                           I
CI                  ( IN 0.087 $ABLATE /TCA/   )                          I
CI       DCHART     REFERENCE CHAR DEPTH IN THROAT                        I
CI                  ( IN 1.33 $ABLATE /TCA/   )                           I
CI       DEL        INITIAL OPTIMIZATION STEP SIZE                        I
CI                  ( --- 5 $INPOPT /OPTIM/   )                           I
CI       DELINC     INCLINATION CHANGE                                    I
CI                  ( DEG 0.0 $ORB ///EQ///   )                           I
CI       DELMIN     MINIMUM OPTIMIZATION STEP SIZE FOR CONVERGENCE        I
CI                  ( --- --- $INPOPT /OPTIM/   )                         I
CI       DELT       TRAJECTORY INTEGRATION TIME STEP INTERVAL             I
CI                  (CONSTANT DURING FLIGHT)                              I
CI                  ( SEC 1 $INTRAJ /TRAJ/   )                            I
CI       DHVAPF     FUEL HEAT OF VAPORIZATION AT NORMAL BOILING POINT     I
CI                  ( BTU/LB --- $LFUEL /PROPRO/   )                      I
CI       DHVAPO     OX HEAT OF VAPORIZATION AT NORMAL BOILING POINT       I
CI                  ( BTU/LB --- $LOXID /PROPRO/   )                      I
CI       DIFTBF     USED TO CALCULATE BARRIER TEMPERATURE FOR REGEN       I
CI                  COOLED CHAMBERS AND TRANS-REGEN CHAMBERS USING        I
CI                    TBARRIER = DIFTBF * (TCORE - TGWNOM) + TGWNOM       I
CI                  ( --- 1.0 $INREGN ///EQ///   )                        I
CI       DMINSG     MINIMUM ALLOWABLE SOLID GRAIN DIAMETER                I
CI                  ( IN 3.0 $SOLDGG /TANKS/   )                          I
CI       DMOTOR     MOTOR OUTSIDE DIAMETER INCLUDING EXTERNAL             I
CI                  INSULATION                                            I
CI                  ( IN 66. $INPGEN ///EQ///   )                         I
CI       DNMLI      MULTILAYER INSULATION (MLI) DENSITY                   I
CI                  ( LBM/IN**3 .002 $TANKHX /TANKS2/   )                 I
CI       DNSOFI     SPRAY ON FOAM INSULATION (SOFI) DENSITY               I
CI                  ( LBM/IN**3 .00127 $TANKHX /TANKS2/   )               I
CI       DREF       REFERENCE VALUE OF DENSITY FOR COOLANT                I
CI                  ( LBM/IN**3 0.0327 $LPROP /COOLNT/   )                I
CI       DREFFL     FUEL REFERENCE DENSITY                                I
CI                  ( LB/IN**3 --- $LFUEL /PROPRO/   )                    I
CI       DREFOX     OX REFERENCE DENSITY                                  I
CI                  ( LB/IN**3 --- $LOXID /PROPRO/   )                    I
CI       DRGLOS     IDEAL VELOCITY LOSSES DUE TO AERODYNAMIC DRAG         I
CI                  ( FT/SEC 0 $INTRAJ /TRAJ/   )                         I
CI       DVMNVR     UNKNOWN DEFINITION                                    I
CI                  ( --- 0.0 $ORB /----/   )                             I
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CI      EAFSKT    MODULUS OF ELASTICITY OF STAGE AFT SKIRT              I
CI                ( LBF/IN**2 29.E6 $INTSTG /MOTOR/  )                  I
CI      EARIR     EARTH INFRA-RED HEAT FLUX (KHXOPT=2)                  I
CI                ( BTU/SEC-IN**2 1.35E-4 $TANKHX /INSLHX/  )           I
CI      EARREF    EARTH REFLECTANCE (ALBEDO) (KHXOPT=2)                 I
CI                ( --- 0.39 $TANKHX /INSLHX/  )                        I
CI      EBRGG     BURN RATE EXPONENT OF SOLID GRAIN                     I
CI                ( --- 0.64 $SOLDGG /GASGEN/  )                        I
CI      ECASE     MODULUS OF ELASTICITY OF CASE MATERIAL                I
CI                ( LBF/IN**2 29.E6 $MATER /MOTOR/  )                   I
CI      ECFTHR    TABLE OF NOZZLE EFFICIENCIES FOR THROTTLED            I
CI                PRESSURE FRACTIONS                                    I
CI                ( --- --- $THROT /THREFF/  )                          I
CI      EDES      ECCENTRICITY OF DESTINATION ORBIT                     I
CI                ( --- 0.0 $ORB ///EQ///  )                            I
CI      EECRAT    EXTENDABLE EXIT CONE EXPANSION RATIO                  I
CI                ( --- 1.5 $NOZZLE ///EQ///  )                         I
CI      EINSTG    MODULUS OF ELASTICITY OF INTERSTAGE MATERIAL AT       I
CI                THE TOP OF EACH LOWER STAGE                           I
CI                ( LBF/IN**2 1.8E6 $INTSTG /MOTOR/  )                  I
CI      ELDENS    INJECTOR ELEMENT DENSITY                              I
CI                ( ELEMENTS/IN**2 3.1 $INJECT ///EQ///  )              I
CI      ELDOME    ELLIPSE RATIO FOR THE CASE/TANK DOMES                 I
CI                ( --- 1. $INPGEN ///EQ///  )                          I
CI      ELRP      PRESSURE TANK ELLIPSE RATIO                           I
CI                ( --- 1.0 $LTANK ///EQ///  )                          I
CI      ELTNK1    ELLIPSE RATIO OF EACH NON-CONVENTIONAL TANK ON        I
CI                STAGE 1                                               I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI      ELTNK2    ELLIPSE RATIO OF EACH NON-CONVENTIONAL TANK ON        I
CI                STAGE 2                                               I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI      ELTNK3    ELLIPSE RATIO OF EACH NON-CONVENTIONAL TANK ON        I
CI                STAGE 3                                               I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI      ELTNK4    ELLIPSE RATIO OF EACH NON-CONVENTIONAL TANK ON        I
CI                STAGE 4                                               I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI      EMISTC    THRUST CHAMBER EMMISIVITY FOR TCA RADIATION           I
CI                COOLING MODEL                                         I
CI                ( --- 0.9 $LIQENG /COOLNT/  )                         I
CI      EMISVE    VEHICLE EMMISIVITY IN ENGINE BAY FOR TCA              I
CI                RADIATION COOLING MODEL                               I
CI                ( --- 0.5 $LIQENG /COOLNT/  )                         I
CI      ENDROV    NUMBER OF ENDS PER ROVING                             I
CI                ( --- 4.0 $FILMNT /MOTOR/  )                          I
CI      ENDVLG    VALUE OF ENDING PARAMETER AT WHICH GUIDANCE           I
CI                SECTION IS TO BE TERMINATED                           I
CI                ( --- --- $GUIDA ///EQ///  )                          I
CI      ENDVLM    VALUE OF MOTOR ENDING PARAMETER AT WHICH MOTOR        I
CI                SECTION IS TO BE TERMINATED                           I
CI                ( --- --- $GUIDA ///EQ///  )                          I
CI      ENGAN1    NON-CONVENTIONAL TANK ENGINE LOCATION ANGLE FOR       I
CI                STAGE 1 (LOCATES ENGINE CENTERLINE ABOUT STAGE        I
CI                CENTERLINE)                                           I
CI                ( DEG 0. $NCTINP /---/  )                             I
CI      ENGAN2    NON-CONVENTIONAL TANK ENGINE LOCATION ANGLE FOR       I
CI                STAGE 2 (SEE ENGAN1)                                  I
CI                ( DEG 0. $NCTINP /---/  )                             I
CI      ENGAN3    NON-CONVENTIONAL TANK ENGINE LOCATION ANGLE FOR       I
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CI                   STAGE 3 (SEE ENGAN1)                                    I
                     ( DEG 0. $NCTINP /---/  )                               I
          ENGAN4     NON-CONVENTIONAL TANK ENGINE LOCATION ANGLE FOR         I
                     STAGE 4 (SEE ENGAN1)                                    I
CI                   ( DEG 0. $NCTINP /---/  )                               I
CI        ENGRD1     NON-CONVENTIONAL TANK ENGINE RADIAL LOCATION FOR        I
CI                   STAGE 1 (0.0=CENTERLINE, 1.0=FARTHEST RADIAL            I
CI                   POSITION)                                               I
CI                   ( --- 0. $NCTINP /---/  )                               I
CI        ENGRD2     NON-CONVENTIONAL TANK ENGINE RADIAL LOCATION FOR        I
CI                   STAGE 2 (SEE ENGRD1)                                    I
CI                   ( --- 0. $NCTINP /---/  )                               I
CI        ENGRD3     NON-CONVENTIONAL TANK ENGINE RADIAL LOCATIONA FOR       I
CI                   STAGE 3 (SEE ENGRD1)                                    I
CI                   ( --- 0. $NCTINP /---/  )                               I
CI        ENGRD4     NON-CONVENTIONAL TANK ENGINE RADIAL LOCATIONA FOR       I
CI                   STAGE 4 (SEE ENGRD1)                                    I
CI                   ( --- 0. $NCTINP /---/  )                               I
CI        ENGSPC     MINIMUM SPACE BETWEEN NOZZLE EXITS IN NON-CONVEN-       I
CI                   TIONAL TANK DESIGN                                      I
CI                   ( IN 2.0 $NCTINP /NCTIN/  )                             I
CI        EPARK      ECCENTRICITY OF PARKING ORBIT                           I
CI                   ( --- 0.0 $ORB ///EQ///  )                              I
CI        EPIPE      ABSOLUTE SURFACE ROUGHNESS OF COOLING CHANNELS          I
CI                   ( IN 0.00008 $INREGN /COOLNT/  )                        I
CI        EPS        NOMINAL EXPANSION RATIO FOR EACH STAGE                  I
CI                   ( --- 10. $INPGEN ///EQ///  )                           I
          EPS4       TOLERANCE FOR USING THE HAARHOFF-BUYS LEAST-            I
                     SQUARES UPDATE                                          I
                     ( --- 0.01 $NLP /---/  )                                I
CI        EPSATT     EXPANSION RATIO AT THE NOZZLE-DOME ATTACH POINT         I
CI                   FOR SOLID STAGES.  EXPANSION RATIO WHERE RADIATION      I
CI                   COOLED NOZZLE IS ATTACHED FOR LIQUID STAGES             I
CI                   ( --- 1. $INPGEN ///EQ///  )                            I
CI        EPSGGB     AREA RATIO OF BLEED NOZZLE                              I
CI                   ( --- 2.0 $PUMP /TPAIN/  )                              I
CI        EPSR       REFERENCE EXPANSION RATIO AT WHICH PROPELLANT           I
CI                   BALLISTIC PERFORMANCE DATA IS INPUT: SHOULD             I
CI                   APPROXIMATE FINAL DESIGN EXPANSION RATIO                I
CI                   ( --- 10. $PROPEL /MOTOR/  )                            I
CI        EPSTH      HOOP FIBER ULTIMATE STRAIN                              I
CI                   ( % 0.015 $FILMNT /MOTOR/  )                            I
CI        EPSTRD     DOWNSTREAM AREA RATIO FOR TRANSPIRATION COOLING         I
CI                   ( --- 1.2 $INREGN /TRANCO/  )                           I
CI        EPSTRU     UPSTREAM AREA RATIO FOR TRANSPIRATION COOLING           I
CI                   ( --- 2 $INREGN /TRANCO/  )                             I
CI        EPTRAT     ATTACH AREA RATIO OF TRANSLATING NOZZLE                 I
CI                   ( --- 50 $LIQENG /TRANOZ/  )                            I
CI        ERETHR     TABLE OF CHAMBER EFFICIENCIES FOR THROTTLED             I
CI                   PRESSURE FRACTIONS                                      I
CI                   ( --- --- $THROT /THREFF/  )                            I
CI        ERFCHR     REFERENCE AREA RATIO FOR DCHARN                         I
CI                   ( --- 7.5 $ABLATE /TCA/  )                              I
          ETABAR     LOSS MULTIPLIER ON BARRIER PERFORMANCE                  I
                     ( --- 0.9 $LQPERF /LIQUID/  )                           I
CI        EXPLFL     FUEL TANK EXPULSION EFFICIENCY                          I
CI                   ( --- .995 $LTANK /TANKS/  )                            I
CI        EXPLOX     OXIDIZER TANK EXPULSION EFFICIENCY                      I
CI                   ( --- .995 $LTANK /TANKS/  )                            I
CI        FALFAF     ALLOWABLE HELICAL FIBER STRESS
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CI                  ( LBF/IN**2 270000.  $FILMNT /MOTOR/   )               I
 I       FANMOT     FRACTION OF MOTOR DIAMETER USED FOR CALCULATING        I
                    EXIT DIAMETER (DANEX) OF ANNULAR ENGINE                I
CI                  ( --- 0.8 $NOZZLE /PLUGCL/   )                         I
CI       FASKTL     AFT SKIRT FRACTIONAL LENGTH OF ENGINE BAY LENGTH       I
CI                  (FOR NON-CONVENTIONAL TANKS IT IS THE AFT SKIRT        I
CI                   FRACTIONAL LENGTH OF STAGE LENGTH)                    I
CI                  ( --- 0.067 $LIQUID /TANKS/   )                        I
CI       FCHGFL     FRACTION OF INJECTOR FACE PRESSURE FOR FUEL            I
CI                  DELTA P ACROSS INJECTOR                                I
CI                  ( --- 0.15 $LIQUID ///EQ///   )                        I
CI       FCHGOX     FRACTION OF INFECTOR FACE PRESSURE FOR OX DELTA P      I
CI                  ACROSS INJECTOR                                        I
CI                  ( --- 0.15 $LIQUID ///EQ///   )                        I
CI       FDP        A VECTOR OF UNSCALED PERTURBATIONS FOR THE CONTROL     I
CI                  VARIABLES, I=1,NX                                      I
CI                  ( --- 1.E-6 $NLP /---/   )                             I
CI       FDPCT      A PERTURBATION FRACTION USED TO GENERATE CONTROL       I
CI                  VARIABLE PERTURBATIONS DURING FINITE DIFFERENCE        I
CI                  DERIVATIVE GENERATION                                  I
CI                  ( --- 1.E-6 $NLP /---/   )                             I
CI       FFSKTL     FORWARD SKIRT FRACTIONAL LENGTH OF FORWARD DOME        I
CI                  HEIGHT (FOR NON-CONVENTIONAL TANKS IT IS THE           I
CI                  FORWARD SKIRT FRACTIONAL LENGTH OF STAGE               I
CI                  DIAMETER)                                              I
CI                  ( --- 0.3 $LIQUID /TANKS/   )                          I
CI       FH2OGG     MOLAR FRACTION OF WATER IN COMBUSTION PRODUCTS         I
 I                  OF GAS GENERATOR                                       I
 I                  ( --- 0.2662 $SOLDGG /GASGEN/   )                      I
CI       FLKFCT     NUMBER OF VELOCITY HEADS LOST IN FUEL FEED LINE        I
CI                  DUE TO BENDS, VALVES, ETC.                             I
CI                  ( VEL-HEADS 5.  $LTANK /TANKS2/   )                    I
CI       FLNPSP     FUEL NET POSITIVE SUCTION PRESSURE IN TANK             I
CI                  ( PSIA 10.  $PUMP /PRESCH/   )                         I
CI       FLOPEL     NUMBER OF FUEL ORIFICES/ELEMENT                        I
CI                  ( --- 2.0 $INJECT /ELEMEN/   )                         I
CI       FLTTIM     STAGE ACTION TIME (USED IN TANK HEAT LOSS )            I
CI                  ( SEC 100.  $TANKHX /INSLHX/   )                       I
CI       FPGGMR     FRACTION OF MAXIMUM GAS GENERATOR OPERATING            I
CI                  PRESSURE LOST ACROSS GAS GENERATOR'S INJECTOR          I
CI                  ( --- 0.65 $PUMP ///EQ///   )                          I
CI       FPULCG     MULTIPLYING FACTOR ON ULLAGE PRESSURE TO CALCULATE     I
CI                  MINIMUM GAS BOTTLE BLOWDOWN PRESSURE                   I
CI                  ( --- 0.8 $COLDG /COLDGP/   )                          I
CI       FPULGG     MULTIPLYING FACTOR ON ULLAGE PRESSURE TO CALCULATE     I
CI                  MINIMUM OPERATING GAS GENERATOR PRESSURE               I
CI                  ( --- 1.1 $SOLDGG /GASGEN/   )                         I
CI       FT         THRUST VALUES INPUT FOR SPECIFYING MOTOR PERFORM-      I
CI                  ANCE.  USED IN VARIABLE THRUST-TIME TABLE WHERE        I
CI                  FT(J,I) CORRESPONDS TO TBRN(J) FOR THE ITH STAGE       I
CI                  ( LBF 0.0 $THVST /PERF/   )                            I
CI       FTHF       ALLOWABLE HOOP FIBER STRESS                            I
CI                  ( LBF/IN**2 300000.  $FILMNT /MOTOR/   )               I
 I       FVAC       VACUUM THRUST PER LIQUID THRUST CHAMBER                I
CI                  ( LBF 0.0 $LIQUID ///EQ///   )                         I
CI       FVENTF     FRACTION OF FUEL TANK NOMINAL ULLAGE PRESSURE AT       I
CI                  WHICH VENT OCCURS                                      I
CI                  ( --- 1.1 $TANKHX /INSLHX/   )                         I
CI       FVENTO     FRACTION OF OX TANK NOMINAL ULLAGE PRESSURE AT         I
CI                  WHICH VENT OCCURS                                      I
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CI                 ( --- 1.1 $TANKHX /INSLHX/   )                      I
CI       GAMDOT    COMMANDED RATE OF CHANGE OF FLIGHT PATH ANGLE;       I
                   INPUT FOR TRAJECTORY GUIDANCE SECTIONS                I
                   ( DEG/SEC 0. $GUIDA ///EQ///   )                      I
CI       GAMGG     GAS GENERATOR COMBUSTION PRODUCTS SPECIFIC HEAT       I
CI                 RATIO                                                 I
CI                 ( --- 1.27 $SOLDGG /GASGEN/   )                       I
CI       GAMGPB    RATIO OF SPECIFIC HEATS OF GAS GENERATOR/PREBURNER    I
CI                 COMBUSTION GAS                                        I
CI                 ( --- 1.25 $PUMP /TPAIN/   )                          I
CI       GAMICG    COLD GAS ISENTROPIC RATIO OF SPECIFIC HEAT            I
CI                 ( --- 1.66 $COLDG /COLDGP/   )                        I
CI       GAMMAC    COMMANDED CONSTANT FLIGHT PATH ANGLE; INPUT FOR       I
CI                 GUIDANCE SECTIONS UTILIZING GUIDANCE OPTION 3         I
CI                 ( DEG -1.E20 $GUIDA ///EQ///   )                      I
CI       GAMMAI    INITIAL MISSILE FLIGHT PATH ANGLE                     I
CI                 ( DEG 90. $INTRAJ ///EQ///   )                        I
CI       GAMPCG    COLD GAS POLYTROPIC GAMMA AT INFINITE TIME            I
CI                 ( --- 1. $COLDG /COLDGP/   )                          I
CI       GASMW     MOLECULAR WEIGHT OF PRESSURIZATION GAS (ISTART=2)     I
CI                 ( LBM/LB-MOLE 28 $PUMP /TPAIN/   )                    I
CI       GGCR      GAS GENERATOR OR PRE-BURNER CONTRACTIN RATIO          I
CI                 ( --- 12 $PUMP /TPAIN/   )                            I
CI       GK        A VECTOR OF PENALTY CONSTANTS CORRESPONDING TO THE    I
CI                 INEQUALITY CONTRAINT FUNCTIONS, I=1,NG                I
CI                 ( --- 1.0 $NLP /---/   )                              I
CI       GKI       DEFAULT INITIAL VALUE OF ALL THE PENALTY CONSTANTS    I
 I                 ASSOCIATED WITH THE INEQUALITY CONSTRINTS IN THE      I
 I                 AUGMENTED LAGRANGIAN FUNCTION                         I
 I                 ( --- 1.0 $NLP /---/   )                              I
CI       GLAM      A VECTOR OF INITIAL LAGRANGE MULTIPLIERS ESTIMATES    I
CI                 CORRESPONDING TO THE INEQUALITY CONSTRAINT            I
CI                 FUNCTIONS G(I)                                        I
CI                 ( --- 0.0 $NLP /---/   )                              I
CI       GMBANG    MAXIMUM ANGLE TO WHICH NOZZLES GIMBAL                 I
CI                 ( DEG 6.0 $LIQUID /GIMBAL/   )                        I
CI       GRVLOS    IDEAL VELOCITY LOSSES DUE TO GRAVITY FORCES           I
CI                 ( FT/SEC 0 $INTRAJ /TRAJ/   )                         I
CI       GTURN     COMMANDED TOTAL ACCELERATION DURING MISSILE TURN;     I
CI                 INPUT FOR GUIDANCE SECTIONS USING GUIDANCE OPT 4      I
CI                 ( DEG 0. $GUIDA ///EQ///   )                          I
CI       GWMING    MINIMUM GUAGE OF CHAMBER GAS WALL                     I
CI                 ( IN 0.025 $INREGN /WTREGN/   )                       I
CI       H         AN APPROXIMATION OF HESSIAN USED IN THE QUASI-        I
CI                 NEWTON UNCONSTRAINED FUNCTION MINIMIZATION            I
CI                 ( --- --- $NLP /RGNSUM/   )                           I
CI       HK        A VECTOR OF PENALTY CONSTANTS CORRESPONDING TO THE    I
CI                 EQUALITY CONSTRAINTS FUNCTIONS, I=1,NH                I
CI                 ( --- 1.0 $NLP /---/   )                              I
CI       HKI       DEFAULT INITIAL VALUE OF ALL THE PENALTY CONSTANTS    I
CI                 ASSOCIATED WITH THE EQUALITY CONSTRAINTS IN THE       I
CI                 AUGMENTED LANGRANGIAN FUNCTION                        I
CI                 ( --- 1.0 $NLP /---/   )                              I
 I       HLAM      A VECTOR OF INITIAL LAGRANGE MULTIPLIERS CORRES-      I
 I                 PONDING TO THE EQUALITY CONSTRAINT FUNCTIONS H(I)     I
CI                 ( --- 0.0 $NLP /---/   )                              I
CI       HLDTIM    STAGE HOLD TIME (USED IN TANK HEAT LOSS)              I
CI                 ( SEC 100. $TANKHX /INSLHX/   )                       I
CI       HOWMAX    MAXIMUM DEPTH TO WIDTH RATIO IN COOLING CHANNELS      I
CI                 ( --- 5.0 $INREGN /COOLNT/   )                        I
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CI      HXALT     AVERAGE ORBITAL ALTITUDE FROM EARTH SURFACE        I
 I                (KHXOPT=2)                                          I
 I                ( MILES 125. $TANKHX /INSLHX/   )                   I
CI      IAM4      FLAG SPECIFYING TRAJECTORY METHOD                   I
CI                -1 = 4TH ORDER RUNGE-KUTTA INTEGRATION THROUGHOUT   I
CI                 0 = 4TH ORDER RUNGE-KUTTA DURING MOTOR BURN        I
CI                     4TH ORDER ADAMS-MOULTON AFTER BURNOUT          I
CI                +1 = 4TH ORDER ADAMS-MOULTON THROUGHOUT FLIGHT      I
CI                ( --- 0 $INTRAJ /TRAJ/   )                          I
CI      IBELL     FLAG INDICATING NOZZLE TYPE                         I
CI                0 = CONICAL NOZZLE                                  I
CI                1 = CONTOURED NOZZLE (CIRCULAR ARC)                 I
CI                2 = ELLIPSOIDAL OR HYPERBOLIC NOZZLE                I
CI                ( --- 0 $NOZZLE /MOTOR/   )                         I
CI      ICARD     FLAG USED TO INDICATE WHEN RESTART CARDS SHOULD     I
CI                BE WRITTEN TO THE LOGICAL OUTPUT DEVICE GIVEN B     I
CI                IO(9). (USUALLY IO(9) IS UNIT 7)                    I
CI                 2 = WRITE RESTART CARDS TO OUTPUT DEVICE IO(9)     I
CI                 NOT 2 = DO NOT WRITE RESTART CARDS                 I
CI                ( --- --- $NLP /---/   )                            I
CI      ICOMPS    COMPOSITE CASE INDICATOR                            I
CI                0 = METAL CASE                                      I
CI                1 = COMPOSIT CASE                                   I
CI                ( --- 0 $MATER /MOTOR/   )                          I
CI      ICON      (I,1) - REFERENCE NUMBER OF VARIABLE TO BE          I
CI                        CONSTRAINED                                 I
CI                (I,2) - CONSTRAINT TYPE                             I
 I                  -1 = LESS THAN OR EQUAL                           I
CI                   0 = EQUAL TO                                     I
CI                  +1 = GREATER THAN OR EQUAL                        I
CI                ( --- --- $INPOPT /OPTIM/   )                       I
CI      ICRYFL    FUEL CRYOGENIC FLAG (0=STORABLE, 1=CRYOGENIC)       I
CI                ( --- 0 $LFLAG /LIQUID/   )                         I
CI      ICRYOX    OXIDIZER CRYOGENIC FLAG (0=STORABLE, 1=CRYOGENIC    I
CI                ( --- 0 $LFLAG /LIQUID/   )                         I
CI      ICS       ICS = 1 - PREPREG WINDING                           I
CI                    = 1 - WET WIND                                  I
CI                ( --- 0 $FILMNT /MOTOR/   )                         I
CI      IDRAW     NON-CONVENTIONAL TANK DRAW FLAG (1=DRAW THREE       I
CI                VIEWS ON ONE PAGE, 2=DRAW EACH VIEW ON A SEPARATE   I
CI                PAGE)                                               I
CI                ( --- 2 $NCTINP /NCTIN/   )                         I
CI      IDTRAN    TRANSPIRATION COOLING CRITERIA FLAG (1=USE QMAXTR   I
CI                TO CALCULATE EPSTRD AND EPSTRU, 2=USE THE INPUT     I
CI                VALUES FOR EPSTRD AND EPSTRU)                       I
CI                ( --- 2 $INREGN /TRANCO/   )                        I
CI      IELDEN    INJECTOR ELEMENT DENSITY FLAG                       I
CI                0 = INPUT NUMBER OF ORIFICES                        I
CI                1 = INPUT ELEMENT DENSITY                           I
CI                ( --- 1 $INJECT /ELEMEN/   )                        I
CI      IENDPG    ENDING PARAMETER INDEX FOR TRAFECTORY GUIDANCE      I
CI                SECTIONS; POSITIVE INTEGER INPUT TERMINATES         I
CI                SECTION FOR AN INCREASING PARAMETER VALUE WHILE     I
 I                NEGATIVE INTEGER TERMINATES SECTION FOR A           I
CI                DECREASING PARAMETER VALUE (FORMERLY ENDPARG)       I
CI                0 = INCREASING SECTION TIME                         I
CI                1 = ANGLE OF ATTACK                                 I
CI                2 = INERTIAL MISSILE ATTITUDE                       I
CI                3 = FLIGHT PATH ANGLE                               I
CI                4 = MACH NUMBER                                     I
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CI                 5 = TOTAL MISSILE VELOCITY                               I
CI                 6 = AVERAGE MISSILE GROUND VELOCITY                      I
                   7 = MISSILE ALTITUDE                                     I
                   8 = MISSILE RANGE                                        I
 I                 9 = MISSILE SEPARATION RANGE                             I
CI                 10 =DYNAMIC PRESSURE                                     I
CI                 11 = PROPELLANT WEIGHT REMAINING                         I
CI                 12 = INCREASING ABSOLUTE TIME                            I
CI                 ( --- --- $GUIDA ///EQ///   )                            I
CI        IENDPM   ENDING PARAMETER INDEX FOR MOTOR SECTIONS.               I
CI                 POSITIVE INTEGER INPUT TERMINATES SECTION FOR            I
CI                 INCREASING PARAMETER VALUE WHILE NEGATIVE INTEGER        I
CI                 INPUT TERMINATES SECTION FOR A DECREASING PARAM-         I
CI                 ETER VALUE. PARAMETER OPTIONS ARE THE SAME AS            I
CI                 FOR ENDPARG  (FORMERLY ENDPARM)                          I
CI                 ( --- --- $GUIDA ///EQ///   )                            I
CI        IENEC    FLAG INDICATING EXTENDABLE EXIT CONE                     I
CI                 0 = NONE                                                 I
CI                 1 = SEGMENT CONE                                         I
CI                 2 = GAS DEPLOYED SKIRT                                   I
CI                 ( --- 0 $NOZZLE /MOTOR/   )                              I
CI        IERRMD   UNKNOWN OPTIMIZATION INPUT                               I
CI                 ( --- 0 $INPOPT /CVBOND/   )                             I
CI        IFREGN   REGEN COOLING FLUID FLAG                                 I
CI                 0 = OXIDIZER IS COOLANT                                  I
CI                 1 = FUEL IS COOLANT                                      I
CI                 ( --- 1 $INREGN /COOLNT/   )                             I
CI        IGUISC   IGUISC(I,1)                                              I
                   CHRONOLOGICAL LIST OF MOTOR OPTIONS TO BE EXER-          I
 I                 CISED DURING FLIGHT.  THIS IS THE FIRST ROW OF A         I
CI                 TWO DIMENSIONAL PROFILE.  AN INTEGER VALUE CORR-         I
CI                 ESPONDING TO THE SELECTED MOTOR OPTION IS INPUT          I
CI                 FOR EACH SECTION. AVAILABLE MOTOR OPTIONS ARE:           I
CI                 0 = COASTING FLIGHT                                      I
CI                 1-4 = STAGE IGNITION                                     I
CI                 5 = WEIGHT JETTISON                                      I
CI                 6 = ENEC DEPLOYMENT (INACTIVE)                           I
CI                 7 = KEPLER EQUATIONS AFTER BURNOUT                       I
CI                 8 = INTEGRATION AFTER BURNOUT                            I
CI                 9 = TERMINATE                                            I
CI                 ******************************************************   I
CI                 IGUISC(I,2)                                              I
CI                 CHRONOLOGICAL LIST OF GUIDANCE OPTIONS TO GE EXER-       I
CI                 CISED DURING FLIGHT.  THIS IS THE SECOND ROW OF A        I
CI                 TWO DIMENSIONAL ARRAY WHICH DESCRIBES THE FLIGHT         I
CI                 PROFILE.  AN INTEGER VALUE CORRESPONDING TO THE          I
CI                 SELECTED GUIDANCE OPTION IS INPUT FOR EACH SECTION       I
CI                 AVAILABLE GUIDANCE OPTIONS ARE :                         I
CI                 1 = CONSTANT ANGLE OF ATTACK (ALPHAC)                    I
CI                 2 = CONSTANT INERTIAL ATTITUDE (CHIPC)                   I
CI                 3 = CONSTANT FLIGHT PATH ANGLE (GAMMAC)                  I
CI                 4 = CONSTANT RATE OF CHANGE OF FLIGHT PATH ANGLE         I
CI                     (GAMDOT)                                             I
 I                 5 = CONSTANT INERTIAL PITCH RATE  (CHIDOT)               I
                   6 = CONSTANT ACCELERATION TURN (CTURN)                   I
CI                 7 = RAIL LAUNCH                                          I
CI                 8 = BALLISTIC FLIGHT (ALPHA = 0)                         I
CI                 9 = MAXIMUM LIFT/DRAG                                    I
CI                 ( --- 1 $GUIDA /TRAJ/   )                                I
CI        IHYPER   HYPERGOLIC PROPELLANT FLAG (REQUIRED FOR NON-            I
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CI                  LIBRARY PROPELLANTS (IPROP=0))                            I
CI                  0 = NOT HYPERGOLIC     1 = HYPERGOLIC                     I
 I                  ( --- 1 $LFLAG /LIQUID/  )                                I
 I       IMAGE      FLAG TO WRITE THE NLP NAMELIST TO THE LOGICAL             I
CI                  OUTPUT DEVICE IO(8) AFTER NLP INPUT IS PERFORMED          I
CI                  0 = DO NOT WRITE THE NLP NAMELIST                         I
CI                  NOT 0 = WRITE THE NLP NAMELIST                            I
CI                  ( --- 0 $NLP /---/  )                                     I
CI       INDES      DESIGN LOOP INDICATOR                                     I
CI                  +1 = MOTOR IS SIMULATED, NO TRAJECTORY INTEGRATION        I
CI                  0 = TRAJECTORY INTEGRATION                                I
CI                  -1 = TRAJECTORY INTEGRATION PLUS DELTA V CALC             I
CI                  -2 = TRAJECTORY USING THRUST-TIME TRACE, NO               I
CI                       MOTOR SIMULATION                                     I
CI                  ( --- --- $INPOPT /TRAJ/  )                               I
CI       INPEXF     INPUT FUEL TANK EXPULSION EFFICIENCY FLAG (0=             I
CI                  CALCULATE EXPULSION EFFICIENCY, 1=USE VALUE INPUT         I
CI                  FOR EXPLFL)                                               I
CI                  ( --- 0 $LFLAG /TANKS/  )                                 I
CI       INPEXO     INPUT OXIDIZER TANK EXPULSION EFFICIENCY FLAG             I
CI                  (0=CALCULATE EXPULSION EFFICIENCY, 1=USE VALUE            I
CI                  INPUT FOR EXPLOX)                                         I
CI                  ( --- 0 $LFLAG /TANKS2/  )                                I
CI       INTNK1     NON-CONVENTIONAL TANK CONTENTS FLAG FOR STAGE 1           I
CI                  (1=OXIDIZER, 2=FUEL, 3=PRESSURANT)                        I
CI                  ( --- 1 $NCTINP /---/  )                                  I
CI       INTNK2     NON-CONVENTIONAL TANK CONTENTS FLAG FOR STAGE 2           I
 I                  (1=OXIDIZER, 2=FUEL, 3=PRESSURANT)                        I
 I                  ( --- 1 $NCTINP /---/  )                                  I
 I       INTNK3     NON-CONVENTIONAL TANK CONTENTS FLAG FOR STAGE 3           I
CI                  (1=OXIDIZER, 2=FUEL, 3=PRESSURANT)                        I
CI                  ( --- 1 $NCTINP /---/  )                                  I
CI       INTNK4     NON-CONVENTIONAL TANK CONTENTS FLAG FOR STAGE 4           I
CI                  (1=OXIDIZER, 2=FUEL, 3=PRESSURANT)                        I
CI                  ( --- 1 $NCTINP /---/  )                                  I
CI       IOBJF      INDEX SPECIFYING THE OPTIMIZATION OBJECTIVE FUNC          I
CI                  ( --- --- $INPOPT /OPTIM/  )                              I
CI       IOPF       OPTIMIZER FLAG                                            I
CI                  0 = OPTIMIZER OFF                                         I
CI                  1 = OPTIMIZER ON                                          I
CI                  ( --- --- $INPOPT /---/  )                                I
CI       IOPT       PARAMETER OPTIMIZATION SWITCHES (SEE METHOD OF            I
CI                  MULTIPLIERS DOCUMENTATION)                                I
CI                  ( --- 0 $INPOPT /OPTIM/  )                                I
CI       IPLOT      INDEX FLAG FOR PLOT DATA (GENERATES TAPE 4 FOR RPL        I
CI                  CALCOMP PLOT ROUTINES).  THE OPTIMIZER SHOULD BE          I
CI                  OFF FOR THIS FEATURE.                                     I
CI                  0 = NO PLOT                                               I
CI                  1 = PLOT                                                  I
CI                  ( --- 0 $INPOPT /TRAJ/  )                                 I
CI       IPLUG      PLUG CLUSTER FLAG                                         I
CI                  0 = NO PLUG CLUSTER                                       I
CI                  1 = PLUG CLUSTER                                          I
 I                  2 = ANNULAR ENGINE                                        I
 I                  ( --- 0 $LIQUID /PLUGCL/  )                               I
CI       IPNLTY     FLAG IDENTIFYING THE TYPE OF AUGMENTED FUNCTION TO        I
CI                  BE USED.  (AT PRESENT ONLY 7 IS ACCEPTABLE)               I
CI                  ( --- 7 $NLP /---/  )                                     I
CI       IPRINT     OUTPUT PRINT INDICATOR                                    I
CI                  IPRINT(1) - INPUT DATA FILE                               I
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CI                 0 = NO PRINTOUT                                        I
                   1= PRINT INPUT                                         I
                   IPRINT(2) - INITIAL GUESS DESIGN                       I
 I                 0 = NO PRINTOUT                                        I
CI                 1 = PRINT MOTOR SUMMARY                                I
CI                 2 = PRINT MOTOR SUMMARY AND TRAJECTORY PROFILE         I
CI                 IPRINT(3) - NOT USED                                   I
CI                 IPRINT(4) - FINAL DESIGN                               I
CI                 0 = NO PRINTOUT                                        I
CI                 1 = PRINT MOTOR SUMMARY                                I
CI                 2 = PRINT MOTOR SUMMARY AND TRAJECTORY PROFILE         I
CI                 IPRINT(5) - NUMBER OF FINAL DESIGN SUMMARIES           I
CI                 ALSO                                                   I
CI                 A VARIABLE OF THE SAME NAME IS USED IN $NLP AS A       I
CI                 FLAG USED TO CONTROL INTERMEDIATE ITERATION            I
CI                 PRINTOUT. VALUES RANGE FROM 0 TO 11. THE GREATER       I
CI                 THE VALUE THE GREATER THE INTERMEDIATE OUTPUT          I
CI                 ( --- 1 $INPOPT /OPTIM/  )                             I
CI       IPRINT    OUTPUT PRINT INDICATOR                                 I
CI                 IPRINT(1) - INPUT DATA FILE                            I
CI                 0 = NO PRINTOUT                                        I
CI                 1= PRINT INPUT                                         I
CI                 IPRINT(2) - INITIAL GUESS DESIGN                       I
CI                 0 = NO PRINTOUT                                        I
CI                 1 = PRINT MOTOR SUMMARY                                I
CI                 2 = PRINT MOTOR SUMMARY AND TRAJECTORY PROFILE         I
CI                 IPRINT(3) - NOT USED                                   I
                   IPRINT(4) - FINAL DESIGN                               I
                   0 = NO PRINTOUT                                        I
CI                 1 = PRINT MOTOR SUMMARY                                I
CI                 2 = PRINT MOTOR SUMMARY AND TRAJECTORY PROFILE         I
CI                 IPRINT(5) - NUMBER OF FINAL DESIGN SUMMARIES           I
CI                 ALSO                                                   I
CI                 A VARIABLE OF THE SAME NAME IS USED IN $NLP AS A       I
CI                 FLAG USED TO CONTROL INTERMEDIATE ITERATION            I
CI                 PRINTOUT. VALUES RANGE FROM 0 TO 11. THE GREATER       I
CI                 THE VALUE THE GREATER THE INTERMEDIATE OUTPUT          I
CI                 ( --- 1 $INPOPT /OPTIM/  )                             I
CI       IPROP     PROPELLANT SELECTION FLAG                              I
CI                 0 = NON-LIBRARY PROPELLANT                             I
CI                 1 = N2O4/MMH                                           I
CI                 2 = MON-25/MHF-3                                       I
CI                 3 = CLF5/MHF-3                                         I
CI                 4 = MON-25/60%MHF-3 + 40% AL                           I
CI                 5 = LO2/LH2                                            I
CI                 6 = LO2/RP-1                                           I
CI                 7 = LO2/CH4                                            I
CI                 8 = LF2/LH2                                            I
CI                 9 = LF2/N2H4                                           I
CI                 ( --- 0 $LFLAG /LIQUID/  )                             I
CI       IPRSIM    PROPELLANT SIMILARITY FLAG ( IPROP = 0 )               I
CI                 ( --- 1 $LPROP /LIQUID/  )                             I
 I       IPUTMP    FLAG TO DETERMINE IF LIQUID PROPELLANT TEMPERATURE     I
                   ARE TO BE INPUT OR IF LIBRARY VALUES ARE TO BE USE     I
CI                 (0=USE LIBRARY VALUES, 1=INPUT TEMPERATURES)           I
CI                 ( --- 0 $LFLAG /TEMSCH/  )                             I
CI       IRPRNT    REGENERATIVE COOLING PRINT FLAG                        I
CI                 0 = NO PRINTOUT OF REGEN SUMMARY                       I
CI                 1 = PRINT REGEN SUMMARY                                I
CI                 ( --- 0 $INREGN /COOLNT/  )                            I
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CI      IRSTRT    FLAG FOR RESTART PURPOSES                                    I
CI                2 = USE THE RESTART VALUES IN THE INPUT XR                   I
                  NOT 2 = DO NOT USE RESTART VALUES                            I
 I                ( --- 1 $NLP /---/  )                                        I
CI      ISCALE    FLAG USED TO INDICATE THE METHOD OF SCALING THE              I
CI                INDEPENDENT VARIABLES AND THE OBJECTIVE AND                  I
CI                CONSTRAINT FUNCTIONS                                         I
CI                1 = NO SCALING USED                                          I
CI                2 = USER-PROVIDED SCALE FACTORS                              I
CI                ( --- 2 $NLP /---/  )                                        I
CI      ISTART    TPA START SYSTEM FLAG                                        I
CI                0=TANK HEAD   1=COLD GAS SPIN   2=START TANKS                I
CI                3=SOLID CARTRIDGE                                            I
CI                ( --- 0 $PUMP /TPAIN/  )                                     I
CI      ITLIM     OPTIMIZER ITERATION LIMIT (BASE POINT)                       I
CI                ( --- 500 $INPOPT /OPTIM/  )                                 I
CI      IUM       FLAG INDICATING THE INITIALIZATION METHOD OF THE             I
CI                QUASI-NEWTON UNCONSTRAINED MINIMIZATION                      I
CI                1 = INITIALIZE HESSIAN TO IDENTITY MATRIX                    I
CI                3 = SET HESSIAN TO PROPER PRODUCT FORM                       I
CI                ( --- 1 $NLP /---/  )                                        I
CI      IXSCAL    UNKNOWN OPTIMIZATION INPUT                                   I
CI                ( --- 0 $INPOPT /---/  )                                     I
CI      JBPFL     FUEL BOOST PUMP SELECTION FLAG                               I
CI                0 = NO BOOST PUMP FOR FUEL                                   I
CI                1 = BOOST PUMP                                               I
CI                ( --- 0 $PUMP /TPAIN/  )                                     I
 I      JBPOX     OXIDIZER BOOST PUMP SELECTION FLAG                           I
 I                0 = NO BOOST PUMP FOR OXIDIZER                               I
CI                1 = BOOST PUMP                                               I
CI                ( --- 0 $PUMP /TPAIN/  )                                     I
CI      JCNFIG    TPA CONFIGURATION FLAG                                       I
CI                1=GEARBOX   2=SINGLE SHAFT TPA   3=TWIN TPA IN               I
CI                SERIES   4=PARALLEL TPAS                                     I
CI                ( --- 2 $PUMP /TPAIN/  )                                     I
CI      KACQFL    KIND OF FUEL ACQUISITION DEVICE (0=NO ACQUISITION            I
CI                DEVICE, 1=TRANSVERSE COLLAPSING ALUMINUM BLADDER,            I
CI                2=FULL BONDED ROLLING DIAPHRAM(AL),3=HALF BRD (AL)           I
CI                4=FULL BRD (SS), 5=HALF BRD (SS), 6=SURFACE                  I
CI                TENSION ACQUISITION DEVICE)                                  I
CI                ( --- 0 $LFLAG /TANKS/  )                                    I
CI      KACQOX    KIND OF OXIDIZER ACQUISITION DEVICE (SEE KACQFL)             I
CI                ( --- 0 $LFLAG /TANKS/  )                                    I
CI      KALCON    CALCULATE TANK INSULATION THERMAL CONDUCTIVITIES             I
CI                FLAG  (0=USE INPUT, 1=CALCULATE)                             I
CI                ( --- 1 $TANKHX /INSLHX/  )                                  I
CI      KALMOD    FLAG DETERMINES CALCULATION MODE FOR NON-CONVEN-             I
CI                TIONAL TANKS (0=USE DIMENSIONLESS INPUT ,1= USE              I
CI                MAJOR TANK DIMENSION (RMAJ))                                 I
CI                ( --- 0 $NCTINP /NCTIN/  )                                   I
CI      KCYCLE    0 = PRESSURE FED                                             I
CI                1 = PUMP FED (GG BLEED)                                      I
CI                2 = STAGED COMBUSTION (FUEL RICH PREBURNER)                  I
 I                3 = EXPANDER CYCLE (HYDROGEN FUEL)                           I
 I                4 = STAGED REACTION (MONOPROPELLANT FUEL)                    I
CI                ( --- 0 $LFLAG /TPAIN/  )                                    I
CI      KDOME     COMMON DOME FLAG FOR AFT AND FORWARD TANKS                   I
CI                0 = SEPARATE HEADS                                           I
CI                1 = COMMON DOME                                              I
CI                ( --- 1 $TNKGEO /TANKS/  )                                   I
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CI      KEXNOZ    NOZZLE EXTENSION FLAG                                  I
                  0 = NO EXTENSION                                       I
                  1 = NOZZLE EXTENSION                                   I
CI                ( --- 1 $LIQENG /MAITCA/  )                            I
CI      KGAS      PROPELLAT TANK PRESSURIZATION FLAG                     I
CI                1 = SOLID GAS GENERATOR                                I
CI                2 = COLD GAS PRESSURIZATION                            I
CI                (USED IF OX AND FUEL TANKS DO NOT USE                  I
CI                 AUTOGENOUS PRESSURIZATION)                            I
CI                ( --- 2 $LFLAG /TANKS/  )                              I
CI      KGASFL    FUEL TANK AUTOGENOUS PRESSURIZATION FLAG               I
CI                (0=USE KGAS TYPE PRESSURIZATION, 1=AUTOGENOUS)         I
CI                ( --- 0 $LFLAG /TANKS/  )                              I
CI      KGASOX    OX TANK AUTOGENOUS PRESSURIZATION FLAG                 I
CI                (0=USE KGAS TYPE PRESSURIZATION, 1=AUTOGENOUS)         I
CI                ( --- 0 $LFLAG /TANKS/  )                              I
CI      KGIMB     MODE OF GIMBALING FLAG FOR MULTIPLE TCA'S              I
CI                (NOT USED AT PRESENT)                                  I
CI                ( --- 2 $LIQUID /GIMBAL/  )                            I
CI      KGPOWR    FLAG WHICH DETERMINES LOCATION OF GIMBALING            I
CI                POWER SUPPLY                                           I
CI                0 = NOT ON STAGE                                       I
CI                1 = ON STAGE                                           I
CI                ( --- 0 $LIQUID /GIMBAL/  )                            I
CI      KHXOPT    TANK HEAT TRANSFER OPTION (0=IGNORE TANK HEAT          I
CI                TRANSFER, 1=EXTERNAL BOUNDARY EXPOSED TO               I
CI                CONDUCTIVE SOURCE, 2=WORST CASE SOLAR RADIATION        I
                  3=CONDUCTIVE AND CONVECTIVE SOURCE WITH GROUND-        I
                  HOLD LAYER OF ICE)                                     I
CI                ( --- 0 $LFLAG /INSLHX/  )                             I
CI      KLINEA    FEED LINE FLAG                                         I
CI                0 = EXTERNAL FEED LINE                                 I
CI                1 = INTERNAL FEED LINE                                 I
CI                ( --- 1 $TNKGEO /TANKS/  )                             I
CI      KNEST     ENGINE NESTING FLAG FOR NON-CONVENTIONAL TANKS         I
CI                (0=NO NESTING, 1=NEST EACH ENGINE INDEPENDENTLY,       I
CI                2=NEST ENGINES TO SAME EXIT PLANE, 3=NEST ENGINES      I
CI                TO EXIT PLANE AT END OF TANKAGE + XMOUNT)              I
CI                ( --- 3 $NCTINP /NCTIN/  )                             I
CI      KNOZ      NOZZLE TYPE FLAG                                       I
CI                1 = CONICAL                                            I
CI                2 = RAO                                                I
CI                ( --- 2 $LIQENG /LIQUID/  )                            I
CI      KOOLNZ    NOZZLE COOLING METHOD FLAG (1=ABLATIVE, 2=REGEN,       I
CI                3=TRANS-REGEN, 4=RADIATION, 5=FILM)                    I
CI                ( --- 4 $LFLAG /COOLNT/  )                             I
CI      KOOLTC    THRUST CHAMBER COOLING METHOD FLAG (1=ABLATIVE,        I
CI                2=REGEN, 3=TRANS-REGEN, 4=RADIATION)                   I
CI                ( --- 1 $LFLAG /COOLNT/  )                             I
CI      KPERF     ENGINE PERFORMANCE FLAG                                I
CI                0 = INPUT PERFORMANCE (DO NOT CALCULATE)               I
CI                1 = CALCULATE ENGINE PERFORMANCE                       I
                  ( --- 1 $LFLAG /MAILPE/  )                             I
        KPRESS    PRESSURE TANK LOCATION FLAG                            I
CI                0 = SPHERICAL IN ENGINE BAY                            I
CI                1 = SUSPENDED FORWARD OF FORWARD TANK                  I
CI                2 = MONOCOQUE SEPARATE DOME                            I
CI                3 = MONOCOQUE COMMON DOME                              I
CI                4 = CYLINDRICAL IN FORWARD TANK                        I
CI                ( --- 0 $TNKGEO /TANKS/  )                             I
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CI      KPRPA     PROPELLANT LOCATION FLAG                           I
CI                1 = FUEL IN AFT TANK                               I
CI                2 = OXIDIZER IN AFT TANK                           I
CI                ( --- 2 $TNKGEO /TANKS/  )                         I
CI      KPUMP     1 = 1 TPA ASSEMBLY PER STAGE                       I
CI                2 = 1 TPA ASSEMBLY PER ENGINE                      I
CI                ( --- 1 $PUMP /TRAIN/  )                           I
CI      KREG      THROAT REGRESSION FLAG                             I
CI                0 = NO REGRESSION                                  I
CI                1 = (NOT USED)                                     I
CI                2 = INPUT THROAT REGRESSION COEFFICIENTS           I
CI                ( --- 0 $LFLAG /LIQUID/  )                         I
CI      KSTAGE    FLAG INDICATING STAGE TYPE                         I
CI                1 = SOLID STAGE                                    I
CI                2 = LIQUID STAGE                                   I
CI                3 = LIQUID STAGE INTEGRATED WITH LOWER STAGE       I
CI                    (MUST USE NON-CONVENTIONAL TANKAGE)            I
CI                ( --- 1 $INPGEN /STAGE/  )                         I
CI      KTANK1    NON-CONVENTIONAL TANK TYPE FLAG FOR STAGE 1        I
CI                (1=CSE, 2=TORUS)                                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTANK2    NON-CONVENTIONAL TANK TYPE FLAG FOR STAGE 2        I
CI                (1=CSE, 2=TORUS)                                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTANK3    NON-CONVENTIONAL TANK TYPE FLAG FOR STAGE 3        I
CI                (1=CSE, 2=TORUS)                                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTANK4    NON-CONVENTIONAL TANK TYPE FLAG FOR STAGE 4        I
CI                (1=CSE, 2=TORUS)                                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTHCK1    NON-CONVENTIONAL TANK WALL THICKNESS FLAG FOR      I
CI                STAGE 1 (0=VARIABLE, 1=CONSTANT)                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTHCK2    NON-CONVENTIONAL TANK WALL THICKNESS FLAG FOR      I
CI                STAGE 2 (0=VARIABLE, 1=CONSTANT)                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTHCK3    NON-CONVENTIONAL TANK WALL THICKNESS FLAG FOR      I
CI                STAGE 3 (0=VARIABLE, 1=CONSTANT)                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTHCK4    NON-CONVENTIONAL TANK WALL THICKNESS FLAG FOR      I
CI                STAGE 4 (0=VARIABLE, 1=CONSTANT)                   I
CI                ( --- 1 $NCTINP /---/  )                           I
CI      KTRNOZ    KIND OF TRANSLATING NOZZLE FLAG (0=NONE, 1=SPRING  I
CI                ACTUATED, 2=GAS DEPLOYED)                          I
CI                ( --- 0 $LIQENG /TRANOZ/  )                        I
CI      KWTMOD    ENGINE WEIGHT MODEL FLAG                           I
CI                -1 = INPUT ENGINE WEIGHT                           I
CI                 0 = SIMPLIFIED ABLATIVE ENGINE WEIGHT MODEL       I
CI                 1 = PHYSICAL MODEL                                I
CI                ( --- 0 $LFLAG /TCA/  )                            I
CI      KXATAH    AFT TANK AFT HEAD CONVEXITY FLAG                   I
CI                -1 = CONVEX FORWARD                                I
CI                 1 = CONVEX AFT                                    I
CI                ( --- 1 $TNKGEO /TANKS/  )                         I
CI      KXATFH    AFT TANK FORWARD HEAD CONVEXITY FLAG               I
CI                -1 = CONVEX FORWARD                                I
CI                 1 = CONVEX AFT                                    I
CI                ( --- -1 $TNKGEO /TANKS/  )                        I
CI      KXFTAH    FORWARD TANK AFT HEAD CONVEXITY FLAG               I
CI                -1 = CONVEX FORWARD                                I
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CI                   1 = CONVEX AFT                                        I
C                   ( ---- -1 $TNKGEO /TANKS/  )                           I
          KXFTFH    FORWARD TANK FORWARD HEAD CONVEXITY FLAG               I
                    -1 = CONVEX FORWARD                                    I
CI                   1 = CONVEX AFT                                        I
CI                  ( --- -1 $TNKGEO /TANKS/  )                            I
CI        LNFULL    LINES FULL AT BURNOUT FLAG(0=EMPTY, 1=FULL)            I
CI                  ( --- 1 $LFLAG /TANKS2/  )                             I
CI        LTURFD    TURBINE FEED LOCATION FLAG                             I
CI                  0 = FEED TURBINE FROM REGEN OUTLET                     I
CI                  1 = FEED TURBINE FROM UPSTREAM OF REGEN JACKET         I
CI                      USING REGEN BYPASS FLOW SET BY THE VARIABLE        I
CI                      BYPREG.                                            I
CI                  ( --- 0 $LFLAG /SCHEDW/  )                             I
CI        LUSEP     PROPELLANT USE FLAG                                    I
CI                  TRUE = ALL PROPELLANT IS TO BE BURNED                  I
CI                  FALSE = THRUST TERMINATES AT THE END OF THE LAST       I
CI                          TIME INTERVAL IN TIMTHR FOR THAT STAGE         I
CI                  ( LOGICAL .TRUE. $THROT /THRLOG/  )                    I
CI        MANDEG    METHOD OF ANNULAR ENGINE EXIT DIAMETER CALCULATION     I
CI                  (0=INPUT DANEX, 1=CALCULATE DANEX AS DMOTOR*FANMOT     I
CI                  ( --- 1 $NOZZLE /PLUGCL/  )                            I
CI        MATNK1    MATERIAL FLAG FOR EACH NON-CONVENTIONAL TANK ON        I
CI                  STAGE 1                                                I
CI                  ( --- 1 $NCTINP /---/  )                               I
CI        MATNK2    MATERIAL FLAG FOR EACH NON-CONVENTIONAL TANK ON        I
CI                  STAGE 2                                                I
 I                  ( --- 1 $NCTINP /---/  )                               I
          MATNK3    MATERIAL FLAG FOR EACH NON-CONVENTIONAL TANK ON        I
 I                  STAGE 3                                                I
CI                  ( --- 1 $NCTINP /---/  )                               I
CI        MATNK4    MATERIAL FLAG FOR EACH NON-CONVENTIONAL TANK ON        I
CI                  STAGE 4                                                I
CI                  ( --- 1 $NCTINP /---/  )                               I
CI        MATPT     MATERIAL FLAG FOR PRESSURE TANK                        I
CI                  ( --- 2 $LIQMAT /TANKS/  )                             I
CI        MATPTL    MATERIAL FLAG FOR PRESSURE TANK LINES                  I
CI                  ( IN ARRAYS RHO, SIGMAX, AND YMOD)                     I
CI                  ( --- 1 $LIQMAT /TANKS/  )                             I
CI        MATSTR    MATERIAL FOR STRUCTURAL WALL                           I
CI                  ( --- 1 $LIQMAT /TANKS/  )                             I
CI        MAXNPI    MAXIMUM NUMBER OF NONLINEAR PROGRAMMING ITERATIONS     I
CI                  ( --- 4 $NLP /---/  )                                  I
CI        MAXUMI    MAXIMUM NUMBER OF ITERATIONS IN THE UNCONSTRAINED      I
CI                  MINIMIZATION                                           I
CI                  ( --- 0 $NLP /---/  )                                  I
CI        MGRAD     FLAG INDICATING THE METHOD OF GRADIENT GENERATION      I
CI                  1 = ONE-SIDED FINITE DIFFERENCES                       I
CI                  2 = SYMMETRIC FINITE DIFFERENCES                       I
CI                  5 = ONE-SIDED FINITE DIFFERENCES                       I
CI                  ( --- 1 $NLP /---/  )                                  I
CI        MLIENV    MULTILAYER INSULATION (MLI) ENVIRONMENT FLAG           I
CI                  (1=GROUND HOLD WITH N2 PURGE, 2=GROUND HOLD WITH       I
                    HE PURGE, 3=SPACE HOLD WITH N2 PURGE AT PRGMLI         I
 I                  PSIA, 4=SPACE HOLD WITH HE AT PRGMLI PSIA)             I
CI                  ( --- 1 $TANKHX /INSLHX/  )                            I
CI        MNCQA     AFT TANK MONOCOQUE FLAG                                I
CI                  0 = SUSPENDED TANK                                     I
CI                  1 = MONOCOQUE TANK                                     I
CI                  ( --- 1 $TNKGEO /TANKS/  )                             I
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CI      MNCQF     FORWARD TANK MONOCOQUE FLAG                          I
CI                0 = SUSPENDED TANK                                   I
CI                1 = MONOCOQUE TANK                                   I
CI                ( --- 1 $TNKGEO /TANKS/  )                           I
CI      MTNKFL    MATERIAL FLAG FOR FUEL TANK AND                      I
CI                FUEL LINES                                           I
CI                ( --- 1 $LIQMAT /TANKS2/  )                          I
CI      MTNKOX    MATERIAL FLAG FOR OXIDIZER TANK AND                  I
CI                OXIDIZER LINES                                       I
CI                ( --- 1 $LIQMAT /TANKS2/  )                          I
CI      MUFMIN    FLAG INDICATING METHOD OF UNCONSTRAINED FUNCTION     I
CI                MINIMIZATION (AT PRESENT ONLY 2 IS ACCEPTABLE)       I
CI                2 = USE QUASI-NEWTON VARIABLE METRIC METHOD          I
CI                ( --- 2 $NLP /---/  )                                I
CI      MUPDAT    FLAG INDICATING METHOD OF UPDATING LAGRANGE MULT-    I
CI                IPLIERS (AT PRESENT ONLY 2 IS ACCEPTABLE)            I
CI                2 = USE BUY'S METHOD FOR EQUALITY AND INEQUALITY     I
CI                    CONSTRAINTS                                      I
CI                ( --- 2 $NLP /---/  )                                I
CI      NCON      NUMBER OF SEGMENTS IN CONVERGENT CHAMBER SECTION     I
CI                FOR HEAT TRANSFER ANALYSIS                           I
CI                ( --- 5 $INREGN /COOLNT/  )                          I
CI      NCTNK     NONCONVENTIONAL TANK SELECTION FLAG (0=TANDEM,       I
CI                1= NON-CONVENTIONAL)                                 I
CI                ( --- 0 $LFLAG /NCTIN/  )                            I
CI      NCYL      NUMBER OF SEGMENTS IN CYLINDRICAL CHAMBER SECTION    I
CI                FOR HEAT TRANSFER ANALYSIS                           I
CI                ( --- 5 $INREGN /COOLNT/  )                          I
CI      NELEM     NUMBER OF INJECTOR ELEMENTS                          I
CI                ( --- 336 $INJECT /LIQUID/  )                        I
CI      NFLORF    NUMBER OF FUEL INJECTOR ORIFICES                     I
CI                ( --- 672 $INJECT /LIQUID/  )                        I
CI      NGIMB     NUMBER OF GIMBALING NOZZLES                          I
CI                ( --- 1 $LIQUID /GIMBAL/  )                          I
CI      NITHX     NUMBER OF ITERATIONS IN SUBROUTINE TANKHX WHICH      I
CI                CONTROLS THE ACCURACY OF TANK HEAT TRANSFER CALCS    I
CI                ( --- 8 $TANKHX /INSLHX/  )                          I
CI      NNOZ      NUMBER OF SOLID MOTOR NOZZLES PER STAGE              I
CI                ( --- 1 $NOZZLE /GENRL/  )                           I
CI      NNZL      NUMBER OF NOZZLE SEGMENTS USED IN HEAT TRANSFER      I
CI                ANALYSIS                                             I
CI                ( --- 5 $INREGN /COOLNT/  )                          I
CI      NOXORF    NUMBER OF OXIDIZER ORIFICES IN INJECTOR FACE         I
CI                ( --- 500 $INJECT /LIQUID/  )                        I
CI      NPCR      NUMBER OF REFERENCE CHAMBER PRESSURES                I
CI                ( --- 1 $PROPEL /MOTOR/  )                           I
CI      NPRB      NUMBER OF PRESSURE BOTTLES IN ENGINE BAY             I
CI                (KPRESS = 0)                                         I
CI                ( --- 1 $TNKGEO /TANKS/  )                           I
CI      NR        NUMBER OF ENGINE RESTARTS (USED TO SIZE START        I
CI                SYSTEM)                                              I
CI                ( --- 1 $PUMP /TPAIN/  )                             I
CI      NSTGES    NUMBER OF STAGES                                     I
CI                ( --- 3 $INPGEN /PERF/  )                            I
CI      NTANKS    TOTAL NUMBER OF NON-CONVENTIONAL TANKS ON STAGE      I
CI                ( --- 3 $NCTINP /NCTIN/  )                           I
CI      NTC       NUMBER OF LIQUID THRUST CHAMBERS OR PLUG MODULES     I
CI                ( --- 1 $LIQENG /LIQUID/  )                          I
CI      NTHEFF    NUMBER OF ENTRIES IN TABLES THRFC, ECFTHR, AND       I
CI                ERETHR FOR EACH STAGE                                I
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CI                  ( --- 7 $THROT /THREFF/  )                     I
 I      NTMPIT      NUMBER OF INTERATIONS ON TEMPERATURE SCHEDULE IN   I
                    SUBROUTINE LSTAGE   ALSO CONTROLS NUMBER OF        I
 I                  ITERATIONS ON FLOWRATE SCHEDULE                    I
CI                  ( --- 1 $LIQUID /TEMSCH/  )                        I
CI      OBJSCL      SCALING FACTOR FOR OBJECTIVE FUNCTION              I
CI                  ( --- --- $INPOPT /OPTIM/  )                       I
CI      OFCORE      MIXTURE OF GAS CORE IN LIQUID COMBUSTION CHAMBER   I
CI                  ( --- 1.9 $LQPERF ///EQ///  )                      I
CI      OFGGPB      MIXTURE RATIO OF GAS GENERATOR PREBURNER           I
CI                  ( --- 0.1 $PUMP /TRAIN/  )                         I
CI      OFMTC       OVERALL ENGINE MIXTURE RATIO  (KPERF=0)            I
CI                  ( --- 1.782 $LQPERF /LIQUID/  )                    I
CI      OFRMX       MIXTURE RATIO ON USER PROPELLANT AT MAX ISP.       I
CI                  PC=500  (IPROP=0)                                  I
CI                  ( --- 2.03 $LPROP /EQUIVR/  )                      I
CI      ORBANG      ANGLE BETWEEN THE EARTH-SUN VECTOR AND VEHICLE     I
CI                  ORBITAL PLANE (KHXOPT=2)                           I
CI                  ( DEG 0.0 $TANKHX /INSLHX/  )                      I
CI      OXKFCT      NUMBER OF VELOCITY HEADS LOST IN OXIDIZER FEED     I
CI                  LINE DUE TO BENDS, VALVES, ETC.                    I
CI                  ( VEL-HEADS 5. $LTANK /TANKS2/  )                  I
CI      OXNPSP      OX NET POSITIVE SUCTION PRESSURE IN TANK           I
CI                  ( PSIA 10. $PUMP /PRESCH/  )                       I
CI      OXOPEL      NUMBER OF OXIDIZER ORIFICES/ELEMENT                I
CI                  ( --- 1.5 $INJECT /ELEMEN/  )                      I
CI      PAMB        AMBIENT PRESSURE CORRECTION FOR VARIABLE THRUST-   I
 I                  TIME TRACE                                         I
 I                  ( PSIA 0.0 $THVST /PERF/  )                        I
CI      PBPRF       FUEL PRESSURE RATIO ACROSS PREBURNER INJECTOR      I
CI                  ( PSIA 1.2 $PUMP /PRESCH/  )                       I
CI      PBPRO       OX PRESSURE RATIO ACROSS PREBURNER INJECTOR        I
CI                  ( PSIA 1.2 $PUMP /PRESCH/  )                       I
CI      PBURST      MINIMUM EXPECTED BURST PRESSURE                    I
CI                  ( LBF/IN**2 1200. $FILMNT /MOTOR/  )               I
CI      PC          NOMINAL OPERATING CHAMBER PRESSURE                 I
CI                  ( LBF/IN**2 600. $INPGEN ///EQ///  )               I
CI      PCR         REFERENCE CHAMBER PRESSURES AT WHICH CSTAR AND     I
CI                  SPECIFIC IMPULSE DATA IS INPUT                     I
CI                  ( LBF/IN**2 600. $PROPEL /MOTOR/  )                I
CI      PCRIT       CRITICAL PRESSURE OF COOLANT                       I
CI                  ( PSIA 1731. $LPROP /COOLNT/  )                    I
CI      PCRITF      FUEL CRITICAL PRESSURE                             I
CI                  ( PSIA --- $LFUEL /PROPRO/  )                      I
CI      PCRITO      OX CRITICAL PRESSURE                               I
CI                  ( PSIA --- $LOXID /PROPRO/  )                      I
CI      PCTHRT      CHAMBER PRESSURE FRACTIONS FOR THROTTLED OPERATION I
CI                  ( --- 1. $THROT /THROTL/  )                        I
CI      PICG        MAX INITIAL PRESSURE OF COLD GAS BOTTLE            I
CI                  ( PSIA 4365. $COLDG ///EQ///  )                    I
CI      PIPKGG      TEMPERATURE SENSITIVITY OF GAS GENERATOR           I
CI                  OPERATING PRESSURE                                 I
CI                  ( 1/DEGR 0.0036 $SOLDGG /GASGEN/  )                I
 I      PLF         VOLUMETRIC LOADING FRACTION FOR EACH STAGE BASED   I
 I                  ON THE VOLUME INSIDE THE LINER, AND REDUCED BY THE I
CI                  SUBMERGED SECTION OF THE NOZZLE                    I
CI                  ( --- .85 $PROPEL ///EQ///  )                      I
CI      PNZREF      REFERENCE NOZZLE CHAMBER PRESSURE                  I
CI                  ( PSIA 125. $LIQENG /TCA/  )                       I
CI      PREF        PRESSURE AT WHICH REFERENCE PROPERTIES APPLY       I
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CI                ( PSIA 14.7 $LPROP /COOLNT/  )                        I
CI       PREFFL   FUEL REFERENCE PRESSURE FOR REFERENCE PROPERTIES      I
CI                ( PSIA --- $LFUEL /PROPRO/  )                         I
CI       PREFOX   OX REFERENCE PRESSURE FOR REFERENCE PROPERTIES        I
CI                ( PSIA --- $LOXID /PROPRO/  )                         I
CI       PRELOS   IDEAL VELOCITY LOSSES DUE TO PRESSURE FORCES          I
CI                ( FT/SEC 0 $INTRAJ /TRAJ/  )                          I
CI       PRFCHM   REFERENCE CHAMBER PRESSURE FOR CHAMBER STRESS         I
CI                ( PSIA 125. $LIQENG /TCA/  )                          I
CI       PRFCHR   REFERENCE CHAMBER PRESSURE FOR CHAR DEPTH             I
CI                ( PSIA 125. $ABLATE /TCA/  )                          I
CI       PRGMLI   MLI PURGE GAS PRESSURE AT SPACE HOLD CONDITIONS       I
CI                ( PSIA 2.0E-7 $TANKHX /INSLHX/  )                     I
CI       PTURBO   TURBINE OUTLET PRESSURE                               I
CI                ( PSIA --- $PUMP /PRESCH/  )                          I
CI       PVMAXF   VAPOR PRESSURE OF FUEL AT TMAX                        I
CI                ( PSIA 3.6 $LPROP /LIQUID/  )                         I
CI       PVMAXO   VAPOR PRESSURE OF OXIDIZER ST TMAX                    I
CI                ( PSIA 2.4 $LPROP /LIQUID/  )                         I
CI       QMAXTR   MAXIMUM HEAT FLUX COOLED BY REGEN JACKET BEFORE       I
CI                TRANSPIRATION COOLING IS USED                         I
CI                ( BTU/IN**2/SEC 1.0 $INREGN /TRANCO/  )               I
CI       QULTC1   CONSTANT IN NUCLEATE BOILING ULTIMATE HEAT FLUX       I
CI                EQUATION                                              I
CI                ( BTU/IN**2/SEC 4.55 $LPROP /COOLNT/  )               I
CI       QULTC2   MULTIPLYING CONSTANT IN NUCLEATE BOILING HEAT         I
CI                FLUX EQUATION                                         I
CI                ( BTU/IN**3/SEC 0.00686 $LPROP /COOLNT/  )            I
CI       RADLO1   NON-CONVENTIONAL TANK RADIAL POSITION FOR STAGE 1     I
CI                (0.0=CENTERLINE, 1.0=FARTHEST RADIAL POSITION)        I
CI                ( --- 0. $NCTINP /---/  )                             I
CI       RADLO2   NON-CONVENTIONAL TANK RADIAL POSITION FOR STAGE 2     I
CI                (SEE RADLO1)                                          I
CI                ( --- 0. $NCTINP /---/  )                             I
CI       RADLO3   NON-CONVENTIONAL TANK RADIAL POSITION FOR STAGE 3     I
CI                (SEE RADLO1)                                          I
CI                ( --- 0. $NCTINP /---/  )                             I
CI       RADLO4   NON-CONVENTIONAL TANK RADIAL POSITION FOR STAGE 4     I
CI                (SEE RADLO1)                                          I
CI                ( --- 0. $NCTINP /---/  )                             I
CI       RADPIN   RADIATION SHIELDS PER INCH IN MULTILAYER INSULA-      I
CI                TION (MLI)                                            I
CI                ( #/IN 40. $TANKHX /INSLHX/  )                        I
CI       RATMLR   RATIO OF NOZZLE LENGTH TO THAT OF A MINIMUM LENGTH    I
CI                RAO NOZZLE                                            I
CI                ( --- 1.177 $LIQENG ///EQ///  )                       I
CI       RATNK1   NON-CONVENTIONAL TANK USABLE VOLUME RATIO FOR         I
CI                STAGE 1 (COMPARED WITH LIKE TANKS TO CALCULATE        I
CI                OVERALL VOLUME FRACTION)(EG. IF THREE FUEL TANKS      I
CI                HAVE VALUES OF 1.,2.,AND 3. THEN THEY EACH HAVE       I
CI                VOLUME FRACTIONS OF 1/6, 1/3, AND 1/2 )               I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI       RATNK2   NON-CONVENTIONAL TANK USABLE VOLUME RATIO FOR         I
CI                STAGE 2 (SEE RATNK1)                                  I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI       RATNK3   NON-CONVENTIONAL TANK USABLE VOLUME RATIO FOR         I
CI                STAGE 3 (SEE RATNK1)                                  I
CI                ( --- 1.0 $NCTINP /---/  )                            I
CI       RATNK4   NON-CONVENTIONAL TANK USABLE VOLUME RATIO FOR         I
CI                STAGE 4 (SEE RATNK1)                                  I
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CI                 ( --- 1.0 $NCTINP /---/  )                         I
 I       RCRT      RATIO OF THROAT RADIUS OF CURVATURE TO THROAT      I
                   RADIUS                                             I
CI                 ( --- 1.2 $NOZZLE /MOTOR/  )                       I
CI       RDIM1     DIMENSIONAL RATIO FOR EACH NON-CONVENTIONAL TANK   I
CI                 ON STAGE 1 (CSE=CYLINDRICAL LENGTH/DIAMETER,       I
CI                 TORUS=HUB RADIUS / TUBE RADIUS)                    I
CI                 ( --- 2.0 $NCTINP /---/  )                         I
CI       RDIM2     DIMENSIONAL RATIO FOR EACH NON-CONVENTIONAL TANK   I
CI                 ON STAGE 2 (SEE RDIM1)                             I
CI                 ( --- 2.0 $NCTINP /---/  )                         I
CI       RDIM3     DIMENSIONAL RATIO FOR EACH NON-CONVENTIONAL TANK   I
CI                 ON STAGE 3 (SEE RDIM1)                             I
CI                 ( --- 2.0 $NCTINP /---/  )                         I
CI       RDIM4     DIMENSIONAL RATIO FOR EACH NON-CONVENTIONAL TANK   I
CI                 ON STAGE 4 (SEE RDIM1)                             I
CI                 ( --- 2.0 $NCTINP /---/  )                         I
CI       REFNWT    REFERENCE NOZZLE WEIGHT                            I
CI                 ( LBM 1000. $PROPEL /MOTOR/  )                     I
CI       REFSTF    FUEL REFERENCE SURFACE TENSION                     I
CI                 ( LB/IN --- $LFUEL /PROPRO/  )                     I
CI       REFSTO    OX REFERENCE SURFACE TENSION                       I
CI                 ( LB/IN --- $LOXID /PROPRO/  )                     I
CI       REFWDT    REFERENCE NOZZLE FLOW RATE                         I
CI                 ( LBM/SEC 100. $PROPEL /MOTOR/  )                  I
CI       REGA      THROAT REGRESSION COEFFICIENT                      I
CI                 ( --- 0.002798 $ABLATE /LIQUID/  )                 I
 I       REGB      THROAT REGRESSION COEFFICIENT                      I
 I                 ( --- 0.0005995 $ABLATE /LIQUID/  )                I
CI       REGC      THROAT REGRESSION COEFFICIENT                      I
CI                 ( --- 0.4246 $ABLATE /LIQUID/  )                   I
CI       RELHUM    RELATIVE HUMIDITY OF AMBIENT ATMOSPHERE FOR USE    I
CI                 WITH KHXOPT=3                                      I
CI                 ( --- 50  $TANKHX /INSLHX/  )                      I
CI       RF        RADIUS OF FORWARD DOME POLAR BOSS OPENING          I
CI                 ( IN 2. $FILMNT /MOTOR/  )                         I
CI       RHCABL    DENSITY OF CHAMBER ABLATIVE MATERIAL               I
CI                 ( LBM/IN**3 0.0632 $LIQMAT /TCA/  )                I
CI       RHCSTR    DENSITY OF CHAMBER STRUCTURAL MATERIAL             I
CI                 ( LBM/IN**3 0.0632 $LIQMAT /TCA/  )                I
CI       RHO       MATERIAL DENSITY TABLE                             I
CI                 ( LBM/IN**3 0.29,0.16,8*0.0 $LIQMAT /MTPROP/  )    I
CI       RHOABP    BAND DENSITY                                       I
CI                 ( ENDS/IN/PLY 35. $FILMNT /MOTOR/  )               I
CI       RHOALF    DENSITY OF HELICAL WINDINGS                        I
CI                 ( LBM/IN**3 0.042 $FILMNT /MOTOR/  )               I
CI       RHOBOT    START BOTTLE MATERIAL DENSITY (ISTART=2)           I
CI                 ( LBM/IN**3 0.16 $PUMP /TPAIN/  )                  I
CI       RHOCAS    CASE MATERIAL DENSITY                              I
CI                 ( LBM/IN**3 .282 $MATER /MOTOR/  )                 I
CI       RHOCLS    REGEN CHAMBER CLOSEOUT MATERIAL DENSITY            I
CI                 ( LBM/IN**3 0.322 $LIQMAT /WTREGN/  )              I
 I       RHOCYL    START CYLINDER MATERIAL DENSITY (ISTART=2)         I
 I                 ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                   I
CI       RHOEXT    DENSITY OF EXTERNAL INSULATION                     I
CI                 ( LBM/IN**3 .06 $MATER /MOTOR/  )                  I
CI       RHOGG     SOLID GRAIN DENSITY                                I
CI                 ( LB/IN**3 0.056 $SOLDGG /GASGEN/  )               I
CI       RHOGW     REGEN CHAMBER GAS WALL MATERIAL DENSITY            I
CI                 ( LBM/IN**3 0.28 $LIQMAT /WTREGN/  )               I
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CI      RHOINJ    INJECTOR MATERIAL DENSITY                                I
CI                ( LBM/IN**3 0.098 $LIQMAT /TCA/  )                       I
CI      RHOINS    DENSITY OF INTERNAL INSULATION                           I
CI                ( LBM/IN**3 .0414 $MATER /MOTOR/  )                      I
CI      RHOINT    DENSITY OF INTERSTAGE MATERIAL                           I
CI                ( LBM/IN**3 .101 $INTSTG /MOTOR/  )                      I
CI      RHOLNR    LINER DENSITY                                            I
CI                ( LBM/IN**3 .0414 $MATER /MOTOR/  )                      I
CI      RHONOZ    DENSITY OF NOZZLE EXIT CONE                              I
CI                ( LBM/IN**3 .06 $NOZZLE /GENRL/  )                       I
CI      RHONZE    NOZZLE EXTENSION MATERIAL DENSITY                        I
CI                ( LB/IN**3 0.32 $LIQMAT /TCA/  )                         I
CI      RHOP      PROPELLANT DENSITY FOR EACH STAGE                        I
CI                ( LBM/IN**3 0. $PROPEL /MOTOR/  )                        I
CI      RHOPLB    PLUG CLUSTER BASE DENSITY ( IPLUG = 1 )                  I
CI                ( LBM/IN**3 0.06 $LIQMAT /PLGBAS/  )                     I
CI      RHOSPH    START SYSTEM SPHERE MATERIAL DENSITY (ISTART=1)          I
CI                ( LB/IN**3 0.1 $PUMP /TPAIN/  )                          I
CI      RHOTFL    FUEL TURBINE BLADE MATERIAL DENSITY(JCNFIG=3 OR 4)       I
CI                ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                         I
CI      RHOTH     DENSITY OF HOOP WINDINGS                                 I
CI                ( LBM/IN**3 0.042 $FILMNT /MOTOR/  )                     I
CI      RHOTOX    OX TURBINE BLADE MATERIAL DENSITY(JCNFIG=3 OR 4          I
CI                ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                         I
CI      RHOTPA    TPA EFFECTIVE DENSITY                                    I
CI                ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                         I
CI      RHOTUR    TURBINE BLADE MATERIAL DENSITY (JCNFIG=1 OR 2)           I
CI                ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                         I
CI      RHOVLV    VALVE MATERIAL DENSITY                                   I
CI                ( LBM/IN**3 0.098 $LIQMAT /TCA/  )                       I
CI      RHPTIN    DENSITY OF TANK INSULATION                               I
CI                ( LBM/IN**3 0.04 $LIQMAT /TANKS/  )                      I
CI      RHTRIN    MATERIAL DENSITY OF TRANSPIRATION COOLING THROAT         I
CI                INSERT                                                   I
CI                ( LBM/IN**3 0.28 $LIQMAT /TRANCO/  )                     I
CI      RMAJ1     MAJOR DIMENSION OF NON-CONVENTIONAL TANK FOR STAGE       I
CI                1.  FOR USE WITH KALMOD=1.  (FOR CSE RMAJ IS TANK        I
CI                RADIUS, FOR TORUS RMAJ IS THE RADIUS FROM THE            I
CI                CENTER POINT TO THE CIRCULAR CENTER LINE)                I
CI                ( IN 25 $NCTINP /---/  )                                 I
CI      RMAJ2     MAJOR DIMENSION OF NON-CONVENTIONAL TANK FOR STAGE       I
CI                2.   (SEE RMAJ1)                                         I
CI                ( IN 25 $NCTINP /---/  )                                 I
CI      RMAJ3     MAJOR DIMENSION OF NON-CONVENTIONAL TANK FOR STAGE       I
CI                3.   (SEE RMAJ1)                                         I
CI                ( IN 25 $NCTINP /---/  )                                 I
CI      RMAJ4     MAJOR DIMENSION OF NON-CONVENTIONAL TANK FOR STAGE       I
CI                4.   (SEE RMAJ1)                                         I
CI                ( IN 25 $NCTINP /---/  )                                 I
CI      RMFFL     FUEL DROPLET RADIUS CORRECTION FACTOR                    I
CI                ( --- 0.33 $LQPERF /LIQUID/  )                           I
CI      RMFOX     OXIDIZER DROPLET RADIUS CORRECTION FACTOR                I
CI                ( --- 0.33 $LQPERF /LIQUID/  )                           I
CI      RNZREF    REFERENCE NOZZLE THROAT RADIUS                           I
CI                ( IN 3.74 $LIQENG /TCA/  )                               I
CI      ROACVL    ACCUMULATOR VALVE MATERIAL DENSITY (ISTART=2)            I
CI                ( LB/IN**3 0.3 $PUMP /TPAIN/  )                          I
CI      ROCART    START CARTRIDGE MATERIAL DENSITY (ISTART=3)              I
CI                ( LBM/IN**3 0.3 $PUMP /TPAIN/  )                         I
CI      ROGRAN    START CARTRIDGE GRAIN DENSITY (ISTART=3)                 I
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CI                    ( LBM/IN**3 0.07 $PUMP /TPAIN/   )                        I
          ROINGG      GAS GENERATOR OR PRE-BURNER INJECTOR MATERIAL             I
                      DENSITY                                                   I
 I                    ( LBM/IN**3 0.3 $PUMP /TPAIN/   )                         I
CI        ROLINE      PROPELLANT LINE MATERIAL DENSITY(ENGINE BAY LINES)        I
CI                    ( LB/IN**3 0.3 $PUMP /TPAIN/   )                          I
CI        ROSPVL      DENSITY OF COLD GAS VALVE MATERIAL (ISTART=1)             I
CI                    ( LBM/IN**3 0.3 $PUMP /TPAIN/   )                         I
CI        ROSTAK      HOT GAS DUCT MATERIAL DENSITY                             I
CI                    ( LBM/IN**3 0.3 $PUMP /TPAIN/   )                         I
CI        ROTRNZ      DENSITY OF TRANSLATING NOZZLE MATERIAL                    I
CI                    ( LB/IN**3 0.28 $LIQMAT /TRANOZ/   )                      I
CI        RRFCHM      REFERENCE CHAMBER RADIUS FOR TCA WEIGHT                   I
CI                    ( IN 5.95 $LIQENG /TCA/   )                               I
CI        RUFFFL      ABSOLUTE SURFACE ROUGHNESS OF FUEL FEED LINE              I
CI                    ( IN .0001 $LTANK /TANKS2/   )                            I
CI        RUFFOX      ABSOLUTE SURFACE ROUGHNESS OF OXIDIZER FEED LINE          I
CI                    ( IN .0001 $LTANK /TANKS2/   )                            I
CI        SABSOR      STAGE ABSORBTIVITY (KHXOPT=2)                             I
CI                    ( --- 0.2 $TANKHX /INSLHX/   )                            I
CI        SACCEL      AVERAGE STAGE ACCELERATION (FOR TANK HEAT LOSS)           I
CI                    ( G'S 2.0 $TANKHX /INSLHX/   )                            I
CI        SAFACT      CASE DESIGN SAFETY FACTOR                                 I
CI                    ( --- 1.5 $MATER /MOTOR/   )                              I
CI        SAMULT      SURFACE AREA MULTIPLIER ON REGEN COOLED ENGINE            I
CI                    ( --- 1.0 $INREGN /WTREGN/   )                            I
 I        SCASE       DESIGN STRENGTH OF CASE MATERIAL (HOOP)                   I
                      ( LBF/IN**2 220000. $MATER /MOTOR/   )                    I
          SDOMEH      DOME HOOP DESIGN STRENGTH                                 I
CI                    ( LBF/IN**2 220000. $MATER /MOTOR/   )                    I
CI        SDOMEM      DOME MERIDIONAL STRENGTH                                  I
CI                    ( LBF/IN**2 220000. $MATER /MOTOR/   )                    I
CI        SEMISI      STAGE EMMISIVITY (KHXOPT=2)                               I
CI                    ( --- 0.9 $TANKHX /INSLHX/   )                            I
CI        SFABL       ABLATIVE THICKNESS SAFETY FACTOR                          I
CI                    ( --- 1. $ABLATE /TCA/   )                                I
CI        SFC         AERODYNAMIC SKIN FRICTION COEFFICIENTS INPUT AS           I
CI                    FUNCTIONS OF MACH NUMBER AND ALTITUDE;  SFC(I,J)          I
CI                    CORRESPONDS TO AMACH(I) AND ALTSF(J)                      I
CI                    ( --- 0. $AEROD /AERO/   )                                I
CI        SFCHM       CHAMBER STRUCTURAL SAFETY FACTOR                          I
CI                    ( --- 1. $LIQENG /TCA/   )                                I
CI        SFFLTK      SAFETY FACTOR FOR FUEL TANK                               I
CI                    ( --- 1.25 $LIQMAT /TWTMLT/   )                           I
CI        SFINST      DESIGN SAFETY FACTOR FOR INTERSTAGE THICKNESS             I
CI                    SIZING                                                    I
CI                    ( --- 1.5 $INTSTG /MOTOR/   )                             I
CI        SFLINE      SAFETY FACTOR FOR PROPELLANT AND PRESSURIZATION           I
CI                    LINES                                                     I
CI                    ( --- 2.0 $LIQMAT /TWTMLT/   )                            I
CI        SFOXTK      SAFETY FACTOR FOR OXIDIZER TANK                           I
CI                    ( --- 1.25 $LIQMAT /TWTMLT/   )                           I
 I        SFPRTK      SAFETY FACTOR FOR PRESSURE TANK                           I
                      ( --- 1.5 $LIQMAT /TWTMLT/   )                            I
CI        SFSTRC      SAFETY FACTOR FOR STRUCTURAL WALL OF STAGE                I
CI                    ( --- 1.25 $LIQMAT /TWTMLT/   )                           I
CI        SFTNK1      DESIGN SAFETY FACTOR FOR EACH NON-CONVENTIONAL            I
CI                    TANK ON STAGE 1                                           I
CI                    ( --- 1.5 $NCTINP /---/   )                               I
CI        SFTNK2      DESIGN SAFETY FACTOR FOR EACH NON-CONVENTIONAL            I
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CI                TANK ON STAGE 2                                    I
CI                ( --- 1.5 $NCTINP /---/  )                         I
CI       SFTNK3   DESIGN SAFETY FACTOR FOR EACH NON-CONVENTIONAL     I
CI                TANK ON STAGE 3                                    I
CI                ( --- 1.5 $NCTINP /---/  )                         I
CI       SFTNK4   DESIGN SAFETY FACTOR FOR EACH NON-CONVENTIONAL     I
CI                TANK ON STAGE 4                                    I
CI                ( --- 1.5 $NCTINP /---/  )                         I
CI       SIGCHM   HOT CHAMBER DESIGN STRENGTH                        I
CI                ( PSI 25000. $LIQMAT /TCA/  )                      I
CI       SIGCLS   DESIGN STRESS OF REGEN JACKET CLOSEOUT MATERIAL    I
CI                ( PSIA 25000 $LIQMAT /TCA/  )                      I
CI       SIGGO    BURN RATE TEMPERATURE SENSITIVITY OF SOLID GRAIN   I
CI                ( 1/DEGR 0.0013 $SOLDGG /GASGEN/  )                I
CI       SIGINJ   INJECTOR MATERIAL DESIGN STRESS                    I
CI                ( PSI 25000. $LIQMAT /TCA/  )                      I
CI       SIGMAX   MATERIAL DESIGN STRESS TABLE                       I
CI                ( NOT INCLUDING SAFETY FACTORS )                   I
CI                ( PSI 112300.,130000.,8*0.  $LIQMAT /MTPROP/  )    I
CI       SIGNZE   DESIGN STRESS OF NOZZLE EXTENSION MATERIAL         I
CI                ( PSIA 25000 $LIQMAT /TCA/  )                      I
CI       SINST    DESIGN STRENGTH OF INTERSTAGE MATERIAL             I
CI                ( LBF/IN**2 220000. $INTSTG /MOTOR/  )             I
CI       SMALL    A SMALL POSITIVE NUMBER                            I
CI                ( --- 1.E-99 $NLP /---/  )                         I
CI       SOFIA    CONSTANT IN SOFI THERMAL CONDUCTIVITY EQUATION     I
CI                K = SOFIA + SOFIB * TEMPERATURE                    I
CI                ( BTU/IN-SEC-DEGR 3.935E-8 $TANKHX /INSLHX/  )     I
CI       SOFIB    CONSTANT IN SOFI THERMAL CONDUCTIVITY EQUATION     I
CI                K = SOFIA + SOFIB * TEMPERATURE                    I
CI                ( BTU/IN-SEC-DEGR**2 5.676E-10 $TANKHX /INSLHX/  ) I
CI       SOLCON   SOLAR HEAT FLUX (KHXOPT=2)                         I
CI                ( BTU/SEC-IN**2 8.28E-4 $TANKHX /INSLHX/  )        I
CI       SPCNOZ   SPACE BETWEEN ADJACENT NOZZLES                     I
CI                ( IN 1.0 $LIQENG /GIMBAL/  )                       I
CI       SPHEAT   MATERIAL SPECIFIC HEAT TABLE                       I
CI                ( BTU/LB-DEGR .12,.13,8*0.  $LIQMAT /MTPROP/  )    I
CI       SPRMX    MAXIMUM ISP FOR USER PROPELLANT AT PC=500          I
CI                AREA RATIO=20   (IPROP=0)                          I
CI                ( SEC 328.8 $LPROP /EQUIVR/  )                     I
CI       SSMIN    MINIMUM SPECIFIC SPEED ALLOWED IN PUMPS            I
CI                ( --- 800.  $PUMP ///EQ///  )                      I
CI       SSSBPF   MAXIMUM SUCTION SPECIFIC SPEED OF FUEL BOOST PUMP  I
                  ( RPM-GPM-FT 30000-OR-40000 $PUMP /TPAIN/  )       I
         SSSBPO   MAXIMUM SUCTION SPECIFIC SPEED OF OX BOOST PUMP    I
                  ( RPM-GPM-FT 30000 $PUMP /TPAIN/  )                I
         SSSFL    MAXIMUM SUCTION SPECIFIC SPEED OF FUEL PUMP        I
                  ( RPM-GPM-FT 20000 $PUMP /TPAIN/  )                I
         SSSMAX   MAXIMUM SUCTION SPECIFIC SPEED ALLOWED IN PUMPS    I
                  ( --- 20000. $PUMP ///EQ///  )                     I
CI       SSSOX    MAXIMUM SUCTION SPECIFIC SPEED OF OXIDIZER PUMP    I
CI                ( RPM-GPM-FT 20000 $PUMP /TPAIN/  )                I
CI       SXX      A VECTOR OF SCALE FACTORS BY WHICH THE UNSCALED    I
CI                INDEPENDENT VARIABLES WILL BE DIVIDED TO OBTAIN    I
CI                THE SCALED VALUES USED INTERNALLY, I=1,NX          I
CI                ( --- 1.0 $NLP /---/  )                            I
CI       SYBOT    START BOTTLE YIELD STRENGTH (ISTART=2)             I
CI                ( PSI 75000 $PUMP /TPAIN/  )                       I
CI       SYCART   YIELD STRENGTH FOR START CARTRIDGE (ISTART=3)      I
CI                ( PSI 100000 $PUMP /TPAIN/  )                      I
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CI       SYCYL     START CYLINDER YIELD STRENGTH (ISTART=2)              I
CI                 ( PSI 30000 $PUMP /TPAIN/  )                          I
         SYDUCT    HOT GAS DUCT MATERIAL YEILD STRENGTH                  I
                   ( PSI 30000 $PUMP /TPAIN/  )                          I
CI       SYINGG    GAS GENERATOR OR PRE-BURNER INJECTOR YIELD            I
CI                 STRENGTH                                              I
CI                 ( PSI 30000 $PUMP /TPAIN/  )                          I
CI       SYLIN     PROPELLANT LINE YIELD STRENGTH (ENGINE BAY LINES)     I
CI                 ( PSI 30000 $PUMP /TPAIN/  )                          I
CI       SYSPH     START SYSTEM SPHERE YIELD STRENGTH (ISTART=1)          I
CI                 ( PSI 47000 $PUMP /TPAIN/  )                          I
CI       TAMICE    AMBIENT TEMPERATURE FOR GROUND HOLD ICE HEAT          I
CI                 TRANSFER CALCULATION (KHXOPT=3)                       I
CI                 ( DEGR 560 $TANKHX /INSLHX/  )                        I
CI       TAMRAD    AMBIENT TEMPERATURE FOR TCA RADIATION COOLING         I
CI                 ( DEGR 560 $LIQENG /COOLNT/  )                        I
CI       TANGL1    NON-CONVENTIONAL TANK LOCATION ANGLE FOR STAGE 1      I
CI                 (LOCATES TANK CENTERLINE ABOUT STAGE CENTERLINE)      I
CI                 ( DEG 0. $NCTINP /---/  )                             I
CI       TANGL2    NON-CONVENTIONAL TANK LOCATION ANGLE FOR STAGE 2      I
CI                 (SEE TANGL1)                                          I
CI                 ( DEG 0. $NCTINP /---/  )                             I
CI       TANGL3    NON-CONVENTIONAL TANK LOCATION ANGLE FOR STAGE 3      I
CI                 (SEE TANGL1)                                          I
CI                 ( DEG 0. $NCTINP /---/  )                             I
CI       TANGL4    NON-CONVENTIONAL TANK LOCATION ANGLE FOR STAGE 4      I
CI                 (SEE TANGL1)                                          I
CI                 ( DEG 0. $NCTINP /---/  )                             I
 I       TAU       FACTOR BY WHICH THE PENALTY CONSTANTS MAY BE          I
 I                 INCREASED BETWEEN NONLINEAR PROGRAMMING               I
CI                 ITERATIONS                                            I
CI                 ( --- 5.0 $NLP /---/  )                               I
CI       TBLDFL    FUEL TANK BLADDER THICKNESS                           I
CI                 ( IN .025 $BLADER /TANKS2/  )                         I
CI       TBLDOX    OXIDIZER TANK BLADDER THICKNESS                       I
CI                 ( IN .025 $BLADER /TANKS2/  )                         I
CI       TBNDFL    FUEL TANK BOND THICKNESS                              I
CI                 ( IN .04 $BLADER /TANKS2/  )                          I
CI       TBNDOX    OXIDIZER TANK BOND THICKNESS                          I
CI                 ( IN .04 $BLADER /TANKS2/  )                          I
CI       TBOGAS    START BOTTLE GAS TEMPERATURE (ISTART=2)               I
CI                 ( DEGR 530 $PUMP /TPAIN/  )                           I
CI       TBOIL     NORMAL BOILING POINT OF COOLANT                       I
CI                 ( DEGR 618 $LPROP /COOLNT/  )                         I
CI       TBOILF    FUEL NORMAL BOILING POINT                             I
CI                 ( DEGR --- $LFUEL /PROPRO/  )                         I
CI       TBOILO    OX NORMAL BOILING POINT                               I
CI                 ( DEGR --- $LOXID /PROPRO/  )                         I
CI       TBRCHR    REFERENCE BURN TIME FOR CHAR DEPTH                    I
CI                 ( SEC 500. $ABLATE /TCA/  )                           I
CI       TBRN      TABLE OF MOTOR BURN TIMES;  INPUT FOR EACH STAGE      I
CI                 ( SEC 0.0 $THVST /PERF/  )                            I
CI       TCMBGG    GAS GENERATOR COMBUSTION TEMPERATURE                  I
 I                 ( DEGR 2130. $SOLDGG /GASGEN/  )                      I
 I       TCONE     THICKNESS OF NOZZLE EXIT CONE                         I
CI                 ( IN 0.0 $NOZZLE /MOTOR/  )                           I
CI       TCRIT     CRITICAL TEMPERATURE OF COOLANT                       I
CI                 ( DEGR 1093. $LPROP /COOLNT/  )                       I
CI       TCRITF    FUEL CRITICAL TEMPERATURE                             I
CI                 ( DEGR --- $LFUEL /PROPRO/  )                         I
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CI       TCRITO    OX CRITICAL TEMPERATURE                                    I
CI                 ( DEGR ---- $LOXID /PROPRO/  )                             I
 I       TDCYGG    TEMPERATURE DECAY TIME CONSTANT                            I
 I                 ( SEC 100. $SOLDGG /GASGEN/  )                             I
CI       TDESTR    DESIGN TEMPERATURE OF TRANSPIRATION COOLED WALL            I
CI                 MATERIAL                                                   I
CI                 ( DEGR 2000 $INREGN /TRANCO/  )                            I
CI       TEXBOU    EXTERNAL BOUNDARY TEMPERATURE (KHXOPT=1)                   I
CI                 ( DEGR 560. $TANKHX /INSLHX/  )                            I
CI       TGEOH     PLATELET THICKNESS OF TRANSPIRATION COOLED SECTION         I
CI                 ( IN .08 $INREGN /TRANCO/  )                               I
CI       TGEOL     PLATELET LAND THICKNESS OF TRANSPIRATION COOLED            I
CI                 SECTION                                                    I
CI                 ( IN .1 $INREGN /TRANCO/  )                                I
CI       TGEOS     SEPARATOR PLATELET THICKNESS IN TRANSPIRATION              I
CI                 COOLED SECTION                                             I
CI                 ( IN .04 $INREGN /TRANCO/  )                               I
CI       TGEOW     PLATELET FLOW PASSAGE WIDTHS IN TRANSPIRATION              I
CI                 COOLED SECTION                                             I
CI                 ( IN .14 $INREGN /TRANCO/  )                               I
CI       TGWNOM    NOMINAL GAS WALL TEMPERATURE (NOT TO BE EXCEEDED)          I
CI                 ( DEGR 2000. $INREGN /COOLNT/  )                           I
CI       THRPC     TABLE OF CHAMBER PRESSURE FRACTIONS FOR CORRES-            I
CI                 PONDING VALUES OF ERETHR AND ECFTHR                        I
CI                 ( ---- ---- $THROT /THREFF/  )                             I
CI       TIMPCG    TIME AT WHICH POLYTROPIC GAMMA EQUALS 1.1                  I
CI                 ( SEC 240. $COLDG /COLDGP/  )                              I
CI       TIMTHR    TIME INTERVALS FOR ENGINE THROTTLING                       I
 I                 ( SEC 0.0 $THROT /THROTL/  )                               I
CI       TINADM    INSULATION THICKNESS IN AFT DOME SECTION                   I
CI                 ( IN 0.  $MATER /MOTOR/  )                                 I
CI       TINFDM    INSULATION THICKNESS IN FORWARD DOME SECTION               I
CI                 ( IN 0.  $MATER /MOTOR/  )                                 I
CI       TINSCS    INSULATION THICKNESS IN CYLINDRICAL SECTION OF THE         I
CI                 MOTOR CASE (LC)                                            I
CI                 ( IN .1 $MATER /MOTOR/  )                                  I
CI       TINSUL    INSULATION THICKNESS FOR PRESSURE TANK                     I
CI                 ( IN 0.0 $LIQMAT /TANKS/  )                                I
CI       TKRCHM    REFERENCE CHAMBER THICKNESS OF ABLATIVE                    I
CI                 ( IN 0.22 $ABLATE /TCA/  )                                 I
CI       TLIMIT    MAXIMUM RUN TIME IN C.P. SECONDS                           I
CI                 ( SEC 4000 $INPOPT /OPTIM/  )                              I
CI       TLNADM    THICKNESS OF LINER IN AFT DOME SECTION                     I
CI                 ( IN 0.  $MATER /MOTOR/  )                                 I
CI       TLNCDM    THICKNESS OF LINER IN FWD DOME SECTION                     I
CI                 ( IN 0.  $MATER /----/  )                                  I
CI       TLNFDM    LINER THICKNESS (FORWARD DOME)                             I
CI                 ( IN ---- $MATER /MOTOR/  )                                I
CI       TLNRCS    THICKNESS OF LINER IN CYLINDRICAL SECTION                  I
CI                 ( IN 0.  $MATER /MOTOR/  )                                 I
CI       TMAX      MAXIMUM VEHICLE OPERATING TEMPERATURE                      I
CI                 ( DEGF 90.0 $LIQUID /TEMPS/  )                             I
CI       TMIN      MINIMUM VEHICLE OPERATING TEMPERATURE                      I
 I                 ( DEGF 60.0 $LIQUID /TEMPS/  )                             I
 I       TMING     MINIMUM GUAGE THICKNESS OF TANKS                           I
CI                 ( IN 0.035 $LIQMAT /TANKS/  )                              I
CI       TMINGL    MINIMUM GUAGE THICKNESS OF LINES                           I
CI                 ( IN 0.065 $LIQMAT /TANKS/  )                              I
CI       TMINGS    MINIMUM GUAGE THICKNESS OF STRUCTURAL WALL                 I
CI                 ( IN 0.035 $LIQMAT /TANKS/  )                              I
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CI      TMLIF     MULTILAYER INSULATION (MLI) THICKNESS FOR FUEL      I
CI                TANK(S)                                             I
CI                ( IN 0.  $TANKHX /INSLHX/   )                       I
CI      TMLIO     MULTILAYER INSULATION (MLI) THICKNESS FOR OXIDIZER  I
CI                TANK(S)                                             I
CI                ( IN 0.  $TANKHX /INSLHX/   )                       I
CI      TNENOM    NOZZLE EXTENSION DESIGN TEMPERATURE                 I
CI                ( DEGR 2000 $LIQENG /COOLNT/   )                    I
CI      TNZMIN    MINIMUM NOZZLE EXTENSION THICKNESS                  I
CI                ( IN 0.01 $LIQENG /TCA/   )                         I
CI      TNZREF    REFERENCE NOZZLE EXTENSION THICKNESS                I
CI                ( IN 0.019 $LIQENG /TCA/   )                        I
CI      TOLFNP    CONVERGENCE TOLERANCE FOR THE CHANGES IN AUGMENTED  I
CI                LAGRANGE FUNCTION AND THE OBJECTIVE FUNCTION        I
CI                BETWEEN SUCCESSIVE ITERATIONS OF THE NON-LINEAR     I
CI                PROGRAMMING METHOD                                  I
CI                ( --- 1.E-4 $NLP /---/   )                          I
CI      TOLGUM    TERMINATION TOLERANCE FOR THE QUASI-NEWTON UNCON-   I
CI                STRAINED FUNCTION MINIMIZATION METHOD ON THE RATIO  I
CI                OF THE CURRENT GRADIENT AND THE GRADIENT BEFORE     I
CI                THE FIRST ONE-DIMENSIONAL SEARCH                    I
CI                ( --- 1.E-2 $NLP /---/   )                          I
CI      TOLHNP    A CONVERGENCE TOLERANCE ON THE SCALED CONSTRAINT    I
CI                VIOLATIONS                                          I
CI                ( --- 1.E-4 $NLP /---/   )                          I
CI      TOLSUM    CONVERGENCE TOLERANCE ON THE MAGNITUDE OF THE       I
CI                CHANGE IN THE INDEPENDENT VARIABLES BETWEEN         I
CI                SUCCESSIVE ITERATIONS OF THE UNCONSTRAINED          I
CI                FUNCTION MINIMIZATION METHOD                        I
CI                ( --- 1.E-7 $NLP /---/   )                          I
CI      TOLZUM    USED TO DETERMINE THE INITIAL STEP LENGTH ON THE    I
CI                FIRST ONE-DIMENSIONAL SEARCH                        I
CI                ( --- -.01 $NLP /---/   )                           I
CI      TOP       NOMINAL VEHICLE OPERATING TEMPERATURE               I
CI                ( DEGF 75.0 $LIQUID /TEMPS/   )                     I
CI      TP        PERIOD OF DESTINATION ORBIT                         I
CI                ( SEC 0.0 $ORB ///EQ///   )                         I
CI      TPLGBS    PLUG CLUSTER BASE THICKNESS                         I
CI                ( IN 0.5 $LIQUID /PLGBAS/   )                       I
CI      TPMAXF    MAX FUEL TEMPERATURE IN TANK                        I
CI                ( DEGR --- $LFUEL /TEMSCH/   )                      I
CI      TPMAXO    MAX OX TEMPERATURE IN TANK                          I
CI                ( DEGR --- $LOXID /TEMSCH/   )                      I
CI      TPMINF    MIN FUEL TEMPERATURE IN TANK                        I
CI                ( DEGR --- $LFUEL /TEMSCH/   )                      I
CI      TPMINO    MIN OX TEMPERATURE IN TANK                          I
CI                ( DEGR --- $LOXID /TEMSCH/   )                      I
CI      TPNOMF    NOMINAL FUEL TEMPERATURE IN TANK                    I
CI                ( DEGR --- $LFUEL /TEMSCH/   )                      I
CI      TPNOMO    NOMINAL OX TEMPERATURE IN TANK                      I
CI                ( DEGR --- $LOXID /TEMSCH/   )                      I
CI      TRANKM    PLATELET MATERIAL THERMAL CONDUCTIVITY IN           I
CI                TRANSPIRATION COOLED SECTION                        I
CI                ( BTU/IN/SEC/DEGR .0004 $INREGN /TRANCO/   )        I
CI      TREF      TEMPERATURE AT WHICH REFERENCE PROPERTIES APPLY     I
CI                ( DEGR 530. $LPROP /COOLNT/   )                     I
CI      TREFFL    FUEL REFERENCE TEMPERATURE FOR REFERENCE PROPERTIE  I
CI                ( DEGR --- $LFUEL /PROPRO/   )                      I
CI      TREFGG    REFERENCE TEMPERATURE FOR BURN RATE COEFFICIENT     I
CI                OF GAS GENERATOR'S SOLID GRAIN                      I
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CI        TREFOX    ( DEGF 80.  $SOLDGG /GASGEN/   )                                I
CI        TREFOX    OX REFERENCE TEMPERATURE FOR REFERENCE PROPERTIES               I
CI                  ( DEGR --- $LOXID /PROPRO/   )                                  I
CI        TRINST    THICKNESS OF TRANSPIRATION COOLING THROAT INSERT                I
CI                  ( IN 0.3 $LIQMAT /TRANCO/  )                                    I
CI        TRMX      CHAMBER TEMPERATURE OF NEW PROPELLANT AT PC=500                 I
CI                   AND OFRMX   (IPROP = 0)                                        I
CI                  ( DEGR 5934. $LPROP /EQUIVR/   )                                I
CI        TSOFIF    SPRAY ON FOAM INSULATION (SOFI) THICKNESS FOR                   I
CI                  FUEL TANK(S)                                                    I
CI                  ( IN 0.  $TANKHX /INSLHX/   )                                   I
CI        TSOFIO    SPRAY ON FOAM INSULATION (SOFI) THICKNESS FOR                   I
CI                  OXIDIZER TANK(S)                                                I
CI                  ( IN 0.  $TANKHX /INSLHX/   )                                   I
CI        TSPCA     SPACE BETWEEN AFT TANK AND VEHICLE SKIN                         I
CI                  ( IN 0.0 $LTANK /TANKS/   )                                     I
CI        TSPCF     SPACE BETWEEN FORWARD TAN AND VEHICLE SKIN                      I
CI                  ( IN 0.0 $LTANK /TANKS/   )                                     I
CI        TSPCP     SPACE BETWEEN PRESSURE TANK AND VEHICLE SKIN                    I
CI                  ( IN 0.0 $LTANK /TANKS/   )                                     I
CI        TSPH      START SYSTEM SPHERE TEMPERATURE (ISTART=1)                      I
CI                  ( DEGR 210.  $PUMP /TPAIN/   )                                  I
CI        TSTRC     STRUCTURAL WALL THICKNESS                                       I
CI                  ( IN --- $LIQUID /TANKS/   )                                    I
CI        TTURBI    GAS TEMPERATURE AT TURBINE INLET                                I
CI                  ( DEGR --- $PUMP /TEMSCH/   )                                   I
CI        TULLFL    FUEL ULLAGE GAS TEMPERATURE.  USED FOR AUTOGENOUS               I
CI                  PRESSURIZATION                                                  I
CI                  ( DEGR 800 $PUMP /TEMSCH/   )                                   I
CI        TULLOX    OX ULLAGE GAS TEMPERATURE.   USED FOR AUTOGENOUS                I
CI                  PRESSURIZATION                                                  I
CI                  ( DEGR 800 $PUMP /TEMSCH/   )                                   I
CI        TURBPR    TURBINE PRESSURE RATIO                                          I
CI                  ( --- 2 $PUMP /PRESCH/   )                                      I
CI        TXINS     THICKNESS OF EXTERNAL ENSULATION                                I
CI                  ( IN 0.  $MATER /MOTOR/   )                                     I
CI        ULLFFL    FUEL TANK ULLAGE FRACTION                                       I
CI                  ( --- 0.02 $LTANK /TANKS2/   )                                  I
CI        ULLFOX    OXIDIZER TANK ULLAGE FRACTION                                   I
CI                  ( --- 0.02 $LTANK /TANKS2/   )                                  I
CI        UOVERC    TURBINE PITCH LINE VELOCITY DIVIDED BY ISENTROPIC               I
CI                  SPOUTING VELOCITY                                               I
CI                  ( --- 0.4 $PUMP /TPAIN/   )                                     I
CI        US        TURBINE BLADE ULTIMATE STRENGTH                                 I
CI                  ( PSI 127000 $PUMP /TPAIN/   )                                  I
CI        VELI      INITIAL VELOCITY AT IGNITION                                    I
CI                  ( FT/SEC 0 $INTRAJ ///EQ///   )                                 I
CI        VREF      REFERENCE VALUE OF VISCOSITY FOR COOLANT                        I
CI                  ( LBM/IN/SEC 5.17E-5 $LPROP /COOLNT/   )                        I
CI        VREFFL    FUEL REFERENCE VISCOSITY                                        I
CI                  ( LB*SEC/IN**2 --- $LFUEL /PROPRO/   )                          I
CI        VREFOX    OX REFERENCE VISCOSITY                                          I
CI                  ( LB*SEC/IN**2 --- $LOXID /PROPRO/   )                          I
CI        VXACFT    HORIZONTAL VELOCITY OF LAUNCH AIRCRAFT (ASSUMED                 I
CI                  CONSTANT AND USED FOR COMPUTING MISSILE SEPARA-                 I
CI                  TION RANGE)                                                     I
CI                  ( FT/SEC 0 $INTRAJ /TRAJ/   )                                   I
CI        WALLK     THERMAL CONDUCTIVITY OF CHAMBER WALL MATERIAL                   I
CI                  (AT AVERAGE WALL OPERATING TEMPERATURE)                         I
CI                  ( BTU/IN/SEC/DEGR 0.00039 $INREGN /COOLNT/   )                  I
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CI        WDOT      TABLE OF WEIGHT FLOW RATE FOR VARIABLE THRUST-        I
CI                  TIME TRACE                                            I
CI                  ( LBF/SEC 0.0 $THVST /PERF/  )                        I
CI        WEXPND    WEIGHT OF EXPENDABLE INERTS FOR EACH STAGE            I
CI                  (EXPENDED LINERLY WITH BURN TIME)                     I
CI                  ( LBM 0.0 $INPGEN /GENRL/  )                          I
CI        WLTHR     LAND WIDTH BETWEEN COOLANT CHANNELS AT THROAT         I
CI                  ( IN 0.03 $INREGN /COOLNT/  )                         I
CI        WMGGPB    MOLECULAR WEIGHT OF GAS GENERATOR/PREBURNER           I
CI                  COMBUSTION GAS                                        I
CI                  ( --- 14 $PUMP /TPAIN/  )                             I
CI        WMISC     MISCELLANEOUS WEIGHT PER STAGE EXCLUDING PAYLOAD      I
CI                  ( LBM 0 $INPGEN /GENRL/  )                            I
CI        WMISFL    MISCELLANEOUS FUEL ADDED TO STAGE (REMAINS ON         I
CI                  STAGE AT BURNOUT)                                     I
CI                  ( LBM 0 $INPGEN /GENRL/  )                            I
CI        WMISOX    MISCELLANEOUS OXIDIZER ADDED TO STAGE (REMAINS ON     I
CI                  STAGE AT BURNOUT)                                     I
CI                  ( LBM 0 $INPGEN /GENRL/  )                            I
CI        WNDMPH    WIND VELOCITY AROUND VEHICLE FOR HEAT TRANSFER        I
CI                  OPTION (KHXOPT=3)                                     I
CI                  ( MPH 10 $TANKHX /INSLHX/  )                          I
CI        WPAYLD    PAYLOAD WEIGHT FORWARD OF THE FINAL PROPULSIVE        I
CI                  STAGE                                                 I
CI                  ( LBM 0 $INPGEN ///EQ///  )                           I
CI        WPERC     PERCENT STAGE WEIGHT USED AS MISC                     I
CI                  ( --- 0. $INPGEN /MOTOR/  )                           I
CI        WPROP     WEIGHT OF STAGE PROPELLANT (THRUST-TIME OPTION)       I
CI                  ( LBM 0.0 $THVST ///EQ///  )                          I
CI        WTHR      COOLANT CHANNEL WIDTH AT CHAMBER THROAT               I
CI                  ( IN 0.03 $INREGN /COOLNT/  )                         I
CI        WTJET     AMOUNT OF INERT WEIGHT JETTISONED DURING THE          I
CI                  CURRENT MOTOR SECTION                                 I
CI                  ( LBM 0.  $GUIDA /PERF/  )                            I
CI        WTLPRP    WEIGHT OF BURNED LIQUID PROPELLANT                    I
CI                  ( LBM 13250.  $LIQUID ///EQ///  )                     I
CI        WTLTCA    WEIGHT OF LIQUID TCA (KWTMOD = -1)                    I
CI                  ( LBM 184.1 $LIQENG /TCA/  )                          I
CI        WTM       WEIGHT OF TOTAL MISSILE SYSTEM                        I
CI                  ( LBM --- $THVST /PERF/  )                            I
CI        WTMCG     MOLECULAR WEIGHT OF COLD GAS PRESSURANT               I
CI                  ( LB/LBMOLE 4.  $COLDG /COLDGP/  )                    I
CI        WTMGG     MOLECULAR WEIGHT OF GAS GENERATOR PRESSURANT          I
CI                  ( LB/LBMOLE 19.0 $SOLDGG /GASGEN/  )                  I
CI                  ( MOLECULAR WEIGHT OF COOLANT $LPROP /COOLNT/         I
CI        WTMOLF    FUEL MOLECULAR WEIGHT                                 I
CI                  ( LB/LBMOLE --- $LFUEL /PROPRO/  )                    I
CI        WTMOLO    OX MOLECULAR WEIGHT                                   I
CI                  ( LB/LBMOLE --- $LOXID /PROPRO/  )                    I
CI        WTSTAG    TOTAL INERT WEIGHT OF THE STAGE                       I
CI                  ( LBM 0.0 $THVST /PERF/  )                            I
CI        XAFSKT    LENGTH OF AFT SKIRT                                   I
CI                  ( IN 0.0 $INTSTG ///EQ///  )                          I
CI        XCYL      LENGTH OF CYLINDRICAL SECTION OF MOTOR CASE           I
CI                  ( IN 10.  $INPGEN ///EQ///  )                         I
CI        XFWSKT    LENGTH OF FWD SKIRT                                   I
CI                  ( IN 0.0 $INTSTG ///EQ///  )                          I
CI        XISP      DELIVERED VACUUM SPECIFIC IMPULSE   (KPERF=0)         I
CI                  ( SEC 314.1 $LQPERF /LIQUID/  )                       I
CI        XISPR     REFERENCE SPECIFIC IMPULSE: INPUT AS A FUNCTION OF    I
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CI                 REFERENCE CHAMBER PRESSURE                            I
 I                 ( SEC 265. $PROPEL /MOTOR/  )                         I
        XITOT      INPUT TOTAL IMPULSE CORRECTION FACTOR FOR VARIABLE    I
 I                 THRUST-TIME TRACE                                     I
CI                 ( LBF/SEC 0.0 $THVST ///EQ///  )                      I
CI      XKALFA     HELICAL BULK FACTOR                                   I
CI                 ( --- 1.9 $FILMNT /MOTOR/  )                          I
CI      XKTH       HOOP BULK FACTOR                                      I
CI                 ( --- 1.6 $FILMNT /MOTOR/  )                          I
CI      XLC        AXIAL CHAMBER CYLINDRICAL LENGTH                      I
CI                 ( IN 0.0 $LIQENG /LIQUID/  )                          I
CI      XLFL       BARRIER LIQUID FILM LENGTH                            I
CI                 ( IN 1.0 $LQPERF ///EQ///  )                          I
CI      XLN        AXIAL CHAMBER CONVERGENT LENGTH                       I
CI                 ( IN 18.7 $LIQENG /LIQUID/  )                         I
CI      XLNOZ      LENGTH OF NOZZLE FROM THROAT TO EXIT PLANE            I
CI                 (KWTMOD = -1)                                         I
CI                 ( IN 76.04 $LIQENG /LSCOM/  )                         I
CI      XMOUNT     LENGTH FROM TANK TO ENGINE GIMBAL POINT               I
CI                 ( IN 2. $LIQENG /LIQUID/  )                           I
CI      XNORO      NUMBER OF ROVINGS                                     I
CI                 ( --- 8.0 $FILMNT /MOTOR/  )                          I
CI      XNRATE     PROPELLANT BURNING RATE PRESSURE EXPONENT IN THE      I
CI                 ST. ROGERTS BURNING RATE LAW                          I
CI                 ( --- 40 $PROPEL /MOTOR/  )                           I
CI      XNUASK     POISSON'S RATIO OF STAGE AFT SKIRT                    I
CI                 ( --- .25 $INTSTG /MOTOR/  )                          I
 I      XNUCSE     POISSON'S RATIO FOR THE CASE MATERIAL                 I
 I                 ( --- .25 $MATER /MOTOR/  )                           I
CI      XNUINS     POISSIN'S RATIO FOR THE INTERSTAGE MATERIAL           I
CI                 ( --- .25 $INTSTG /MOTOR/  )                          I
CI      XR         A VECTOR OF SCALED INDEPENDENT VARIABLES USED TO      I
CI                 RESTART A SOLUTION WHEN IRSTRT = 2                    I
CI                 ( --- --- $NLP /---/  )                               I
CI      YMOD       MATERIAL ELASTIC MODULUS TABLE                        I
CI                 ( PSI 29E6,17E6,8*0 $LIQMAT /MTPROP/  )               I
CI      YS         TURBINE BLADE YIELD STRENGTH                          I
CI                 ( PSI 104000 $PUMP /TPAIN/  )                         I
CIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
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10. A FINAL RECOMMENDATION

The ELES-1984 computer code is a landmark development in the preliminary systems analysis of liquid rocket vehicles. It is capable of revealing subsystem interactions and design choice impacts on total vehicle performance. Its use enables very rapid determinations of optimum vehicle designs.

The complexity which allows the benefits of ELES to be realized is also responsible for the appreciable input error potential. There is an infinite number of input data sets which will produce garbage as output.

- Review your design worksheet
- Review your input data set for compatibility with both the design concept and the input rules
- Review the output carefully for compatibility with both the design concept and engineering judgements